

## Chapter 6

# Gabor Wavelets in Behavioral Biometrics

**M. Ashraful Amin**

*City University of Hong Kong, Hong Kong*

**Hong Yan**

*City University of Hong Kong, Hong Kong*

### ABSTRACT

*The Gabor wavelets are employed regularly in various biometrics applications because of their biological relevance and computational properties. These wavelets have kernels similar to the 2D receptive field profiles of the mammalian cortical simple cells. They exhibit desirable characteristics of spatial locality and orientation selectivity, and are optimally localized in the space and frequency domains. Physiological, biometric systems such as face, fingerprint, and iris based human identification have shown great improvement in identification accuracies if Gabor wavelets are used for feature extraction. Moreover, some behavioral biometric systems such as speaker and gait based applications have shown more than 7% increase in identification accuracies. In this study, we provide a brief discussion on the origin of Gabor wavelets, then an illustration of “how to use Gabor wavelets” to extract features for a generic biometric application is discussed. We also provide an implementation pseudocode for the wavelet. It also offers an elaborate discussion on biometric applications with specific emphasis on behavioral biometric systems that have used Gabor wavelets. We also provide guideline for some biometric systems that have not yet applied Gabor wavelets for feature extraction.*

### INTRODUCTION

Biometrics involves the development of statistical and mathematical methods applicable to data analysis problems in the biological sciences. More specifically, the term “biometrics” is derived from

the Greek words bio (life) and metric (to measure). The sole purpose of biometrics is either identification or verification. This is performed based on two unique characteristics of human; the physiological uniqueness and the behavioral uniqueness. Physiological uniqueness is the characteristics that people are born with, which include fingerprint, face, and iris, etc. Behavioral uniqueness is the characteristics

DOI: 10.4018/978-1-60566-725-6.ch006

that people adapt to as they grow-up, which include gait, speech, etc. These are called behavioral, because uniqueness of these acts is expressed through behavior of an individual, for example, the way one walks (gait), and talks (speech).

Possibly the first known example of biometrics in practice was in India and China around the 15<sup>th</sup> century, where children's palm prints and footprints was marked on paper with ink to distinguish the young children from one another and also to analyze their future. In the 1960's, scientists started to use computer for automated face and speech recognition. Many applications have been developed and different approaches have been taken into account to further modify the existing systems. Among all approaches, biologically inspired computational methods such as Gabor Wavelets are more powerful in terms of optimality, as they seem to be in coherence with the physics of the natural world.

In 1946 using Schwarz inequality arguments, Dennis Gabor proved the "indeterminacy relations of quantum mechanics" (Gabor, 1946). He proved that a signal's specificity, simultaneously in time and frequency is fundamentally limited by a lower bound on the product of its bandwidth and duration. Gabor referred to Heisenberg & Weyl's uncertainty-related-proofs for the natural world and derived the uncertainty relation for information. Based on this understanding he found the general family of signals that optimize this trade-off and thus achieve the theoretical lower limit of joint uncertainty in time and frequency. The so-called Gabor signals take the general form:

$$s(t) = e^{\left[-\frac{(t-t_0)^2}{\sigma^2}\right]} e^{i\omega t} \quad (1)$$

Here the complex notation describes the modulation product of a sine wave with arbitrary frequency  $\omega$  and a Gaussian envelope of arbitrary duration  $\sigma$  occurring at epoch  $t_0$ . Gabor also proposed representing arbitrary signals by a pseudo

expansion set of these elementary signals, which he termed "logons" in the information plane, indexed by all different frequencies of modulation and all different epochs of time.

The research on suitability of Gabor's theory in computer vision found its motivation in the discovery of a group of neuroscientists and psychologists who claimed by showing experimental results that in visual perception natural images are decomposed into Fourier-like spatial-frequency components (Campbell & Robson, 1968; Kulikowski & Bishop, 1981; Maffei & Fiorentini, 1973; Pollen et al., 1971). In 1980 Marcelja published a paper where Dennis Gabor's "Theory of communications" was pointed out to all vision scientists by interpretations of cortical simple cell receptive-field profiles. Then subsequent research (Daugman, 1980; DeValois et al., 1982; Poleen & Ronner, 1981; Tootell et al., 1981) confirmed that usually two to five interleaved regions of simulative-restrictive influences weighted by a tapering envelope constitute the receptive-field profile of a simple cell, and Gabor signals with suitably chosen parameters invariably give a good fit to such spatial profiles.

In a series of works Daugman (Daugman, 1980; Daugman, 1985; Daugman, 1988; Daugman, 1993b) resolved some of the theoretical problems related to the Gabor representations of image. He introduced the two dimensional (2D) Gabor representations because they comport with the basic fact that a visual neuron's receptive field is localized in a 2D spatial visual manifold. Moreover he contributed to the research of the orientation selectivity of simple cells by explicitly analyzing in the uncertainty framework and relating the functionality of the cells to other tuning variables which specifically include spatial frequency and 2D spatial resolution. In order to model the receptive fields of the orientation-selective simple cells, Daugman (Daugman, 1980; Daugman, 1985) generalized the Gabor function (equation 1) to the following 2D form:

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