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ORIGINAL RESEARCH PAPER

FPGA-based fast computation of gray-level morphological granulometries

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Abstract Morphological granulometries constitute one of the most useful and versatile image analysis techniques applied to a wide range of tasks, from size distribution of objects, to feature extraction and to texture characterization in industrial and research applications where high-performance instrumentation and online signal processing are required. Since granulometries are based on sequences of openings with structuring elements (SEs) of increasing size, they are computational demanding on non-specialized hardware. In this paper, a pipelined hardware architecture for fast computation of gray-level morphological granulometries is presented, centered around two systolic-like processing arrays able to process with flat SEs of different shapes and sizes. To validate the proposed scheme, the architecture was modeled, simulated and implemented into a field programmable gate array. Implementation results show that the architecture is able to compute particle size distribution on 512×512 sized images with flat non-rectangular SEs of up to 51×51, in around 60 ms at a clock frequency of 260 MHz. It is shown that a speed up over two orders of magnitude is obtained compared to a naive software implementation. The architecture performance compares favorably to similar hardware architectural schemes and to optimized high-performance graphical processing units-based implementations.

Keywords Granulometry · Gray-level morphology · FPGA · Hardware acceleration

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1 Introduction

Granulometry can be defined as the process of measuring the size and distribution of different objects in an image of granular material [14, 15]. Its importance relies on the fact that granulometries allow estimation of a priori unknown geometrical characteristics and distribution of objects without explicit image segmentation [18, 19]. The analysis of granulometric properties of materials and substances by image processing is relevant in a great variety of industrial applications which can range from the pharmaceutical sector to the food sector, papermaking and coating, crack detection and basic materials production [4, 13]. Also, granulometries are used in computer vision and pattern recognition applications where shape description and texture of objects are useful information such as in the case of analysis of metallographic images, morphological characterization of blood cells, and the evaluation of corneal endothelium status [16]. In such applications, the size, shape, arrangement and proportions of objects can be used to capture some essential features of images and then used for matching shapes, texture analysis, or recognizing objects. Under an industrial scenario, a real-time automatic granulometric vision system for on-line quality control would be of great benefit to the industry, both for process control and product optimization. Particularly, the granulometric analysis of materials is of great relevance since the properties and the characteristics of the final products are strongly correlated to the distribution of shapes and sizes of the particles composing the mixtures and ingredients used in production.

Commonly, granulometry is carried out through mathematical morphology techniques based on openings and closings, but some other approaches have been reported in the literature such as the correlation-based approach [11] or

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