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A new image representation for compact and secure communication

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Abstract

In many areas of nuclear materials management there is a need for communication, archival, and retrieval of annotated image data between heterogeneous platforms and devices to effectively implement safety, security, and safeguards of nuclear materials.

Current image formats such as JPEG are not ideally suited in such scenarios as they are not scalable to different viewing formats, and do not provide a high-level representation of images that facilitate automatic object/change detection or annotation .

The new Scalable Vector Graphics (SVG) open standard for representing graphical information, recommended by the World Wide Web Consortium (W3C) is designed to address issues of image scalability, portability, and annotation. However, until now there has been no viable technology to efficiently field images of high visual quality under this standard.

Recently, LANL has developed a vectorized image representation that is compatible with the SVG standard and preserves visual quality. This is based on a new geometric framework for characterizing complex features in real-world imagery that incorporates perceptual principles of processing visual information known from cognitive psychology and vision science, to obtain a polygonal image representation of high fidelity. This representation can take advantage of all textual compression and encryption routines unavailable to other image formats. Moreover, this vectorized image representation can be exploited to facilitate automated object recognition that can reduce time required for data review. The objects/features of interest in these vectorized images can be annotated via animated graphics to facilitate quick and easy display and comprehension of processed image content.

Keywords: Image, segmentation, vectorization, recognition, annotation, representation, compression, polygon, graphics, SVG

Introduction

Image segmentation is the first, and perhaps the most critical, image processing step to automating image understanding by computers. Segmentation consists of decomposing an image into its constituent salient features and objects that define the semantic content of the image. Image segmentation sets the stage for object detection and recognition by providing a high-level representation of an image in terms of regions of uniform color/intensity and geometric regularity.

Objects in images are typically contiguous subsets of such regions. Thus, image segmentation transforms an image from a low-level pixel-based representation to an intermediate-level region-based representation that enables the piecing together of the ‘jigsaw puzzle’ of regions into individual objects of the image. Image segmentation can be thought of as representing the process of perception in human vision. This representation does not assume *a priori* knowledge of the objects in an image, rather it uses local regularities and structure in an image to parse the image into distinct parts.

There has been no universally applicable method to date that can segment all images equally well. Although there are several segmentation methods developed over the decades, almost all can be classified, broadly speaking, into one of two categories: 1) methods that seek structure by decomposing an image into regions of uniform color or intensity, generally assuming that, to a large extent, parts of an object are dominated by one color; 2) methods that seek structure by identifying parts of an image that exhibit rapid change in color/intensity, generally assuming that, to a large extent, boundaries of objects are sites of such rapid change in intensity.

Digital images are made up of pixels of subtly varying intensities that are dithered in such a way as to produce the effects of shade and gradation of color. Methods of the first kind rely on binning pixels into fewer classes. This generally results in speckle noise due to neighboring pixel differences being enhanced. It also has the effect of marring edges that have more gradual variation in intensity across them, or creating false edges due to gradual variation in intensity across a region. While methods of the second kind do produce edges that belong to object boundaries, these edges are typically fragmented and as such do not bear any relationship to one another. Thus, additional work is required to group and inter-relate edges belonging to the same object.

Existing segmentation methods typically generate a pixelated image, only using fewer colors than the original. Thus, extracting structures from the segmented image is generally not addressed. In the method presented here, a digitized (i.e., pixelated) image is transformed into a vectorized image wherein the objects of interest are readily obtained at a higher level of representation as attributed polygons. Vectorizing an image involves the representation of an image in terms of geometric primitives such as points, straight lines, polygons, arcs, and their relative positional arrangements along with attributes such as spectral values, intensity, and the like. In contrast, a digitized image uses pixels arranged in a grid as primitives to represent the image.

Vectorization helps to explicitly delineate complex structures and allow the direct scaling of images without significant loss or change of image quality. The selective processing and manipulation of individual structures is thereby enabled to provide a higher level description of images that is adaptable to individual image characteristics. The image can then be manipulated in terms of its constituent structures. This is a substantial gain from the point of view of understanding an image, where the goal is to automatically comprehend a scene in terms of the objects present in the scene and their interrelationships.

Technology description

Our recent work in the area of image segmentation is supported by the LDRD program and is an extension of the scope and methods of our earlier work [1-5] on object recognition to object extraction from images. As noted above, structures in images manifest through regional uniformities and boundary discontinuities. We recognize that both these characterizations are closely related and are jointly responsible for delineation of objects and features in images. Accordingly, we have developed [6] a region-contour segmentation scheme that takes into consideration contours resulting from color gradients in an image, as well as their interrelationships in terms of bounding a common region, to identify structures that stand out in the image. The ensemble of all such structures yields a segmentation of the image. These structures are specified as polygons, by means of a sequence of vectors corresponding to chains of vertices along polygon boundaries, and associated with a color vector that is the estimated aggregate color of the segmented structure. Thus, the resulting segmented image is a vectorized collage of polygons. An object in an image is comprised of one or several polygonal structures in the segmentation of the image. Our method of segmentation outlined here sets the stage for higher level image analysis, and, in particular, the successive grouping of polygonal structures into objects and features of interest.

In our previous work [1-4] we employed constrained Delaunay triangulations (CDTs) and the chordal axis transform (CAT) of closed polygonal contours of shapes to characterize the shapes in terms of their visually salient parts. In this work we use CDTs of open contours that are derived from gradient-based edge detection on images to obtain a tessellation of the intercontour regions. The triangles and their edges so obtained serve to relate *cobordant* contour fragments that bound a common region. They also help interpolate missing edge and region information to attain completions of object contours. We use this geometric paradigm to implement ‘perceptual’ filters that model certain well-known criteria for perceptual organization employed in human vision. Some examples of such criteria are proximity, collinearity, closure, symmetry and good continuation. The criteria are implemented via nonlinear filters that jointly determine whether the edge between two adjacent triangles should be deleted or retained, or, what is the same, whether two adjacent triangles should be merged into a single polygon or not. Thus, whenever an edge is deleted, a region continuation is achieved. Similarly, whenever an edge is retained a contour continuation is achieved. Thus, our approach to segmentation explicitly accounts for the region-contour duality of inferring form from images.

Edge pixels of a digital (i.e., pixel-based) image (Fig. 1a.) are detected by means of an edge detection algorithm such as the well-known Canny edge detector (Fig. 1b.). Neighboring edge pixels are then linked to obtain contour chains. The chordal axis transform (CAT) is applied to the set of contour chains to extract attributed skeletons of the regions between the contour chains. The CAT employs a CDT (Fig. 1c.) of the contour set to obtain the skeletal characterization of the regions. The CDT is used to sample triangles for color information (Fig. 1d.), and, as mentioned above, the edges of the triangles are evaluated for retention or deletion by a set of perceptual filters that are attuned to structural cues inherent in the input contours and output skeletons of the CAT. The retained edges of the triangles that are transverse to the local CAT skeleton determine cuts in the CAT skeleton. The resulting subskeletons (Fig. 1e.) are skeletons of new polygonal regions that define the vectorized segmentation of the input digital image (Fig. 1f.). These polygons are attributed with color and structural information of their various parts. This representation will enable further high-level processing of structural information to extract and recognize objects, detect features of interest based on generic structure or color properties, and efficiently represent images in terms of objects with high visual fidelity for purposes of transmission and archival.

Efficient vectorized representation

The resulting polygonal segmentation is readily amenable to efficient representation under the new graphical file format_Scalable Vector Graphics (SVG) [7] proposed as a future standard by the World Wide Web Consortium (W3C). The SVG file format is supported currently by a publicly available viewer plug-in to Internet browsers such as Internet Explorer and Netscape, published by Adobe Systems Inc. (http://www.adobe.com/svg/viewer/install/main.html.) The SVG format, as a subset of XML, affords a powerful set of display tools and filters that may be leveraged to develop important web-based imaging applications in conjunction with our vectorized image segmentation algorithm.

A typical SVG specification employed by our algorithm to write vectorized image files is as follows:

```
<?xml version="1.0" standalone="yes"?>

<svg>
```

```
<path d="M x y l _x _y l _x _y l _x _y l ... l _x _y z"
fill="rgb(R1,G1,B1)"/>

<path d="M x y l _x _y l _x _y l _x _y l ... l _x _y z"
fill="rgb(R2,G2,B2)"/>

...

<path d="M x y l _x _y l _x _y l _x _y l ... l _x _y z"
fill="rgb(R3,G3,B3)"/>

</svg>
```

where each polygon is specified as a closed "path" d starting at an integer vertex (x,y), and moving to successive vertices via a straight line by incrementing previous vertex coordinates by integers _x and _y.

As is evident, this specification explicitly makes available all the polygons in the segmentation along with color attributes (other attributes may also be specified as needed). This enables direct examination of the svg file for feature detection and object recognition purposes without reconstructing the complete image. The svg specification is amenable to textual compression such as gzip, yielding, on an average, a compression of 1:4 over input JPEG image files. The gzipped svg files, with extensions '.svgz', can be viewed directly by the Adobe SVG viewer without separately having to decompress these files first.

Our segmentation algorithm also permits the implementation of object and feature extraction as add on filters that single out polygons with desired shape/color properties. These filtered polygons can be displayed in special colors or animations within the svg output files (Figs. 3, 4). This provides an easy-to-understand annotation mechanism for embedding automated detection information in the vectorized image files. This feature is implemented in svg by a specification such as:

```
<path d="M x y l _x _y l _x _y l _x _y l ... l _x _y z"
fill="rgb(R1,G1,B1)">
<animateColor attributeName="fill" attributeType="CSS" from="rgb(R1,G1,B1)"
to="rgb(R2,G2,B2)" begin="10s" dur="0.2s" repeatDur="indefinite" fill="freeze"
/>
```

encryption algorithms for secure transmission over the Internet or between wireless devices.
Thus, the combination of our vectorized segmentation and object/feature extraction algorithm, along with the efficiency and annotatability of the SVG format, provides a potent image analysis platform for many security-based applications.

Applications

The vectorized image segmentation algorithm described here was developed with image understanding at large in mind. Consequently, it enjoys wide applicability, ranging from optical character recognition to satellite image analysis. In this paper we will focus on remote monitoring and security applications. A generic scenario of application (Fig. 2) would involve one or several cameras mounted at different points through a facility, and connected to a processing unit. Alternately, the cameras could have independent on-board processing capability. Images from the cameras would be acquired either continuously, periodically, or based on external triggers (such as radiation sensors), and processed to obtain vectorized segmentations in terms of attributed polygons. The resulting vector images would then be subject to change detection and/or object recognition, resulting in the filtering of a set of polygons corresponding to regions of change or objects of interest. The filtered polygons would then be used to annotate SVG files, which would be subsequently gzipped for compression. These files could then be encrypted and archived, disseminated via email, or posted on a secure Internet or intranet website for viewing by authorized security personnel. Appropriate versions of this basic set up could be employed to analyze and deliver real-time information on-line regarding events and threats in the vicinity of vaults, processing areas, storage areas, facility perimeters, and portal monitors.

This technology could be used to enhance the capabilities of the Unattended Remote Monitoring (UNARM) System [8], used by the IAEA, by adding an active video monitoring component.

Another possible area of application for this technology is materials or container inventory wherein it may be useful to count items, detect tamperered or missing items.

Conclusion

A novel technology for high-level image representation, understanding, and annotation is presented. The algorithmic framework characterizing the technology is broad-based and allows development of specialized tools for image analysis for a variety of applications. The architectural emphasis discussed here is geared towards remote monitoring and security applications in the area of nuclear materials and facility management. The main advantages of the proposed technology are compactness of image information, image scalability, high-level feature access and analysis, on-line access and distribution, real-time evaluation, and smart image annotation for easy comprehension and archival. The technology may be implemented as a stand-alone monitoring system or be incorporated into existing frameworks such as UNARM.

References

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Fig. 1 a. Input image

Fig. 1 b. Canny edge contours

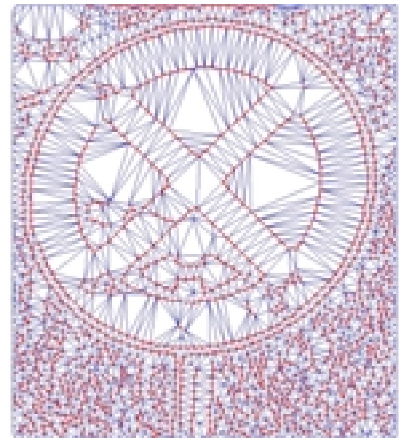

Fig. 1 c. Constrained Delaunay triangulation (blue) of contours

Fig. 1 d. Monte Carlo sampling of triangle colors

Fig. 1 e. CAT skeleton graph (yellow) showing various connected components

Fig. 1 f. Polygonal (vectorized) segmentation of input image

Fig. 1. Key stages of vectorized image segmentation

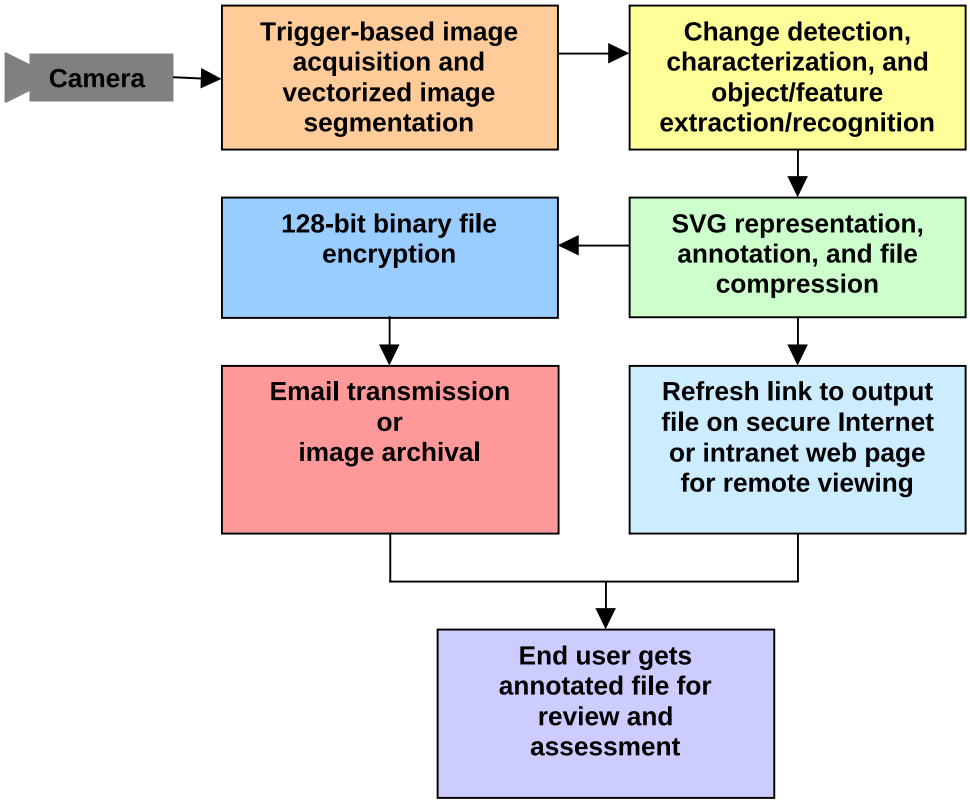

Fig. 2. A schematic diagram of image vectorization architecture as applicable to remote monitoring and security.

Fig 3a. Pixel image of boiler room

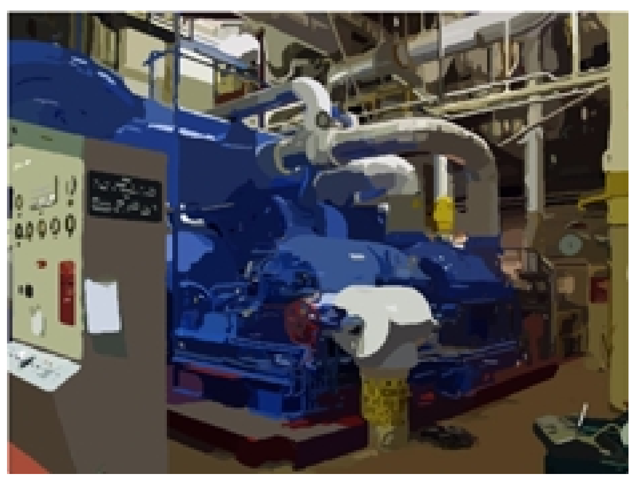

Fig 3b. Vectorized image segmentation

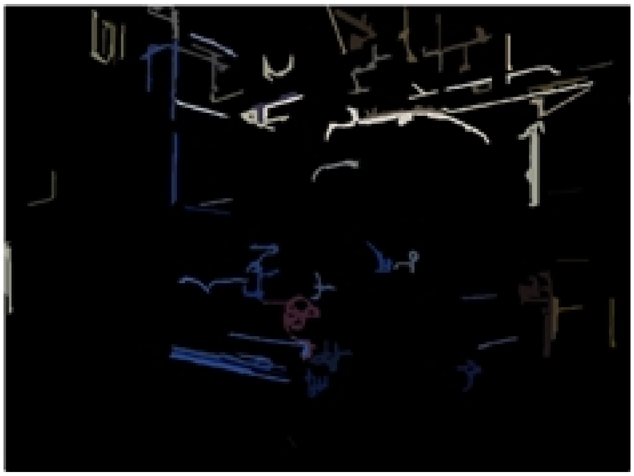

Fig 3c. Detection of candidate thin pipes

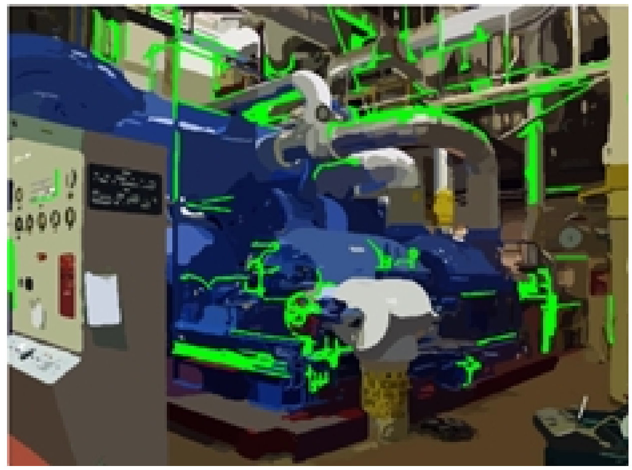

Fig 3d. Annotation of vector image

Fig. 3 Vectorized segmentation, feature detection, and image annotation

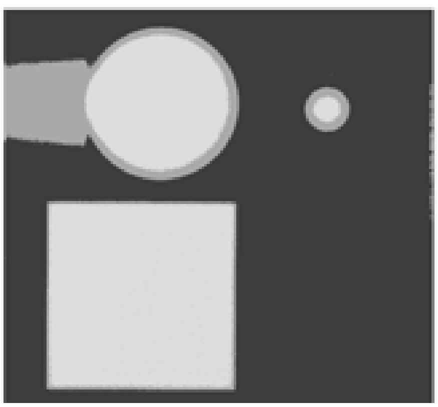

Fig. 4a. Histogram Equalized radiograph

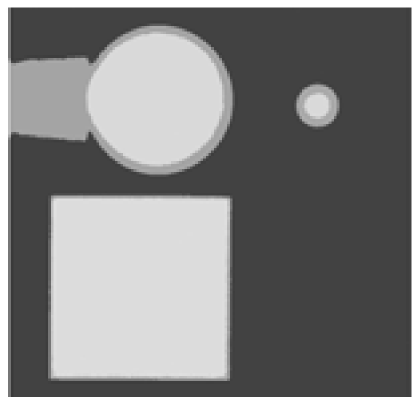

Fig. 4b. Vectorized segmentation

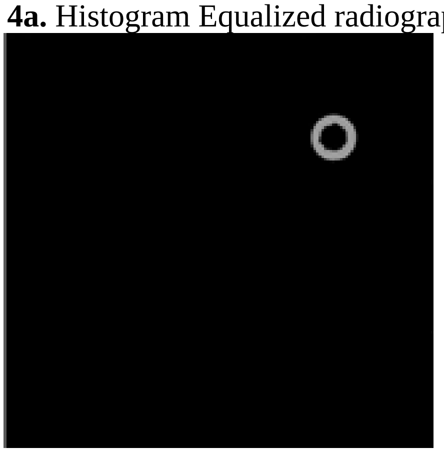

Fig. 4c. Annular Shell detection

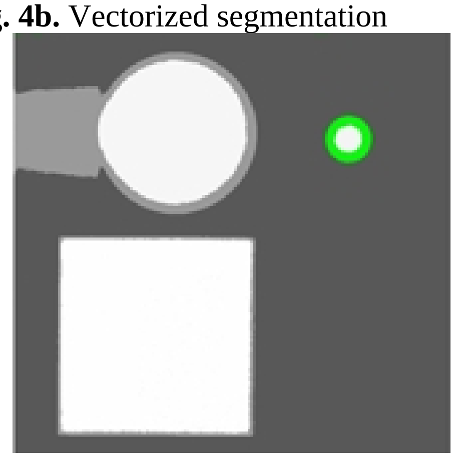

Fig. 4d. Vectorized image annotation

Fig. 4 Vectorized object segmentation, detection, and annotation of radiograph