Classifier-enhanced algorithm for compressive spatio-spectral edge detection

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***Abstract*—A novel compressive edge-detection algorithm for spectral imagery is demonstrated using real long-wave spectral imagery. The idea of the algorithm is based on identifying joint spatial and spectral features via statistical learning.**

Edge detection is an important tool in the analysis and interpretation of spectral imagery. Most conventional edge detectors are designed by assuming a model for edges that characterizes the change in intensity across an image. Nevertheless, this approach is not well-suited for spectral images (multispectral and hyperspectral images), where each pixel is represented by a high dimensional spectral vector. One of the key challenges in detecting edges between different materials is the presence of the so-called iso-luminant edges, edges defined by wavelength changes rather than intensity changes. In such scenarios, an iso-luminant edge should be detected based upon spectral information rather than intensity [1].

A few approaches have been pursued in defining a "multi-color" edge detector. The most common is the gradient-based approach, such as the Multi Color Gradient (MCG), [2]. A second approach is based upon pixel ordering [3]. It is known that the MCG approach can fail to detect edges in the case of opposing gradients present in different spectral bands. In addition, to detect iso-luminant edges, the MCG approach must use a very low threshold, which, in turn, produces false edges [4]. On the other hand, the pixel-ordering approach solves the problem of opposing gradients by associating vector order statistics at the expense of increasing algorithm complexity. Extensions of the order-statistics approach are also present in the literature [5], [6].

Recently, our group presented a novel approach, termed the Spectral Ratio Contrast (SRC), to perform multispectral edge detection by using the spectral contrast of materials on specific bands [7]. The novelty of this approach is that it uses the concept of spectral ratio signatures. We have demonstrated that the SRC algorithm outperform the MCG approach when iso-luminant edges are present. The MCG approach is not well-suited for iso-luminant edges because the strength of the MCG value is thresholded by a fixed value across all the classes of materials that are present in imagery. As a key difference, the SRC approach allows individual selection of signatures and tolerances for each pair of classes of materials. Therefore, the thresholding process is changed depending upon the spectral properties of each pair of classes of materials; thus, weak edges can be identified without introducing a high number of false edges. The SRC algorithm is a two-stage approach: training and testing stages. In the training stage, a small set of ratios of spectral-band outputs that most profoundly identify edges between each pair of materials is selected. This selection is made judiciously and sparingly recognizing the very few bands, across all bands, that permit a good discrimination between each pair of materials. Through this process, the SRC algorithm achieve substantial levels of data compression at the edge extraction stage. Moreover, for each pair of materials, a threshold is obtained that separates the two materials based on the ratios described earlier. The testing stage is the edge-extraction process performed by utilizing a spatio-spectral mask that returns the ratios of spectral-band outputs, defined in the training stage, by considering neighboring pixels. The spectral ratios are then compared with the thresholds obtained in the training stage for each pair of materials and pairwise edges are declared whenever the ratio exceeds the corresponding threshold for each pair. The outcome of the combination of filtering the spectral (multidimensional) image with the spatio-spectral mask and the threshold-comparison step is the edge map. While the SRC approach can detect iso-luminant edges better than other techniques, some false edges are still generated albeit less than those produced by MCG and order-statistics methods.

In this paper, we develop an extension of the SRC edge-detection algorithm, termed the adaptive SRC (ASRC) algorithm, that includes critical information resulting from multispectral classification of the very spectral image whose edges are to be identified. As such, the ASRC algorithm fuses thematic classification with spectral edge detection. The thematic classification is embedded in the SRC algorithm by modifying the thresholds according to which the edges are declared, at each candidate location for an edge, according to the classification results for the surrounding pixels. Thus, the ASRC is an adaptive version of the SRC in that the edge-detection threshold at each pixel is suitably modified by utilizing the results of the thematic classification, which incorporate information associated with the spatial location of the classes within the scene. To reiterate, by fusing the thematic classifier with the spectral edge detector, the thresholding process is adaptively changed depending on the outcome of the "spectral segmentation" of the scene.

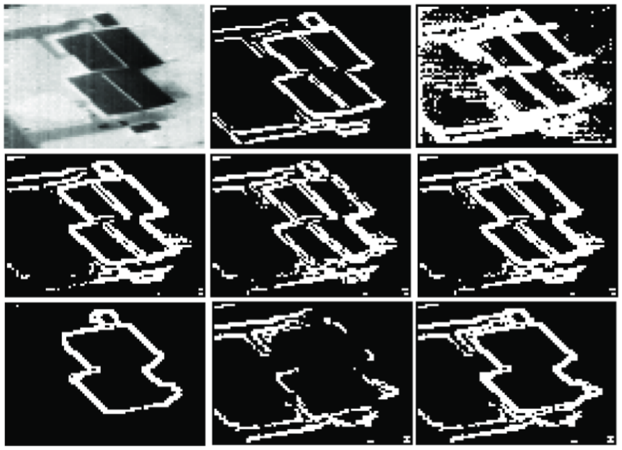

Fig. 1. Comparison between the MCG edge detector, the SRC algorithm and the ASRC algorithm for the AHI data. First row, from left to right: HS data acquired using the AHI sensor, edge maps for the MCG edge detector for two tolerances 0.1 and 0.01, respectively. Second and third rows show the results of the SRC and ASRC algorithms, respectively. First column: edges between ground and building; second column: edges between ground and road; and third column: combined edges.

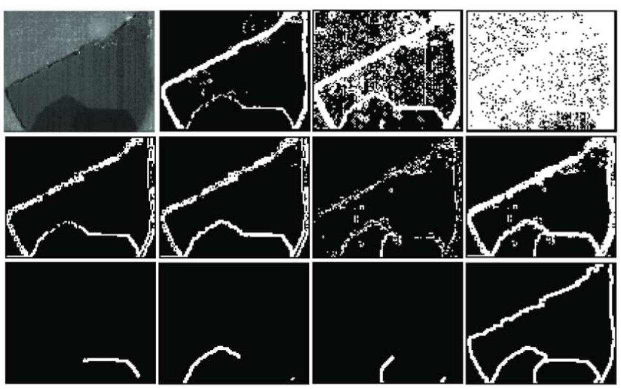

Fig. 2. Comparison between MCG edge detector, the SRC algorithm, and the ASRC algorithm over DWELL MS data. First row, from left to right: DWELL detector data at one band, edge maps for the MCG edge detector results, for tolerances 0.01, 0.001 and 0.0001, respectively. Second row: results for the SRC approach, and third row: results for the Enhanced SRC approach. Since second row, from left to right: First column: Phyllite-Limestone pair, second column: Phyllite-Granite pair, and third column: Limestone-Granite pair. Fourth column: combined edge.

We conducted experiments with both hyperspectral (HS) and multispectral (MS) imagery, and the results are shown in Figs. 1 and 2, respectively. In each case, we compared the performance of the proposed ASRC algorithm (bottom row) to the MCG [2] (top row) and SRC edge detector [7] (middle row). In Fig. 1, an image (top-left) by the Airborne Hyperspectral Imager (AHI) is shown. Three different classes are present in the image: road, ground and building. The results of applying the MCG edge detector with two different tolerances are also shown (middle-top and right-top). The results from the SRC and ASRC algorithms are shown in the second and third rows, respectively. The performance of the MCG edge detector is almost indistinguishable from that of the SRC algorithm. However, the ASRC algorithm has the advantage of reducing false edges, e.g., top of the building's roof (bottom-left). This is one feature of the ASRC algorithm. Similar to the SRC algorithm, another feature of the ASRC algorithm over the MCG algorithm is data compression at the sensing stage. The ASRC algorithm requires only two out of the 190 available spectral bands, a 98.95% of compression in the sensed data. The ASRC offers another performance advantage for images that contain iso-luminant edges as see next.

In Fig. 2, we use MS imagery acquired using a bias-tunable DWELL detector developed by our group [8]. Three different types of rocks are present in the image: phyllite, limestone and granite. The edge between limestone and granite is iso-luminant, as shown in the top-left image. Here, the MCG edge detector fails to detect such iso-luminant edge while the SRC algorithm detects it, albeit with the penalty of having false edges (second row: right). The key advantage of the ASRC algorithm over the SRC algorithm is that it reduces the detection of false edges substantially, owing to the fusion of thematic classification in the edge-detection process. The data-compressive feature of the ASRC is evident in this example as well: the ASRC algorithm requires only two out of ten available bands to perform the edge detection.

In summary, we presented an enhanced spectral edge-detection algorithm that fuses spectral classification with a recently reported spatio-spectral edge detection. The fusion process reduces false edges, as demonstrated through application of the algorithm to AHI and DWELL infrared spectral imagery. Moreover, similar to the SRC algorithm, substantial compression is achieved in the sensed by instructing the sensor to sense at only a few spectral bands to perform the task of edge detection.

This work was supported by the National Consortium for MASINT Research Partnership Project and the National Science Foundation (Awards ECCS-0925757, IIS-0434102 and ECS-0401154). S. E. Godoy is co-sponsored by the Comisión Nacional de Investigación Científica y Tecnológica (CONICYT), Chile.

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