Vector Quantizer Designs for Joint Compression and Terrain Categorization of Multispectral Imagery[1]

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ABSTRACT

We evaluate two vector quantizer designs for compression of multispectral imagery and their impact on terrain categorization performance. The mean-squared error (MSE) and classification performance of the two quantizers are compared, and it is shown that a simple two-stage design minimizing MSE subject to a constraint on classification performance has a significantly better classification performance than a standard MSE-based tree-structured vector quantizer followed by maximum-likelihood classification. This improvement in classification performance is obtained with minimal loss in MSE performance. Our results show that it is advantageous to tailor compression algorithm designs to the required data exploitation tasks. Applications of joint compression/classification include compression for the archival or transmission of Landsat imagery that is later used for land utility surveys and/or radiometric analysis.

1 Introduction

The vast majority of vector quantizer (VQ) design algorithms presume the use of mean-squared error (MSE) as a metric. The shortcomings of MSE on perceptual quality in image coding are well known. In this paper, we show that MSE-based quantization severely degrades the performance of M-ary classification algorithms following compression and decompression. Appropriate design criteria for the joint compression and classification problem should include some combination of MSE and Bayes risk. In the context of multispectral imagery, MSE is a reasonable criterion for quantizers that are designed to preserve the root mean-squared (RMS) radiometric accuracy of the imagery. Bayes risk, on the other hand, is appropriate for designs that optimize terrain categorization performance, since it directly relates to classification performance.

We explore two vector quantizer designs, an *independent* design and a *joint* design. The independent design uses a standard MSE-based tree-structured vector quantizer (TSVQ) followed by a maximum-likelihood classifier that optimizes probability of correct classification

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[5]. The joint design, on the other hand, optimizes MSE performance subject to a constraint on classification performance. For this latter design, a two-stage quantizer is used [6,7]. The first quantization stage is a tree-structured classifier (TSC) [1,2] that essentially performs a coarse quantization of the multispectral pixel feature space. This coarse quantizer is then refined using a second quantizer that is designed using a MSE criterion. An alternative to the joint compression/classification problem has recently been proposed by Cosman et. al. [3].

We present results on the MSE and terrain categorization performance of these two quantizer designs at various information compression rates for Landsat-4 Thematic Mapper data collected over Ann Arbor, Michigan are presented. Empirical results indicate that the joint design provides superior classification performance with minimal MSE degradation.

2 Results

We demonstrate that for MSE-based TSVQ codebook designs having large or even moderate compression ratios of 8:1 or better, classification performance on compressed imagery is severely degraded relative to the performance of the classical maximum-likelihood classifier operating on uncompressed imagery. This performance degradation is due to the fact that at high compression ratios (that is, low code rates), there is a tendency for classes having large component variances to mask other classes that have smaller variances—even when the classes are well separated. This is because the MSE criterion protects against large errors regardless of the resulting classification performance.

Figure 1 shows a scatter plot from two bands of Landsat-4 multispectral data for a simple four-class problem; band 5 radiances are plotted against the corresponding band 3 radiances for four terrain categories: clouds, soil, water and wetlands. Two different algorithms were used to partition the scatter plot into four regions. The partition selected by an MSE-based TSVQ is shown in solid lines while the partition selected by a tree-structured classifier is shown in dashed lines. Also shown in Figure 1 are the corresponding *codewords*: each data point falling into a given partition element is represented by the codeword for that partition element.

In Figure 1, the large-variance class (clouds) is "over coded." In the MSE-based partition, the soil and wetland classes are not distinguished since they fall into a single partition element. In this case, compression of the data with the TSVQ would result in a loss of classification performance. Nonetheless, the four classes are well separated and a classifier partition can be designed to separate all four classes. Indeed, the classifier partition allows each of the four terrain categories to be distinguished.

The independent and joint compression/terrain categorization designs were applied to the six reflective bands from a 185×185 km^2 Landsat-4 frame collected over the southeast
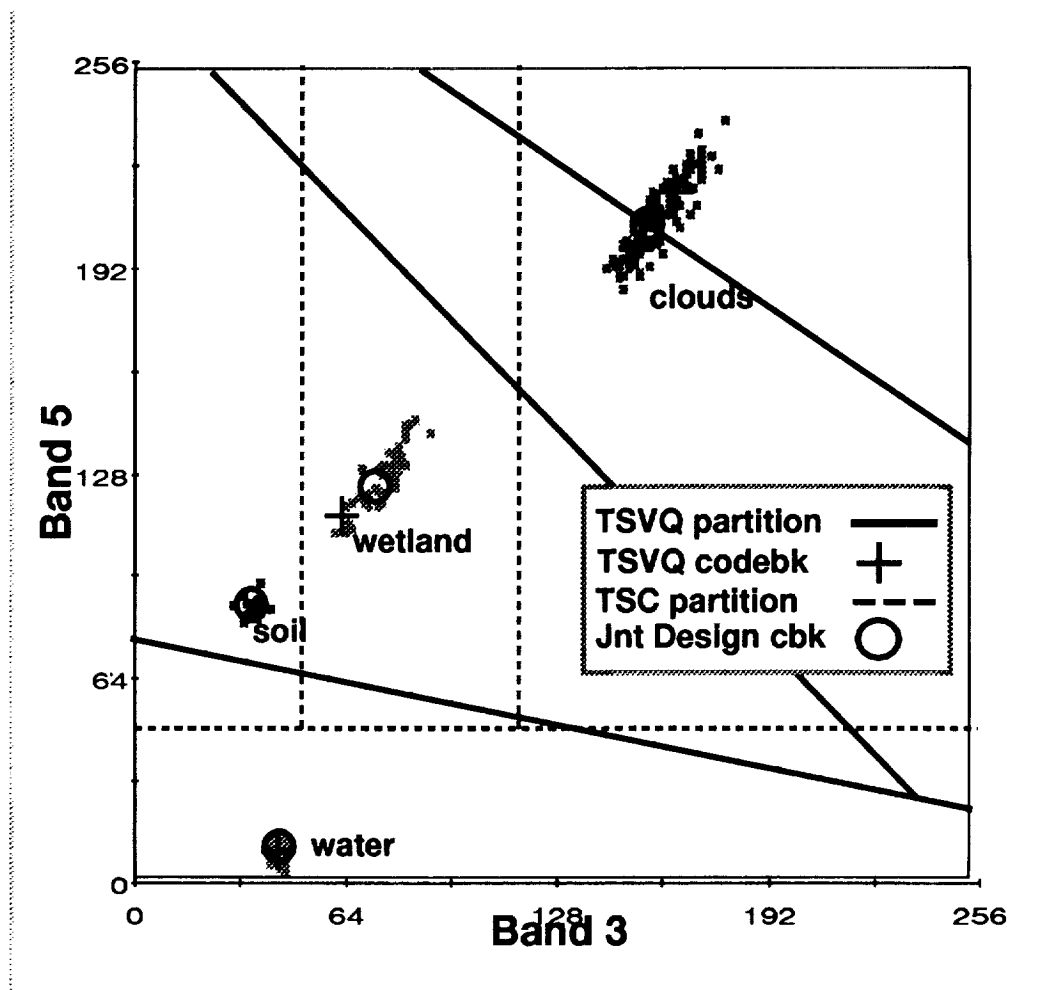
Figure 1. Two feature-space partitions for the four-class terrain categorization example.

Michigan area. A total of 10 general terrain classes: urban, agricultural, bare soil, range, deciduous, conifer, water, barren and cloud covered were located and identified by an experienced image interpreter. Figure 2 shows a quantitative performance comparison between the independent and joint design approaches. Specifically, Figure 2 shows both the MSE and classification error rate as a function of the code rate. The classification error rate is computed with respect to the terrain categorization performance on the original data. The various curves in Figure 2 show the performance of four VQ designs: the independent design, and joint designs in which the first stage (i.e., the classifier) is allocated 5, 6, and 8 bits. The original data rate is 48 bits per pixel (bpp) (i.e., six bands at 8 bits/band/pixel). The plots show that a substantial rate decrease can be achieved while still retaining the same classification error rate. In particular, at a 4:1 compression rate, or 12 bpp, the joint scheme has a 4% RMS radiometric error and a 2% classification error. This should be compared to the independent scheme which has a slightly lower RMS radiometric error of 0.5%, but a significantly larger classification error of 25%.

Finally, Figure 3 shows the output of the terrain categorization step after compression at a 12:1 compression ratio (i.e., a data rate of 4 bits/multispectral pixel). Figure 3a shows the original classification output. Figure 3b shows the output of the independent compression/classification design (i.e., the supervised maximum-likelihood classifier operating on data that has been compressed 12:1 with a MSE-based tree-structured vector quantizer). Figure 3c shows the output of the joint compression/classification design. In the independent design, the water category is classified as a non-category, while many of the other classes are missing completely. On the other hand, in the joint design much of the original spatial structure in the classification map is preserved and the classification errors are spatially localized. In fact, when we examined the difference between the joint design output in Figure 3c and the original classifier output in Figure 3a, we found that approximately 93% of the classification errors occurred over regions that were 3 × 3 pixels across or smaller.

3   Conclusions

We compared two quantizer designs for the problem of joint compression/terrain categorization of multispectral imagery. The first quantizer design was an *independent* design, consisting of a mean-squared error (MSE) based quantizer design followed by a maximum-likelihood classifier. The second design was a *joint* design that employed a two-stage quantizer. The first stage consisted of a tree-structured classifier that performed a coarse quantization of the image data. This coarse quantization was then refined using a standard MSE-based tree-structured quantizer. One can view this two-stage process as one particular approach to minimizing MSE subject to a constraint on allowable classification error.

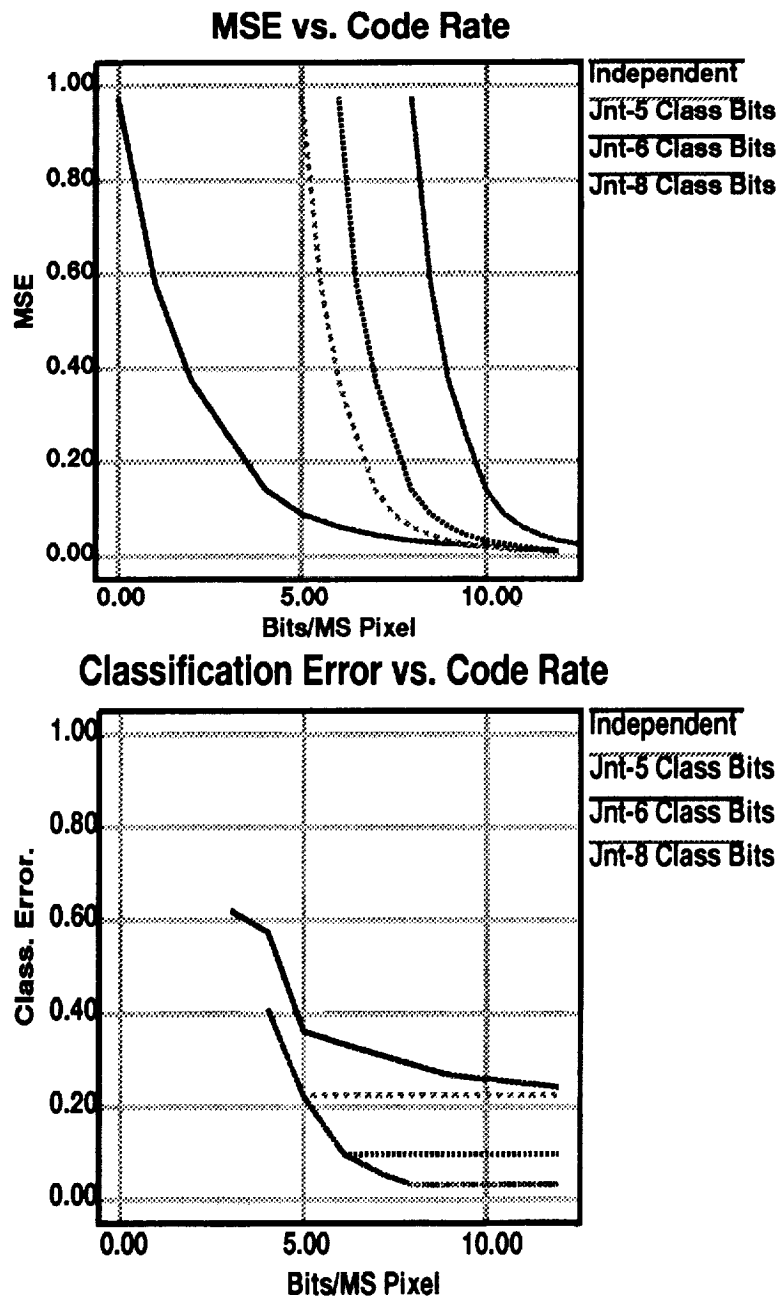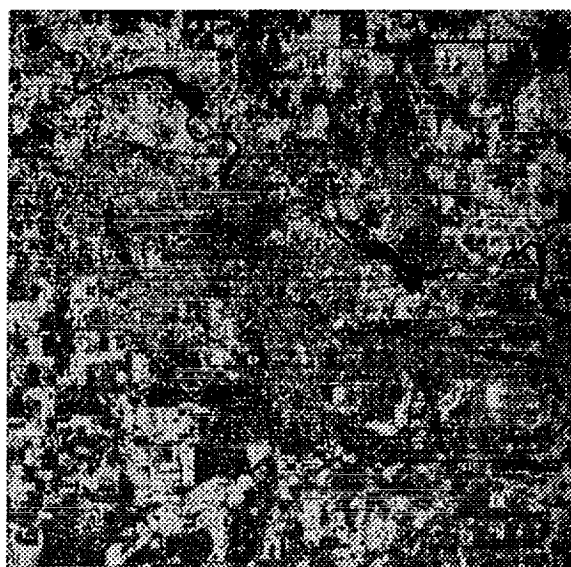We showed that the joint design achieved a significant improvement in classification per-
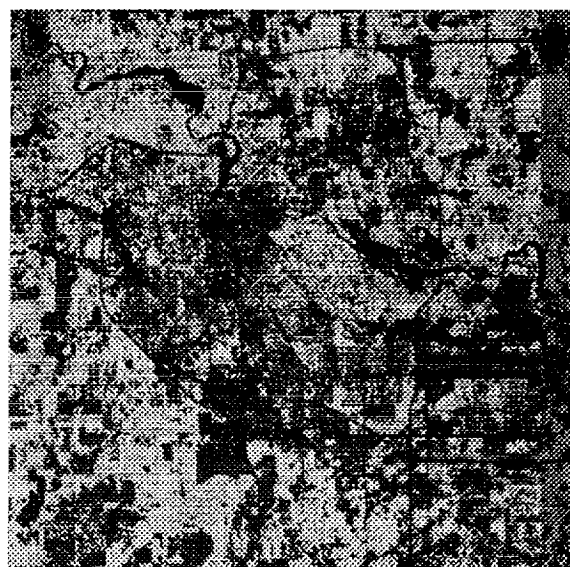
MSE vs. Code Rate

Classification Error vs. Code Rate

Figure 2. MSE and Classification performance of the two compression/
classification schemes

(a) Original Classification

(b) ML Classifier, 12:1 Compression

■ water
■ urban
■ range
▦ agricult.
■ bare soil
▩ deciduous
■ conifer
▦ quarry
▦ barren
▩ golf course
■ non category

(c) TSC, 12:1 Compression

Figure 3. Joint compression/terrain categorization examples: (a) Original terrain categorization, (b) independent compression/classification designs, (c) joint classification/compression design.

formance with only a minor degradation in MSE performance. This suggests that significant increases in data exploitation utility can be achieved by modifying compression algorithm design criteria to include metrics appropriate to the required exploitation tasks.

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