Project 3

**Locality-constrained Linear Coding for Scene Classification**

Giang Doan, Emily Busche

[{gdoan@cs.wisc.edu](mailto:%7bgdoan@cs.wisc.edu), [ebusche@cs.wisc.edu](mailto:ebusche@cs.wisc.edu)}

### 1. Download images (Emily)

The 15-class natural scene dataset was downloaded into a file called **scene\_categories(1)** (with the subclasses in separate folders inside this folder) which was in the project folder. You can change the path to these images by updating the **image\_dir** variable in **Example.m**.

### 2. Download baseline and set up your pipeline (Emily)

For the pipeline, I modified the baseline code in the following ways:

1. **Example.m**

This is the main file used to run the image classification code. It contains the variables for the parameters that are modified in the various experiments that were run.

1. **labelImages.m**

This file moves the images to a single folder and renames them in a way that makes identification easier.

1. **SVMclass.m**

This file performs the classification and prints out the confusion matrix for the test images. We use LIBSVM for classification. To get LIBSVM to run, go into libsvm-3.18\matlab in matlab and run make.

### 3. Implement LLC method by modifying the spatial pyramid code (Giang)

I modified some files when implementing LLC method:

1. **BuildPyramid2.m**

This file will call new methods to generate SIFT descriptor, calculate dictionary, build histogram with LLC and compile pyramid.

1. **GenerateSiftDescriptors2.m**

This file is a modified version of **GenerateSiftDescriptor.m**. I modified it to extract proper features for LLC method.

1. **CalculateDictionary2.m**

This file is a modified version of **CalculateDictionary.m**. Here I replaced *sp\_kmeans* method with *FastKMean* to train a k means cluster model faster.

1. **BuildHistograms2.m**

This file is a modified version of **BuildHistogram.m.** In this file, I implemented LLC method (function *CalculateLLC*) as in the paper which uses locality constrained linear coding.

1. **CompilePyramid2.m**

This file is a modified version of **CompilePyramid.m**. LLC uses max pooling to form the histogram feature.

### 4. Evaluate your implementation on the 15-class natural scene dataset (Emily)

For testing, we used 1,500 test images (15 classes, 100 images per class), gridSpacing = 8, patchSize = 16, dictionary size 200 and 2 pyramid levels. The unedited spatial pyramid code gave a mean accuracy of 69.02%, and the LLC code gave a mean accuracy of 73.59%.

Spatial Pyramid Confusion Matrix

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | suburb | coast | forest | highway | insidecity | mountain | country | street | building | office | bedroom | industrial | kitchen | livingroom | store | Total | Mean accuracy |
| suburb | 125 | 0 | 3 | 0 | 2 | 2 | 0 | 2 | 2 | 0 | 0 | 2 | 0 | 1 | 2 | 141 | 88.65% |
| coast | 1 | 193 | 1 | 19 | 0 | 7 | 37 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 260 | 74.23% |
| forest | 3 | 0 | 214 | 0 | 0 | 5 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 228 | 93.86% |
| highway | 0 | 15 | 0 | 116 | 1 | 6 | 11 | 3 | 0 | 0 | 0 | 6 | 0 | 0 | 2 | 160 | 72.50% |
| insidecity | 7 | 0 | 0 | 3 | 134 | 0 | 2 | 17 | 4 | 1 | 1 | 16 | 13 | 2 | 8 | 208 | 64.42% |
| mountain | 1 | 6 | 10 | 5 | 0 | 233 | 14 | 1 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 274 | 85.04% |
| country | 7 | 48 | 18 | 1 | 0 | 33 | 196 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 310 | 63.23% |
| street | 1 | 1 | 0 | 0 | 4 | 3 | 0 | 169 | 4 | 0 | 0 | 7 | 0 | 1 | 2 | 192 | 88.02% |
| building | 0 | 0 | 1 | 0 | 16 | 1 | 0 | 4 | 199 | 0 | 0 | 23 | 2 | 3 | 7 | 256 | 77.73% |
| office | 0 | 1 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 76 | 8 | 3 | 16 | 4 | 3 | 115 | 66.09% |
| bedroom | 0 | 1 | 0 | 1 | 0 | 2 | 0 | 2 | 1 | 6 | 57 | 6 | 11 | 26 | 3 | 116 | 49.14% |
| industrial | 7 | 3 | 1 | 4 | 21 | 8 | 2 | 4 | 30 | 5 | 5 | 92 | 6 | 2 | 21 | 211 | 43.60% |
| kitchen | 0 | 0 | 0 | 0 | 8 | 1 | 0 | 0 | 1 | 5 | 11 | 0 | 62 | 18 | 4 | 110 | 56.36% |
| livingroom | 2 | 0 | 0 | 0 | 3 | 2 | 0 | 2 | 1 | 10 | 31 | 6 | 15 | 107 | 10 | 189 | 56.61% |
| store | 0 | 0 | 5 | 1 | 31 | 5 | 1 | 4 | 13 | 2 | 0 | 11 | 12 | 10 | 120 | 215 | 55.81% |
| Total | 154 | 268 | 253 | 150 | 224 | 308 | 266 | 216 | 256 | 105 | 115 | 174 | 137 | 174 | 185 |  | 69.02% |

LLC Confusion Matrix

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | suburb | coast | forest | highway | insidecity | mountain | country | street | building | office | bedroom | industrial | kitchen | livingroom | store | Total | Mean accuracy |
| suburb | 129 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 1 | 0 | 5 | 141 | 91.49% |
| coast | 0 | 215 | 2 | 4 | 0 | 9 | 29 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 260 | 82.69% |
| forest | 0 | 0 | 208 | 0 | 0 | 15 | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 228 | 91.23% |
| highway | 0 | 14 | 0 | 133 | 2 | 3 | 3 | 4 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 160 | 83.13% |
| insidecity | 1 | 0 | 0 | 1 | 166 | 0 | 1 | 25 | 7 | 3 | 0 | 2 | 1 | 0 | 1 | 208 | 79.81% |
| mountain | 0 | 7 | 11 | 3 | 0 | 231 | 18 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 274 | 84.31% |
| country | 3 | 54 | 15 | 3 | 0 | 33 | 194 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 310 | 62.58% |
| street | 0 | 0 | 0 | 2 | 4 | 2 | 1 | 177 | 4 | 0 | 1 | 1 | 0 | 0 | 0 | 192 | 92.19% |
| building | 0 | 0 | 0 | 0 | 24 | 1 | 0 | 4 | 216 | 0 | 2 | 3 | 1 | 0 | 5 | 256 | 84.38% |
| office | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 89 | 2 | 3 | 15 | 6 | 0 | 115 | 77.39% |
| bedroom | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 12 | 52 | 8 | 8 | 30 | 3 | 116 | 44.83% |
| industrial | 11 | 2 | 0 | 0 | 11 | 0 | 0 | 1 | 13 | 2 | 9 | 116 | 3 | 6 | 37 | 211 | 54.98% |
| kitchen | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 6 | 17 | 5 | 57 | 22 | 2 | 110 | 51.82% |
| livingroom | 2 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 6 | 32 | 7 | 24 | 105 | 11 | 189 | 55.56% |
| store | 1 | 0 | 2 | 0 | 12 | 0 | 0 | 1 | 3 | 2 | 2 | 21 | 10 | 16 | 145 | 215 | 67.44% |
| Total | 148 | 292 | 239 | 146 | 222 | 295 | 248 | 222 | 244 | 121 | 118 | 172 | 120 | 185 | 213 |  | 73.59% |

### 5. Bonus

a. **Optimize codebook:**

* + - **Use fast k-mean for faster clustering (Giang):**

As mentioned in (3c), I used a new algorithm fast k-mean to train a k means cluster model faster than the original k-mean algorithm in *sp\_kmeans*.

* + - **Build optimized codebook (Emily)**:

I implemented the codebook optimization code described in algorithm 4.1 in the file **CodebookOpt.m**. It is called by **CalculateDictionary2.m**, but because the optimization did not show much improvement that line has been commented out (see **Try different parameters and experimental settings** section).

b. **Try different parameters and experimental settings:**

Several tests were performed by trying different values for the parameters. For all testing, we used 1,500 test images (15 classes, 100 images per class), gridSpacing = 8, and patchSize = 16.

**Changing the Dictionary size**

We tested the LLC code with 2 pyramid and varied the dictionary size. As we increased the dictionary size, the accuracy increased. Increasing the dictionary size by 100 lead to about a 2.5% increase in accuracy.

Confusion Matrix with 300 Dictionary Size (mean accuracy 76.49%)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | suburb | coast | forest | highway | insidecity | mountain | country | street | building | office | bedroom | industrial | kitchen | livingroom | store | Total | Mean accuracy |
| suburb | 135 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 3 | 141 | 95.74% |
| coast | 0 | 222 | 2 | 1 | 0 | 4 | 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 260 | 85.38% |
| forest | 0 | 0 | 211 | 0 | 0 | 9 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 228 | 92.54% |
| highway | 0 | 12 | 0 | 134 | 2 | 3 | 6 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 160 | 83.75% |
| insidecity | 2 | 0 | 0 | 4 | 169 | 0 | 0 | 24 | 4 | 0 | 0 | 2 | 0 | 1 | 2 | 208 | 81.25% |
| mountain | 0 | 9 | 11 | 1 | 0 | 242 | 10 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 274 | 88.32% |
| country | 1 | 44 | 21 | 3 | 0 | 35 | 202 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 310 | 65.16% |
| street | 0 | 0 | 1 | 2 | 6 | 1 | 0 | 176 | 5 | 0 | 0 | 1 | 0 | 0 | 0 | 192 | 91.67% |
| building | 0 | 0 | 1 | 1 | 24 | 1 | 0 | 2 | 221 | 0 | 0 | 3 | 1 | 0 | 2 | 256 | 86.33% |
| office | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 94 | 2 | 2 | 13 | 4 | 0 | 115 | 81.74% |
| bedroom | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 7 | 52 | 7 | 10 | 31 | 6 | 116 | 44.83% |
| industrial | 8 | 2 | 0 | 1 | 9 | 1 | 1 | 2 | 12 | 2 | 7 | 122 | 5 | 6 | 33 | 211 | 57.82% |
| kitchen | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 7 | 4 | 62 | 29 | 2 | 110 | 56.36% |
| livingroom | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 7 | 18 | 3 | 26 | 126 | 8 | 189 | 66.67% |
| store | 1 | 0 | 2 | 0 | 12 | 2 | 0 | 1 | 4 | 2 | 3 | 15 | 8 | 15 | 150 | 215 | 69.77% |
| Total | 148 | 289 | 250 | 147 | 223 | 300 | 257 | 212 | 247 | 118 | 89 | 160 | 125 | 213 | 207 |  | 76.49% |

Confusion Matrix with 400 Dictionary Size (mean accuracy 78.03%)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | suburb | coast | forest | highway | insidecity | mountain | country | street | building | office | bedroom | industrial | kitchen | livingroom | store | Total | Mean accuracy |
| suburb | 138 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 141 | 97.87% |
| coast | 0 | 219 | 2 | 3 | 0 | 5 | 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 260 | 84.23% |
| forest | 0 | 0 | 213 | 0 | 0 | 10 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 228 | 93.42% |
| highway | 0 | 13 | 1 | 135 | 2 | 1 | 5 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 160 | 84.38% |
| insidecity | 1 | 0 | 0 | 2 | 175 | 0 | 0 | 22 | 5 | 1 | 0 | 0 | 0 | 0 | 2 | 208 | 84.13% |
| mountain | 0 | 4 | 14 | 2 | 0 | 239 | 13 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 274 | 87.23% |
| country | 0 | 40 | 15 | 4 | 0 | 29 | 217 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 310 | 70.00% |
| street | 0 | 0 | 0 | 0 | 7 | 2 | 0 | 177 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 192 | 92.19% |
| building | 0 | 0 | 0 | 1 | 24 | 3 | 0 | 2 | 216 | 0 | 1 | 1 | 1 | 0 | 7 | 256 | 84.38% |
| office | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 98 | 5 | 3 | 7 | 2 | 0 | 115 | 85.22% |
| bedroom | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 2 | 59 | 4 | 13 | 30 | 5 | 116 | 50.86% |
| industrial | 6 | 2 | 0 | 0 | 6 | 1 | 1 | 2 | 9 | 3 | 6 | 130 | 4 | 4 | 37 | 211 | 61.61% |
| kitchen | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 8 | 1 | 62 | 30 | 5 | 110 | 56.36% |
| livingroom | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 6 | 23 | 8 | 19 | 123 | 9 | 189 | 65.08% |
| store | 0 | 0 | 1 | 0 | 10 | 0 | 0 | 1 | 4 | 1 | 2 | 13 | 9 | 16 | 158 | 215 | 73.49% |
| Total | 146 | 278 | 247 | 147 | 224 | 292 | 271 | 214 | 242 | ## | ## | 161 | ## | 205 | 224 |  | 78.03% |

**Changing the Pyramid Levels**

We tested the LLC code with a dictionary size of 200 and varied the number of pyramid levels. When the pyramid levels increase from 2 to 3 levels, the mean accuracy increased from 73.59% to 79.47%. However, increasing the number of levels from 3 to 4 showed a slight decreasing in accuracy (to 79.22%). Increasing the number of pyramid levels can improve performance, but there is a limit to how many levels produce an increase in performance.

Confusion Matrix with 3 Pyramid Levels (mean accuracy 79.47%)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | suburb | coast | forest | highway | insidecity | mountain | country | street | building | office | bedroom | industrial | kitchen | livingroom | store | Total | Mean accuracy |
| suburb | 140 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 141 | 99.29% |
| coast | 0 | 217 | 2 | 8 | 0 | 2 | 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 260 | 83.46% |
| forest | 0 | 0 | 209 | 0 | 0 | 13 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 228 | 91.67% |
| highway | 0 | 14 | 0 | 130 | 2 | 3 | 7 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 160 | 81.25% |
| insidecity | 0 | 1 | 0 | 1 | 172 | 0 | 0 | 26 | 6 | 0 | 0 | 0 | 0 | 1 | 1 | 208 | 82.69% |
| mountain | 0 | 5 | 12 | 6 | 0 | 238 | 10 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 274 | 86.86% |
| country | 0 | 46 | 13 | 3 | 0 | 28 | 216 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 310 | 69.68% |
| street | 0 | 0 | 0 | 1 | 6 | 2 | 0 | 176 | 6 | 0 | 0 | 0 | 0 | 0 | 1 | 192 | 91.67% |
| building | 0 | 0 | 1 | 0 | 24 | 3 | 0 | 1 | 221 | 0 | 0 | 1 | 1 | 0 | 4 | 256 | 86.33% |
| office | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 96 | 3 | 3 | 10 | 3 | 0 | 115 | 83.48% |
| bedroom | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 62 | 8 | 7 | 31 | 4 | 116 | 53.45% |
| industrial | 2 | 0 | 0 | 1 | 2 | 0 | 1 | 1 | 7 | 0 | 4 | 151 | 2 | 4 | 36 | 211 | 71.56% |
| kitchen | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 9 | 1 | 70 | 22 | 4 | 110 | 63.64% |
| livingroom | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 5 | 20 | 7 | 12 | 132 | 11 | 189 | 69.84% |
| store | 0 | 0 | 1 | 0 | 3 | 0 | 0 | 2 | 3 | 5 | 2 | 7 | 7 | 19 | 166 | 215 | 77.21% |
| Total | 142 | 283 | 238 | 150 | 209 | 290 | 269 | 217 | 246 | 113 | 100 | 179 | 109 | 212 | 228 |  | 79.47% |

Confusion Matrix with 4 Pyramid Levels (mean accuracy 79.22%)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | suburb | coast | forest | highway | insidecity | mountain | country | street | building | office | bedroom | industrial | kitchen | livingroom | store | Total | Mean accuracy |
| suburb | 138 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 141 | 97.87% |
| coast | 0 | 221 | 2 | 6 | 0 | 2 | 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 260 | 85.00% |
| forest | 0 | 0 | 208 | 0 | 0 | 16 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 228 | 91.23% |
| highway | 0 | 14 | 0 | 128 | 2 | 5 | 7 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 160 | 80.00% |
| insidecity | 0 | 2 | 0 | 1 | 167 | 0 | 0 | 30 | 6 | 0 | 1 | 0 | 0 | 0 | 1 | 208 | 80.29% |
| mountain | 0 | 6 | 13 | 5 | 0 | 233 | 13 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 274 | 85.04% |
| country | 0 | 43 | 12 | 3 | 0 | 30 | 218 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 310 | 70.32% |
| street | 0 | 0 | 0 | 1 | 8 | 2 | 1 | 174 | 5 | 0 | 0 | 1 | 0 | 0 | 0 | 192 | 90.63% |
| building | 0 | 0 | 1 | 0 | 26 | 2 | 0 | 0 | 224 | 0 | 0 | 0 | 1 | 0 | 2 | 256 | 87.50% |
| office | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 96 | 1 | 3 | 11 | 4 | 0 | 115 | 83.48% |
| bedroom | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 63 | 8 | 8 | 28 | 5 | 116 | 54.31% |
| industrial | 3 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 6 | 0 | 3 | 153 | 2 | 5 | 36 | 211 | 72.51% |
| kitchen | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 8 | 2 | 65 | 28 | 5 | 110 | 59.09% |
| livingroom | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 4 | 14 | 8 | 11 | 137 | 13 | 189 | 72.49% |
| store | 0 | 0 | 1 | 0 | 4 | 1 | 0 | 1 | 3 | 3 | 2 | 1 | 9 | 21 | 169 | 215 | 78.60% |
| Total | 141 | 286 | 237 | 144 | 208 | 292 | 271 | 218 | 247 | ## | 92 | 178 | 107 | 223 | 233 |  | 79.22% |

**Combined test**

Combining the knowledge we learned from the previous tests, we increased the pyramid levels to 3 and the dictionary size to 300. This produced a mean accuracy of 79.72% an improvement over all previous tests.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | suburb | coast | forest | highway | insidecity | mountain | country | street | building | office | bedroom | industrial | kitchen | livingroom | store | Total | Mean accuracy |
| suburb | 138 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 141 | 97.87% |
| coast | 0 | 227 | 2 | 2 | 0 | 2 | 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 260 | 87.31% |
| forest | 0 | 0 | 210 | 0 | 0 | 14 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 228 | 92.11% |
| highway | 0 | 13 | 0 | 130 | 2 | 3 | 7 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 160 | 81.25% |
| insidecity | 0 | 1 | 0 | 2 | 174 | 0 | 0 | 24 | 6 | 1 | 0 | 0 | 0 | 0 | 0 | 208 | 83.65% |
| mountain | 0 | 6 | 13 | 3 | 0 | 239 | 10 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 274 | 87.23% |
| country | 0 | 40 | 13 | 3 | 0 | 30 | 220 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 310 | 70.97% |
| street | 0 | 0 | 0 | 3 | 7 | 1 | 0 | 176 | 4 | 0 | 0 | 1 | 0 | 0 | 0 | 192 | 91.67% |
| building | 0 | 0 | 1 | 0 | 22 | 1 | 0 | 2 | 226 | 0 | 0 | 0 | 1 | 0 | 3 | 256 | 88.28% |
| office | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 102 | 1 | 1 | 9 | 2 | 0 | 115 | 88.70% |
| bedroom | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 5 | 59 | 6 | 9 | 31 | 4 | 116 | 50.86% |
| industrial | 3 | 1 | 0 | 0 | 8 | 1 | 1 | 3 | 10 | 1 | 3 | 145 | 3 | 3 | 29 | 211 | 68.72% |
| kitchen | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 7 | 5 | 62 | 24 | 6 | 110 | 56.36% |
| livingroom | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 17 | 6 | 11 | 141 | 9 | 189 | 74.60% |
| store | 0 | 0 | 2 | 0 | 7 | 1 | 0 | 1 | 5 | 3 | 2 | 4 | 6 | 20 | 164 | 215 | 76.28% |
| Total | 141 | 288 | 241 | 143 | 220 | 294 | 269 | 216 | 254 | 122 | 89 | 170 | 101 | 222 | 215 |  | 79.72% |

**Codebook optimization**

We implemented the codebook optimization algorithm in the LLC paper. To compare it to our initial LLC test, we used a dictionary size of 200 and 2 pyramid levels to compare to spatial pyramids. We used the entire training set for our X and used and . The optimized codebook version of LLC performed only slightly better than our original test with a mean accuracy of 73.83%.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | suburb | coast | forest | highway | insidecity | mountain | country | street | building | office | bedroom | industrial | kitchen | livingroom | store | Total | Mean accuracy |
| suburb | 133 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 2 | 141 | 94.33% |
| coast | 0 | 216 | 2 | 2 | 0 | 7 | 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 260 | 83.08% |
| forest | 0 | 0 | 208 | 0 | 0 | 9 | 7 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 228 | 91.23% |
| highway | 0 | 21 | 1 | 122 | 2 | 4 | 5 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 160 | 76.25% |
| insidecity | 1 | 0 | 0 | 1 | 166 | 0 | 0 | 26 | 5 | 3 | 1 | 2 | 0 | 2 | 1 | 208 | 79.81% |
| mountain | 0 | 8 | 11 | 5 | 0 | 235 | 13 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 274 | 85.77% |
| country | 2 | 49 | 19 | 2 | 0 | 23 | 209 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 310 | 67.42% |
| street | 0 | 0 | 1 | 0 | 5 | 2 | 0 | 174 | 9 | 0 | 0 | 1 | 0 | 0 | 0 | 192 | 90.63% |
| building | 0 | 0 | 1 | 0 | 24 | 2 | 0 | 2 | 218 | 0 | 1 | 3 | 1 | 0 | 4 | 256 | 85.16% |
| office | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 91 | 5 | 2 | 16 | 1 | 0 | 115 | 79.13% |
| bedroom | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 6 | 50 | 8 | 8 | 36 | 6 | 116 | 43.10% |
| industrial | 9 | 0 | 0 | 1 | 11 | 0 | 1 | 4 | 14 | 2 | 5 | 126 | 4 | 4 | 30 | 211 | 59.72% |
| kitchen | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 8 | 10 | 3 | 55 | 28 | 5 | 110 | 50.00% |
| livingroom | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 9 | 29 | 10 | 27 | 101 | 12 | 189 | 53.44% |
| store | 2 | 0 | 2 | 0 | 11 | 0 | 0 | 1 | 2 | 2 | 2 | 20 | 8 | 18 | 147 | 215 | 68.37% |
| Total | 147 | 294 | 246 | 133 | 221 | 284 | 268 | 220 | 251 | 121 | 103 | 180 | 119 | 190 | 208 |  | 73.83% |