

# Machine Learning HW3

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# 1 Classification Tasks

## 1.1 Overall Description

In this homework, I implemented Principal Component Analysis (PCA) to reduce the dimensionality. I use the Proportion of Variance (PoV) with the threshold of 0.95 to select the number of principal components. After that, I implemented three classification methods: Artificial Neural Networks (ANN), Logistic Discrimination Function (LDF), and Support Vector Machines (SVM) to classify the data.

The code of this homework was modified from my previous homeworks (HW1 and HW2), and is organized into three main files: `ann.py`, `ldf.py`, and `svm.py`, each corresponding to one of the classification methods. Please read `README.md` before running the code.

## 1.2 Artificial Neural Networks

As LDF can be considered as a single-layer neuron network (i.e. no hidden layers), thus I decided to finish the ANN part first.

The ANN was implemented from scratch in C++, including the forward propagation, backpropagation, and parameter updates (using simple SGD), without relying on high-level deep learning libraries. This simple AN consists three types of layers: linear layer, sigmoid activation layer, and relu activation layer. User can flexibly stack these layers to form a neural network of any architecture.

### 1.2.1 Model Description

The input layer of the ANN has the same number of neurons as the number of principal components after PCA. Then, I experimented with different architectures and finally decided to use two hidden layers with 10 and 5 neurons respectively, both using ReLU activation function. The output layer has a single neuron with sigmoid activation function to output the probability of the positive class. The learning rate was set to 0.005 due to the small dataset size and to ensure stable convergence.

To decide the training epochs, I implemented early stopping mechanism based on validation loss. The training process will stop if the validation loss does not improve for 10 consecutive epochs. The definition of "improve" here is that the validation loss decreases by at least 0.001 compared to the previous best validation loss. To avoid early stopping too early due to random fluctuations in validation loss, I set a minimum number of epochs (15 epochs) before early stopping can take effect, i.e., the training will run for at least 15 epochs regardless of validation loss. I set the maximum number of epochs to 1000 to prevent excessively long training times in case the early stopping condition is never met, but in practice, the training usually stops well before reaching this limit.

### 1.2.2 Results

The overall performance of ANN is shown in the table 1, and the ROC curve is shown in the figure 1. The training log is included in the appendix A.

Metric	Value
Accuracy	0.8544 (88/103)
Sensitivity	0.8293 (34/41)
Specificity	0.8710 (54/62)
Test AUC	0.9327
Train AUC	0.9714

Table 1: Performance of ANN

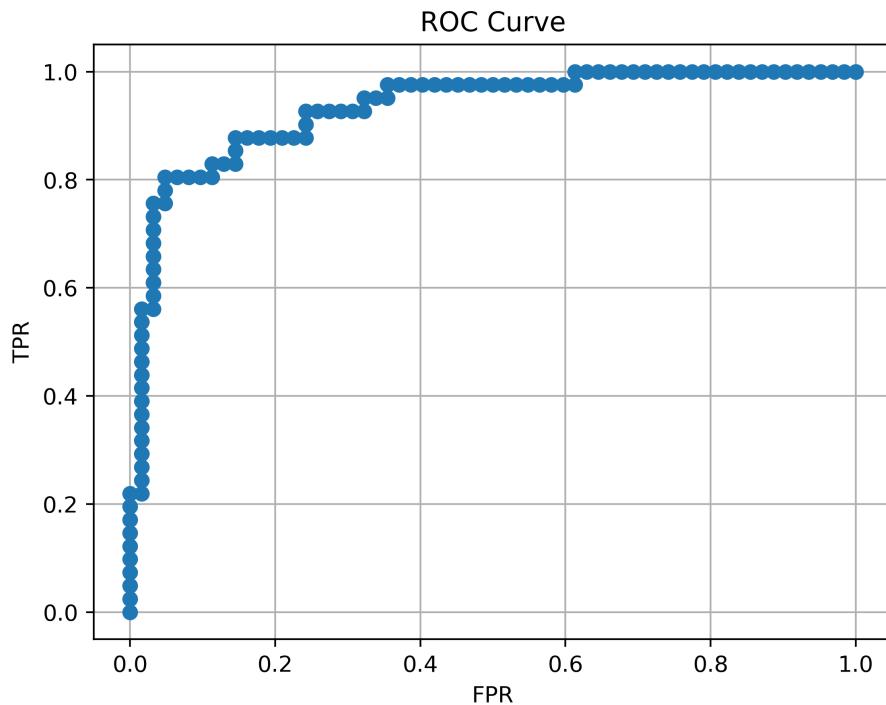


Figure 1: ROC Curve of ANN

## 1.3 Logistic Discrimination

### 1.3.1 Model Description

The Logistic Discrimination Function (LDF) was implemented as a simple ANN with 0 hidden layers and 1 input layer. The input layer has the same number of neurons as the number of principal components after PCA. The output layer has a single neuron with sigmoid

activation function to output the probability of the positive class. The learning rate was set to 0.005.

The early stopping mechanism is the same as that of ANN, with a minimum of 15 epochs, patience of 10 epochs, and a maximum of 1000 epochs.

### 1.3.2 Results

The overall performance of LDF is shown in the table 2, and the ROC curve is shown in the figure 2. The training log is included in the appendix B.

Metric	Value
Accuracy	0.8738 (90/103)
Sensitivity	0.7805 (32/41)
Specificity	0.9355 (58/62)
Test AUC	0.9284
Train AUC	0.9538

Table 2: Performance of LDF

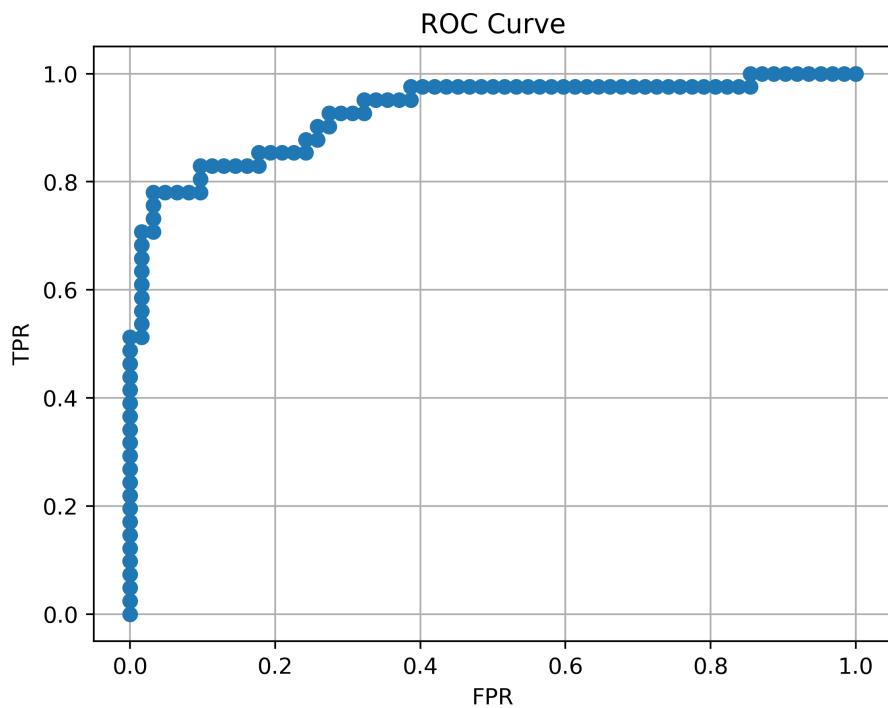


Figure 2: ROC Curve of LDF

## 1.4 Support Vector Machines

### 1.4.1 Model Description

In this homework, a binary Support Vector Machine (SVM) classifier with a radial basis function (RBF) kernel was implemented from scratch in Python. The training procedure is based on the Sequential Minimal Optimization (SMO) algorithm, which optimizes the dual formulation of the SVM objective function. The regularization parameter  $C$  was set to 1.0, and the kernel parameter  $\gamma$  was set to 0.05 based on preliminary experiments with different parameter values.

During training, the RBF kernel matrix of the training set was precomputed to improve computational efficiency. The algorithm iteratively scans the training samples and identifies those that violate the Karush-Kuhn-Tucker (KKT) optimality conditions based on their prediction errors. For each violating sample, a second sample is selected, and the corresponding pair of Lagrange multipliers is updated according to the SMO update rules while respecting the box constraints. The bias term is updated after each pairwise optimization step to ensure consistency of the decision function.

After training, the learned dual parameters are used to compute raw decision scores for both training and test data. Model performance is evaluated using the area under the ROC curve (AUC), which is computed from the decision scores without probability calibration.

### 1.4.2 Results

The overall performance of SVM is shown in the table 3, and the ROC curve is shown in the figure 3. The training log is included in the appendix C.

Metric	Value
Accuracy	0.7282 (75/103)
Sensitivity	0.3902 (16/41)
Specificity	0.9516 (59/62)
Test AUC	0.8666
Train AUC	0.9992

Table 3: Performance of SVM

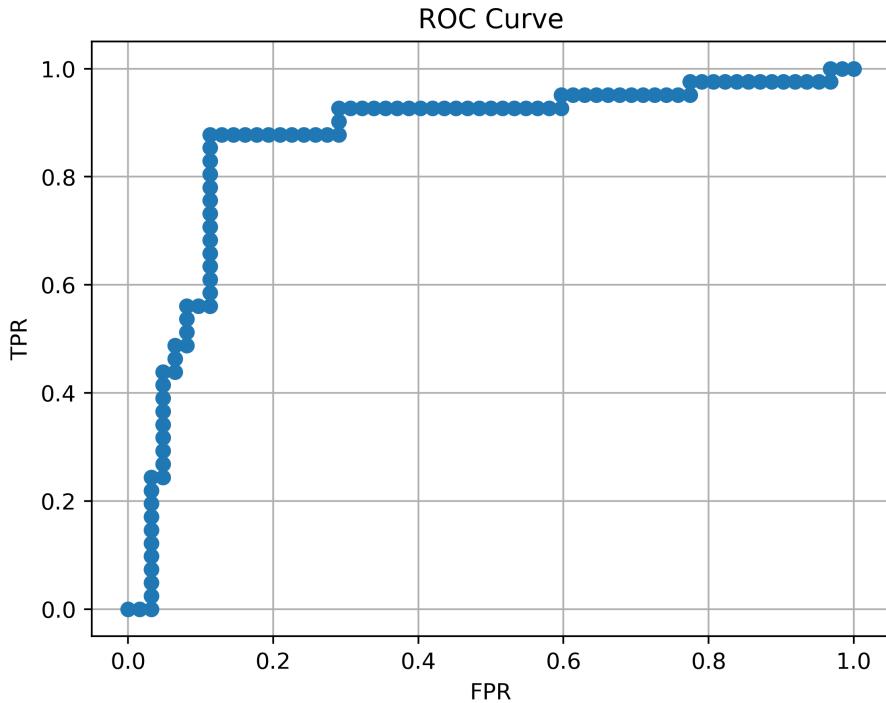


Figure 3: ROC Curve of SVM

## 1.5 SVM with Sklearn

However, there are several limitations in the custom SVM implementation. The adopted SMO algorithm is a simplified version and does not incorporate advanced heuristics for selecting the second working variable or accelerating convergence. In addition, the number of outer iterations is fixed to 100, rather than being determined by convergence criteria based on optimality conditions. As a result, the obtained solution may be suboptimal compared to mature SVM solvers.

Implementing a fully optimized SVM solver from scratch is nontrivial and difficult to accomplish within the limited time. Therefore, an additional SVM implementation based on the scikit-learn library was included as a reference baseline. The implementation of this library-based SVM was assisted by ChatGPT.

The performance of the scikit-learn SVM is summarized in Table 4, and the corresponding ROC curve is shown in Figure 4. As expected, the library-based implementation achieves better performance than the handcrafted SVM implementation.

Metric	Value
Accuracy	0.8738 (90/103)
Sensitivity	0.8049 (33/41)
Specificity	0.9194 (57/62)
Test AUC	0.9264
Train AUC	0.9610

Table 4: Performance of SVM with Sklearn

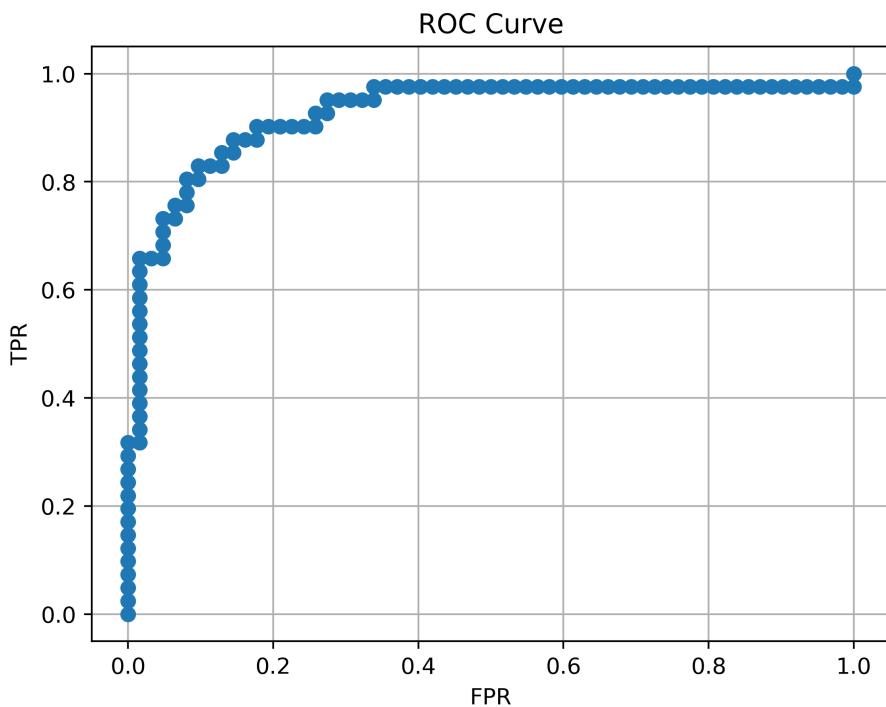


Figure 4: ROC Curve of SVM with Sklearn

## 2 Methods comparison

Table 5 is an overall comparison of the models implemented across the three homeworks: Bayesian Classifier(BC) with forward selection(FS) from HW1, BC with PCA from HW2, and the three models from this homework: Artificial Neural Networks (ANN), Logistic Discrimination Function (LDF), and Support Vector Machines (SVM).

Table 5: Performance comparison of different models

Metric	BC + FS	BC + PCA	ANN	LDF	SVM	SVM (Sklearn)
Accuracy	0.8350	0.8835	0.8544	0.8738	0.7282	0.8738
Sensitivity	0.8537	0.8537	0.8293	0.7805	0.3902	0.8049
Specificity	0.8226	0.9032	0.8710	0.9355	0.9516	0.9194
Test AUC	0.9233	0.9256	0.9327	0.9284	0.8666	0.9264

Among all evaluated models, the artificial neural network (ANN) achieved the best overall performance, with the highest test AUC (0.9327) and a balanced trade-off between sensitivity (0.8293) and specificity (0.8710). This may be attributed to its flexibility in modeling complex, non-linear decision boundaries. This may cause it overfitting, but also endowed it with great potential. With proper regularization and hyperparameter tuning, ANN can generalize well to unseen data.

The linear discriminant function (LDF) and the SVM implemented using scikit-learn exhibited comparable discriminative ability, with test AUC values close to that of ANN. LDF favored higher specificity at the expense of sensitivity, whereas the scikit-learn SVM provided a more balanced classification behavior. In contrast, the handcrafted SVM performed the worst, due to its simplified implementation and suboptimal hyperparameter choices.

For the Bayesian classifier, both feature selection (FS) and principal component analysis (PCA) led to comparable classification performance, with similar test AUC values.

In contrast, PCA achieved a more balanced performance, with higher specificity and overall accuracy while maintaining comparable sensitivity. By projecting the original features into a lower-dimensional orthogonal subspace, PCA effectively reduced feature redundancy and noise, which may explain its improved stability and generalization compared to direct feature selection. These results suggest that PCA provides a more robust feature representation for the Bayesian classifier in this dataset.

The worst AUC in these models (handcrafted SVM) is still 0.8666, which indicates that the dataset is not robustly separable. Thus I can't draw a definitive conclusion about which model is the best.

## A Training Logs of ANN

---

```
1 [INFO] Data loaded successfully:
2   SeqNum GroundTruth Gender ... NoseSurfA      NoseW NasoFacialA
3   0       1           0     2 ... 3972.311567 34.479069 32.325195
4   1       2           0     2 ... 4217.911999 38.170299 41.061411
5   2       3           0     2 ... 4010.477059 36.962578 36.151195
6   3       4           0     2 ... 3796.839953 38.330882 32.658731
7   4       5           0     2 ... 4011.612497 35.772898 36.637580
8
9 [5 rows x 22 columns]
10 [INFO] Starting Leave-One-Out Cross-Validation...
11 start with thresh=0.95
12 LOOCV Fold 1/103
13 [INFO] selected 7 principal components to retain 95.39% variance.
14 [INFO] Early stopping at epoch 302
15 Fold 1 Training AUC: 0.9664
16 Fold 1 Test Probability: 0.0000 (True Label: 0)
17 LOOCV Fold 2/103
18 [INFO] selected 7 principal components to retain 95.47% variance.
19 [INFO] Early stopping at epoch 289
20 Fold 2 Training AUC: 0.9736
21 Fold 2 Test Probability: 0.6670 (True Label: 0)
22 LOOCV Fold 3/103
23 [INFO] selected 7 principal components to retain 95.48% variance.
24 [INFO] Early stopping at epoch 264
25 Fold 3 Training AUC: 0.9716
26 Fold 3 Test Probability: 0.0256 (True Label: 0)
27 LOOCV Fold 4/103
28 [INFO] selected 7 principal components to retain 95.48% variance.
29 [INFO] Early stopping at epoch 417
30 Fold 4 Training AUC: 0.9732
31 Fold 4 Test Probability: 0.0000 (True Label: 0)
32 LOOCV Fold 5/103
33 [INFO] selected 7 principal components to retain 95.43% variance.
34 [INFO] Early stopping at epoch 294
35 Fold 5 Training AUC: 0.9668
36 Fold 5 Test Probability: 0.0002 (True Label: 0)
37 LOOCV Fold 6/103
38 [INFO] selected 7 principal components to retain 95.48% variance.
39 [INFO] Early stopping at epoch 405
40 Fold 6 Training AUC: 0.9700
41 Fold 6 Test Probability: 0.0193 (True Label: 0)
42 LOOCV Fold 7/103
43 [INFO] selected 7 principal components to retain 95.48% variance.
44 [INFO] Early stopping at epoch 317
45 Fold 7 Training AUC: 0.9796
46 Fold 7 Test Probability: 0.0000 (True Label: 0)
47 LOOCV Fold 8/103
48 [INFO] selected 7 principal components to retain 95.46% variance.
49 [INFO] Early stopping at epoch 268
50 Fold 8 Training AUC: 0.9644
51 Fold 8 Test Probability: 0.0007 (True Label: 0)
52 LOOCV Fold 9/103
53 [INFO] selected 7 principal components to retain 95.52% variance.
54 [INFO] Early stopping at epoch 372
55 Fold 9 Training AUC: 0.9828
```

```
56 Fold 9 Test Probability: 0.0000 (True Label: 0)
57 LOOCV Fold 10/103
58 [INFO] selected 7 principal components to retain 95.50% variance.
59 [INFO] Early stopping at epoch 447
60 Fold 10 Training AUC: 0.9876
61 Fold 10 Test Probability: 0.9040 (True Label: 0)
62 LOOCV Fold 11/103
63 [INFO] selected 7 principal components to retain 95.49% variance.
64 [INFO] Early stopping at epoch 276
65 Fold 11 Training AUC: 0.9596
66 Fold 11 Test Probability: 0.6357 (True Label: 0)
67 LOOCV Fold 12/103
68 [INFO] selected 7 principal components to retain 95.51% variance.
69 [INFO] Early stopping at epoch 201
70 Fold 12 Training AUC: 0.9564
71 Fold 12 Test Probability: 0.3151 (True Label: 0)
72 LOOCV Fold 13/103
73 [INFO] selected 7 principal components to retain 95.52% variance.
74 [INFO] Early stopping at epoch 262
75 Fold 13 Training AUC: 0.9538
76 Fold 13 Test Probability: 0.6008 (True Label: 0)
77 LOOCV Fold 14/103
78 [INFO] selected 7 principal components to retain 95.51% variance.
79 [INFO] Early stopping at epoch 430
80 Fold 14 Training AUC: 0.9612
81 Fold 14 Test Probability: 0.0007 (True Label: 0)
82 LOOCV Fold 15/103
83 [INFO] selected 7 principal components to retain 95.47% variance.
84 [INFO] Early stopping at epoch 380
85 Fold 15 Training AUC: 0.9674
86 Fold 15 Test Probability: 0.0000 (True Label: 0)
87 LOOCV Fold 16/103
88 [INFO] selected 7 principal components to retain 95.53% variance.
89 [INFO] Early stopping at epoch 298
90 Fold 16 Training AUC: 0.9704
91 Fold 16 Test Probability: 0.0000 (True Label: 0)
92 LOOCV Fold 17/103
93 [INFO] selected 7 principal components to retain 95.49% variance.
94 [INFO] Early stopping at epoch 358
95 Fold 17 Training AUC: 0.9520
96 Fold 17 Test Probability: 0.0000 (True Label: 0)
97 LOOCV Fold 18/103
98 [INFO] selected 7 principal components to retain 95.49% variance.
99 [INFO] Early stopping at epoch 485
100 Fold 18 Training AUC: 0.9844
101 Fold 18 Test Probability: 0.0006 (True Label: 0)
102 LOOCV Fold 19/103
103 [INFO] selected 7 principal components to retain 95.50% variance.
104 [INFO] Early stopping at epoch 295
105 Fold 19 Training AUC: 0.9658
106 Fold 19 Test Probability: 0.0000 (True Label: 0)
107 LOOCV Fold 20/103
108 [INFO] selected 7 principal components to retain 95.49% variance.
109 [INFO] Early stopping at epoch 371
110 Fold 20 Training AUC: 0.9772
111 Fold 20 Test Probability: 0.0327 (True Label: 0)
112 LOOCV Fold 21/103
113 [INFO] selected 7 principal components to retain 95.57% variance.
114 [INFO] Early stopping at epoch 190
```

```
115 Fold 21 Training AUC: 0.9606
116 Fold 21 Test Probability: 0.0081 (True Label: 0)
117 LOOCV Fold 22/103
118 [INFO] selected 7 principal components to retain 95.51% variance.
119 [INFO] Early stopping at epoch 498
120 Fold 22 Training AUC: 0.9858
121 Fold 22 Test Probability: 0.0954 (True Label: 0)
122 LOOCV Fold 23/103
123 [INFO] selected 7 principal components to retain 95.50% variance.
124 [INFO] Early stopping at epoch 505
125 Fold 23 Training AUC: 0.9696
126 Fold 23 Test Probability: 0.0021 (True Label: 0)
127 LOOCV Fold 24/103
128 [INFO] selected 7 principal components to retain 95.51% variance.
129 [INFO] Early stopping at epoch 302
130 Fold 24 Training AUC: 0.9824
131 Fold 24 Test Probability: 0.0002 (True Label: 0)
132 LOOCV Fold 25/103
133 [INFO] selected 7 principal components to retain 95.54% variance.
134 [INFO] Early stopping at epoch 476
135 Fold 25 Training AUC: 0.9680
136 Fold 25 Test Probability: 0.0045 (True Label: 0)
137 LOOCV Fold 26/103
138 [INFO] selected 7 principal components to retain 95.51% variance.
139 [INFO] Early stopping at epoch 233
140 Fold 26 Training AUC: 0.9624
141 Fold 26 Test Probability: 0.0954 (True Label: 0)
142 LOOCV Fold 27/103
143 [INFO] selected 7 principal components to retain 95.58% variance.
144 [INFO] Early stopping at epoch 500
145 Fold 27 Training AUC: 0.9632
146 Fold 27 Test Probability: 0.0209 (True Label: 0)
147 LOOCV Fold 28/103
148 [INFO] selected 7 principal components to retain 95.53% variance.
149 [INFO] Early stopping at epoch 392
150 Fold 28 Training AUC: 0.9684
151 Fold 28 Test Probability: 0.0301 (True Label: 0)
152 LOOCV Fold 29/103
153 [INFO] selected 7 principal components to retain 95.52% variance.
154 [INFO] Early stopping at epoch 345
155 Fold 29 Training AUC: 0.9728
156 Fold 29 Test Probability: 0.0002 (True Label: 0)
157 LOOCV Fold 30/103
158 [INFO] selected 7 principal components to retain 95.50% variance.
159 [INFO] Early stopping at epoch 265
160 Fold 30 Training AUC: 0.9752
161 Fold 30 Test Probability: 0.5682 (True Label: 0)
162 LOOCV Fold 31/103
163 [INFO] selected 7 principal components to retain 95.49% variance.
164 [INFO] Early stopping at epoch 178
165 Fold 31 Training AUC: 0.9708
166 Fold 31 Test Probability: 0.0162 (True Label: 0)
167 LOOCV Fold 32/103
168 [INFO] selected 7 principal components to retain 95.50% variance.
169 [INFO] Early stopping at epoch 289
170 Fold 32 Training AUC: 0.9660
171 Fold 32 Test Probability: 0.3021 (True Label: 0)
172 LOOCV Fold 33/103
173 [INFO] selected 7 principal components to retain 95.50% variance.
```

```
174 [INFO] Early stopping at epoch 279
175 Fold 33 Training AUC: 0.9588
176 Fold 33 Test Probability: 0.5341 (True Label: 0)
177 LOOCV Fold 34/103
178 [INFO] selected 7 principal components to retain 95.48% variance.
179 [INFO] Early stopping at epoch 172
180 Fold 34 Training AUC: 0.9620
181 Fold 34 Test Probability: 0.0029 (True Label: 0)
182 LOOCV Fold 35/103
183 [INFO] selected 7 principal components to retain 95.61% variance.
184 [INFO] Early stopping at epoch 458
185 Fold 35 Training AUC: 0.9776
186 Fold 35 Test Probability: 0.0348 (True Label: 0)
187 LOOCV Fold 36/103
188 [INFO] selected 7 principal components to retain 95.48% variance.
189 [INFO] Early stopping at epoch 426
190 Fold 36 Training AUC: 0.9792
191 Fold 36 Test Probability: 0.0023 (True Label: 0)
192 LOOCV Fold 37/103
193 [INFO] selected 7 principal components to retain 95.50% variance.
194 [INFO] Early stopping at epoch 226
195 Fold 37 Training AUC: 0.9640
196 Fold 37 Test Probability: 0.7347 (True Label: 0)
197 LOOCV Fold 38/103
198 [INFO] selected 7 principal components to retain 95.50% variance.
199 [INFO] Early stopping at epoch 517
200 Fold 38 Training AUC: 0.9839
201 Fold 38 Test Probability: 0.9999 (True Label: 1)
202 LOOCV Fold 39/103
203 [INFO] selected 7 principal components to retain 95.54% variance.
204 [INFO] Early stopping at epoch 308
205 Fold 39 Training AUC: 0.9754
206 Fold 39 Test Probability: 0.7580 (True Label: 1)
207 LOOCV Fold 40/103
208 [INFO] selected 7 principal components to retain 95.49% variance.
209 [INFO] Early stopping at epoch 274
210 Fold 40 Training AUC: 0.9718
211 Fold 40 Test Probability: 0.7059 (True Label: 1)
212 LOOCV Fold 41/103
213 [INFO] selected 7 principal components to retain 95.54% variance.
214 [INFO] Early stopping at epoch 193
215 Fold 41 Training AUC: 0.9677
216 Fold 41 Test Probability: 0.0591 (True Label: 1)
217 LOOCV Fold 42/103
218 [INFO] selected 7 principal components to retain 95.44% variance.
219 [INFO] Early stopping at epoch 161
220 Fold 42 Training AUC: 0.9637
221 Fold 42 Test Probability: 0.9237 (True Label: 1)
222 LOOCV Fold 43/103
223 [INFO] selected 7 principal components to retain 95.37% variance.
224 [INFO] Early stopping at epoch 313
225 Fold 43 Training AUC: 0.9730
226 Fold 43 Test Probability: 0.9999 (True Label: 1)
227 LOOCV Fold 44/103
228 [INFO] selected 7 principal components to retain 95.51% variance.
229 [INFO] Early stopping at epoch 319
230 Fold 44 Training AUC: 0.9552
231 Fold 44 Test Probability: 0.8789 (True Label: 1)
232 LOOCV Fold 45/103
```

```
233 [INFO] selected 7 principal components to retain 95.48% variance.  
234 [INFO] Early stopping at epoch 396  
235 Fold 45 Training AUC: 0.9762  
236 Fold 45 Test Probability: 0.0029 (True Label: 1)  
237 LOOCV Fold 46/103  
238 [INFO] selected 7 principal components to retain 95.47% variance.  
239 [INFO] Early stopping at epoch 196  
240 Fold 46 Training AUC: 0.9685  
241 Fold 46 Test Probability: 0.9292 (True Label: 1)  
242 LOOCV Fold 47/103  
243 [INFO] selected 7 principal components to retain 95.53% variance.  
244 [INFO] Early stopping at epoch 583  
245 Fold 47 Training AUC: 0.9597  
246 Fold 47 Test Probability: 0.8113 (True Label: 1)  
247 LOOCV Fold 48/103  
248 [INFO] selected 7 principal components to retain 95.55% variance.  
249 [INFO] Early stopping at epoch 332  
250 Fold 48 Training AUC: 0.9774  
251 Fold 48 Test Probability: 0.9998 (True Label: 1)  
252 LOOCV Fold 49/103  
253 [INFO] selected 7 principal components to retain 95.50% variance.  
254 [INFO] Early stopping at epoch 428  
255 Fold 49 Training AUC: 0.9661  
256 Fold 49 Test Probability: 0.7874 (True Label: 1)  
257 LOOCV Fold 50/103  
258 [INFO] selected 7 principal components to retain 95.24% variance.  
259 [INFO] Early stopping at epoch 304  
260 Fold 50 Training AUC: 0.9714  
261 Fold 50 Test Probability: 1.0000 (True Label: 1)  
262 LOOCV Fold 51/103  
263 [INFO] selected 7 principal components to retain 95.43% variance.  
264 [INFO] Early stopping at epoch 209  
265 Fold 51 Training AUC: 0.9706  
266 Fold 51 Test Probability: 0.8804 (True Label: 1)  
267 LOOCV Fold 52/103  
268 [INFO] selected 7 principal components to retain 95.52% variance.  
269 [INFO] Early stopping at epoch 476  
270 Fold 52 Training AUC: 0.9852  
271 Fold 52 Test Probability: 0.0061 (True Label: 0)  
272 LOOCV Fold 53/103  
273 [INFO] selected 7 principal components to retain 95.49% variance.  
274 [INFO] Early stopping at epoch 944  
275 Fold 53 Training AUC: 0.9854  
276 Fold 53 Test Probability: 0.0684 (True Label: 0)  
277 LOOCV Fold 54/103  
278 [INFO] selected 7 principal components to retain 95.43% variance.  
279 [INFO] Early stopping at epoch 290  
280 Fold 54 Training AUC: 0.9730  
281 Fold 54 Test Probability: 0.9878 (True Label: 1)  
282 LOOCV Fold 55/103  
283 [INFO] selected 7 principal components to retain 95.50% variance.  
284 [INFO] Early stopping at epoch 291  
285 Fold 55 Training AUC: 0.9776  
286 Fold 55 Test Probability: 0.4820 (True Label: 0)  
287 LOOCV Fold 56/103  
288 [INFO] selected 7 principal components to retain 95.55% variance.  
289 [INFO] Early stopping at epoch 462  
290 Fold 56 Training AUC: 0.9754  
291 Fold 56 Test Probability: 0.4762 (True Label: 1)
```

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292 LOOCV Fold 57/103
293 [INFO] selected 7 principal components to retain 95.49% variance.
294 [INFO] Early stopping at epoch 420
295 Fold 57 Training AUC: 0.9637
296 Fold 57 Test Probability: 0.9449 (True Label: 1)
297 LOOCV Fold 58/103
298 [INFO] selected 7 principal components to retain 95.59% variance.
299 [INFO] Early stopping at epoch 261
300 Fold 58 Training AUC: 0.9786
301 Fold 58 Test Probability: 0.2510 (True Label: 1)
302 LOOCV Fold 59/103
303 [INFO] selected 7 principal components to retain 95.40% variance.
304 [INFO] Early stopping at epoch 314
305 Fold 59 Training AUC: 0.9831
306 Fold 59 Test Probability: 0.9982 (True Label: 1)
307 LOOCV Fold 60/103
308 [INFO] selected 7 principal components to retain 95.45% variance.
309 [INFO] Early stopping at epoch 229
310 Fold 60 Training AUC: 0.9573
311 Fold 60 Test Probability: 0.9354 (True Label: 1)
312 LOOCV Fold 61/103
313 [INFO] selected 7 principal components to retain 95.49% variance.
314 [INFO] Early stopping at epoch 289
315 Fold 61 Training AUC: 0.9764
316 Fold 61 Test Probability: 0.0236 (True Label: 0)
317 LOOCV Fold 62/103
318 [INFO] selected 7 principal components to retain 95.54% variance.
319 [INFO] Early stopping at epoch 477
320 Fold 62 Training AUC: 0.9812
321 Fold 62 Test Probability: 0.3910 (True Label: 0)
322 LOOCV Fold 63/103
323 [INFO] selected 7 principal components to retain 95.50% variance.
324 [INFO] Early stopping at epoch 417
325 Fold 63 Training AUC: 0.9808
326 Fold 63 Test Probability: 0.3443 (True Label: 0)
327 LOOCV Fold 64/103
328 [INFO] selected 7 principal components to retain 95.48% variance.
329 [INFO] Early stopping at epoch 164
330 Fold 64 Training AUC: 0.9564
331 Fold 64 Test Probability: 0.0103 (True Label: 0)
332 LOOCV Fold 65/103
333 [INFO] selected 7 principal components to retain 95.49% variance.
334 [INFO] Early stopping at epoch 342
335 Fold 65 Training AUC: 0.9784
336 Fold 65 Test Probability: 0.0000 (True Label: 0)
337 LOOCV Fold 66/103
338 [INFO] selected 7 principal components to retain 95.53% variance.
339 [INFO] Early stopping at epoch 284
340 Fold 66 Training AUC: 0.9700
341 Fold 66 Test Probability: 0.0381 (True Label: 0)
342 LOOCV Fold 67/103
343 [INFO] selected 7 principal components to retain 95.52% variance.
344 [INFO] Early stopping at epoch 259
345 Fold 67 Training AUC: 0.9756
346 Fold 67 Test Probability: 0.1022 (True Label: 0)
347 LOOCV Fold 68/103
348 [INFO] selected 7 principal components to retain 95.50% variance.
349 [INFO] Early stopping at epoch 890
350 Fold 68 Training AUC: 0.9700
```

```
351 Fold 68 Test Probability: 0.1372 (True Label: 0)
352 LOOCV Fold 69/103
353 [INFO] selected 7 principal components to retain 95.46% variance.
354 [INFO] Early stopping at epoch 574
355 Fold 69 Training AUC: 0.9836
356 Fold 69 Test Probability: 0.1233 (True Label: 0)
357 LOOCV Fold 70/103
358 [INFO] selected 7 principal components to retain 95.55% variance.
359 [INFO] Early stopping at epoch 310
360 Fold 70 Training AUC: 0.9704
361 Fold 70 Test Probability: 0.0107 (True Label: 0)
362 LOOCV Fold 71/103
363 [INFO] selected 7 principal components to retain 95.52% variance.
364 [INFO] Early stopping at epoch 283
365 Fold 71 Training AUC: 0.9772
366 Fold 71 Test Probability: 0.0015 (True Label: 0)
367 LOOCV Fold 72/103
368 [INFO] selected 7 principal components to retain 95.52% variance.
369 [INFO] Early stopping at epoch 283
370 Fold 72 Training AUC: 0.9772
371 Fold 72 Test Probability: 0.0550 (True Label: 0)
372 LOOCV Fold 73/103
373 [INFO] selected 7 principal components to retain 95.52% variance.
374 [INFO] Early stopping at epoch 509
375 Fold 73 Training AUC: 0.9600
376 Fold 73 Test Probability: 0.3368 (True Label: 0)
377 LOOCV Fold 74/103
378 [INFO] selected 7 principal components to retain 95.54% variance.
379 [INFO] Early stopping at epoch 193
380 Fold 74 Training AUC: 0.9568
381 Fold 74 Test Probability: 0.0610 (True Label: 0)
382 LOOCV Fold 75/103
383 [INFO] selected 7 principal components to retain 95.49% variance.
384 [INFO] Early stopping at epoch 401
385 Fold 75 Training AUC: 0.9583
386 Fold 75 Test Probability: 0.9222 (True Label: 1)
387 LOOCV Fold 76/103
388 [INFO] selected 7 principal components to retain 95.50% variance.
389 [INFO] Early stopping at epoch 214
390 Fold 76 Training AUC: 0.9618
391 Fold 76 Test Probability: 0.0078 (True Label: 0)
392 LOOCV Fold 77/103
393 [INFO] selected 7 principal components to retain 95.52% variance.
394 [INFO] Early stopping at epoch 333
395 Fold 77 Training AUC: 0.9788
396 Fold 77 Test Probability: 0.0025 (True Label: 0)
397 LOOCV Fold 78/103
398 [INFO] selected 7 principal components to retain 95.48% variance.
399 [INFO] Early stopping at epoch 318
400 Fold 78 Training AUC: 0.9696
401 Fold 78 Test Probability: 0.0007 (True Label: 0)
402 LOOCV Fold 79/103
403 [INFO] selected 7 principal components to retain 95.45% variance.
404 [INFO] Early stopping at epoch 216
405 Fold 79 Training AUC: 0.9726
406 Fold 79 Test Probability: 0.9951 (True Label: 1)
407 LOOCV Fold 80/103
408 [INFO] selected 7 principal components to retain 95.48% variance.
409 [INFO] Early stopping at epoch 437
```

```
410 Fold 80 Training AUC: 0.9798
411 Fold 80 Test Probability: 0.9993 (True Label: 1)
412 LOOCV Fold 81/103
413 [INFO] selected 7 principal components to retain 95.51% variance.
414 [INFO] Early stopping at epoch 341
415 Fold 81 Training AUC: 0.9692
416 Fold 81 Test Probability: 0.2935 (True Label: 0)
417 LOOCV Fold 82/103
418 [INFO] selected 7 principal components to retain 95.48% variance.
419 [INFO] Early stopping at epoch 378
420 Fold 82 Training AUC: 0.9768
421 Fold 82 Test Probability: 0.0015 (True Label: 0)
422 LOOCV Fold 83/103
423 [INFO] selected 7 principal components to retain 95.48% variance.
424 [INFO] Early stopping at epoch 347
425 Fold 83 Training AUC: 0.9786
426 Fold 83 Test Probability: 0.9274 (True Label: 1)
427 LOOCV Fold 84/103
428 [INFO] selected 7 principal components to retain 95.46% variance.
429 [INFO] Early stopping at epoch 533
430 Fold 84 Training AUC: 0.9835
431 Fold 84 Test Probability: 0.7104 (True Label: 1)
432 LOOCV Fold 85/103
433 [INFO] selected 7 principal components to retain 95.50% variance.
434 [INFO] Early stopping at epoch 346
435 Fold 85 Training AUC: 0.9839
436 Fold 85 Test Probability: 1.0000 (True Label: 1)
437 LOOCV Fold 86/103
438 [INFO] selected 7 principal components to retain 95.48% variance.
439 [INFO] Early stopping at epoch 211
440 Fold 86 Training AUC: 0.9718
441 Fold 86 Test Probability: 0.8934 (True Label: 1)
442 LOOCV Fold 87/103
443 [INFO] selected 7 principal components to retain 95.54% variance.
444 [INFO] Early stopping at epoch 475
445 Fold 87 Training AUC: 0.9774
446 Fold 87 Test Probability: 0.9977 (True Label: 1)
447 LOOCV Fold 88/103
448 [INFO] selected 7 principal components to retain 95.50% variance.
449 [INFO] Early stopping at epoch 349
450 Fold 88 Training AUC: 0.9742
451 Fold 88 Test Probability: 0.9962 (True Label: 1)
452 LOOCV Fold 89/103
453 [INFO] selected 7 principal components to retain 95.48% variance.
454 [INFO] Early stopping at epoch 406
455 Fold 89 Training AUC: 0.9760
456 Fold 89 Test Probability: 0.0001 (True Label: 0)
457 LOOCV Fold 90/103
458 [INFO] selected 7 principal components to retain 95.52% variance.
459 [INFO] Early stopping at epoch 383
460 Fold 90 Training AUC: 0.9692
461 Fold 90 Test Probability: 0.9989 (True Label: 0)
462 LOOCV Fold 91/103
463 [INFO] selected 7 principal components to retain 95.49% variance.
464 [INFO] Early stopping at epoch 437
465 Fold 91 Training AUC: 0.9848
466 Fold 91 Test Probability: 0.0004 (True Label: 0)
467 LOOCV Fold 92/103
468 [INFO] selected 7 principal components to retain 95.49% variance.
```

```
469 [INFO] Early stopping at epoch 545
470 Fold 92 Training AUC: 0.9734
471 Fold 92 Test Probability: 0.9141 (True Label: 1)
472 LOOCV Fold 93/103
473 [INFO] selected 7 principal components to retain 95.44% variance.
474 [INFO] Early stopping at epoch 424
475 Fold 93 Training AUC: 0.9778
476 Fold 93 Test Probability: 1.0000 (True Label: 1)
477 LOOCV Fold 94/103
478 [INFO] selected 7 principal components to retain 95.40% variance.
479 [INFO] Early stopping at epoch 381
480 Fold 94 Training AUC: 0.9653
481 Fold 94 Test Probability: 0.5406 (True Label: 1)
482 LOOCV Fold 95/103
483 [INFO] selected 7 principal components to retain 95.41% variance.
484 [INFO] Early stopping at epoch 389
485 Fold 95 Training AUC: 0.9766
486 Fold 95 Test Probability: 1.0000 (True Label: 1)
487 LOOCV Fold 96/103
488 [INFO] selected 7 principal components to retain 95.50% variance.
489 [INFO] Early stopping at epoch 440
490 Fold 96 Training AUC: 0.9867
491 Fold 96 Test Probability: 0.9930 (True Label: 1)
492 LOOCV Fold 97/103
493 [INFO] selected 7 principal components to retain 95.60% variance.
494 [INFO] Early stopping at epoch 240
495 Fold 97 Training AUC: 0.9669
496 Fold 97 Test Probability: 0.3981 (True Label: 1)
497 LOOCV Fold 98/103
498 [INFO] selected 7 principal components to retain 95.50% variance.
499 [INFO] Early stopping at epoch 297
500 Fold 98 Training AUC: 0.9643
501 Fold 98 Test Probability: 0.2609 (True Label: 1)
502 LOOCV Fold 99/103
503 [INFO] selected 7 principal components to retain 95.47% variance.
504 [INFO] Early stopping at epoch 273
505 Fold 99 Training AUC: 0.9780
506 Fold 99 Test Probability: 0.9989 (True Label: 1)
507 LOOCV Fold 100/103
508 [INFO] selected 7 principal components to retain 95.53% variance.
509 [INFO] Early stopping at epoch 373
510 Fold 100 Training AUC: 0.9788
511 Fold 100 Test Probability: 0.9771 (True Label: 1)
512 LOOCV Fold 101/103
513 [INFO] selected 7 principal components to retain 95.48% variance.
514 [INFO] Early stopping at epoch 209
515 Fold 101 Training AUC: 0.9496
516 Fold 101 Test Probability: 0.7546 (True Label: 1)
517 LOOCV Fold 102/103
518 [INFO] selected 7 principal components to retain 95.53% variance.
519 [INFO] Early stopping at epoch 560
520 Fold 102 Training AUC: 0.9778
521 Fold 102 Test Probability: 0.8303 (True Label: 1)
522 LOOCV Fold 103/103
523 [INFO] selected 7 principal components to retain 95.51% variance.
524 [INFO] Early stopping at epoch 440
525 Fold 103 Training AUC: 0.9550
526 Fold 103 Test Probability: 0.0928 (True Label: 1)
527
```

```

528 [INFO] LOOCV Finished
529
530 - Overall Model Performance (from LOOCV posteriors)
531 [INFO] ROC Curve is saved as roc_curve_ann.png
532
533 Metrics (using threshold = 0.5):
534     Accuracy: 0.8544 (88/103)
535     Sensitivity: 0.8293 (34/41)
536     Specificity: 0.8710 (54/62)
537 Test AUC: 0.9327
538 Train AUC: 0.9715

```

---

## B Train Logs of LDF

```

1 [INFO] Data loaded successfully:
2   SeqNum GroundTruth Gender ... NoseSurfA NoseW NasoFacialA
3   0       1           0     2 ... 3972.311567 34.479069 32.325195
4   1       2           0     2 ... 4217.911999 38.170299 41.061411
5   2       3           0     2 ... 4010.477059 36.962578 36.151195
6   3       4           0     2 ... 3796.839953 38.330882 32.658731
7   4       5           0     2 ... 4011.612497 35.772898 36.637580
8
9 [5 rows x 22 columns]
10 [INFO] Starting Leave-One-Out Cross-Validation...
11 start with thresh=0.95
12 LOOCV Fold 1/103
13 [INFO] selected 7 principal components to retain 95.39% variance.
14 [INFO] Early stopping at epoch 222
15 Fold 1 Training AUC: 0.9552
16 Fold 1 Test Probability: 0.0010 (True Label: 0)
17 LOOCV Fold 2/103
18 [INFO] selected 7 principal components to retain 95.47% variance.
19 [INFO] Early stopping at epoch 183
20 Fold 2 Training AUC: 0.9584
21 Fold 2 Test Probability: 0.7432 (True Label: 0)
22 LOOCV Fold 3/103
23 [INFO] selected 7 principal components to retain 95.48% variance.
24 [INFO] Early stopping at epoch 265
25 Fold 3 Training AUC: 0.9544
26 Fold 3 Test Probability: 0.0356 (True Label: 0)
27 LOOCV Fold 4/103
28 [INFO] selected 7 principal components to retain 95.48% variance.
29 [INFO] Early stopping at epoch 142
30 Fold 4 Training AUC: 0.9556
31 Fold 4 Test Probability: 0.0097 (True Label: 0)
32 LOOCV Fold 5/103
33 [INFO] selected 7 principal components to retain 95.43% variance.
34 [INFO] Early stopping at epoch 224
35 Fold 5 Training AUC: 0.9536
36 Fold 5 Test Probability: 0.0696 (True Label: 0)
37 LOOCV Fold 6/103
38 [INFO] selected 7 principal components to retain 95.48% variance.
39 [INFO] Early stopping at epoch 170
40 Fold 6 Training AUC: 0.9524
41 Fold 6 Test Probability: 0.0465 (True Label: 0)

```

```
42 LOOCV Fold 7/103
43 [INFO] selected 7 principal components to retain 95.48% variance.
44 [INFO] Early stopping at epoch 231
45 Fold 7 Training AUC: 0.9544
46 Fold 7 Test Probability: 0.0013 (True Label: 0)
47 LOOCV Fold 8/103
48 [INFO] selected 7 principal components to retain 95.46% variance.
49 [INFO] Early stopping at epoch 192
50 Fold 8 Training AUC: 0.9532
51 Fold 8 Test Probability: 0.0273 (True Label: 0)
52 LOOCV Fold 9/103
53 [INFO] selected 7 principal components to retain 95.52% variance.
54 [INFO] Early stopping at epoch 215
55 Fold 9 Training AUC: 0.9540
56 Fold 9 Test Probability: 0.0766 (True Label: 0)
57 LOOCV Fold 10/103
58 [INFO] selected 7 principal components to retain 95.50% variance.
59 [INFO] Early stopping at epoch 190
60 Fold 10 Training AUC: 0.9548
61 Fold 10 Test Probability: 0.4281 (True Label: 0)
62 LOOCV Fold 11/103
63 [INFO] selected 7 principal components to retain 95.49% variance.
64 [INFO] Early stopping at epoch 264
65 Fold 11 Training AUC: 0.9568
66 Fold 11 Test Probability: 0.6446 (True Label: 0)
67 LOOCV Fold 12/103
68 [INFO] selected 7 principal components to retain 95.51% variance.
69 [INFO] Early stopping at epoch 220
70 Fold 12 Training AUC: 0.9520
71 Fold 12 Test Probability: 0.3875 (True Label: 0)
72 LOOCV Fold 13/103
73 [INFO] selected 7 principal components to retain 95.52% variance.
74 [INFO] Early stopping at epoch 267
75 Fold 13 Training AUC: 0.9556
76 Fold 13 Test Probability: 0.6513 (True Label: 0)
77 LOOCV Fold 14/103
78 [INFO] selected 7 principal components to retain 95.51% variance.
79 [INFO] Early stopping at epoch 190
80 Fold 14 Training AUC: 0.9524
81 Fold 14 Test Probability: 0.0735 (True Label: 0)
82 LOOCV Fold 15/103
83 [INFO] selected 7 principal components to retain 95.47% variance.
84 [INFO] Early stopping at epoch 214
85 Fold 15 Training AUC: 0.9552
86 Fold 15 Test Probability: 0.0065 (True Label: 0)
87 LOOCV Fold 16/103
88 [INFO] selected 7 principal components to retain 95.53% variance.
89 [INFO] Early stopping at epoch 224
90 Fold 16 Training AUC: 0.9536
91 Fold 16 Test Probability: 0.0461 (True Label: 0)
92 LOOCV Fold 17/103
93 [INFO] selected 7 principal components to retain 95.49% variance.
94 [INFO] Early stopping at epoch 166
95 Fold 17 Training AUC: 0.9552
96 Fold 17 Test Probability: 0.0051 (True Label: 0)
97 LOOCV Fold 18/103
98 [INFO] selected 7 principal components to retain 95.49% variance.
99 [INFO] Early stopping at epoch 237
100 Fold 18 Training AUC: 0.9524
```

```
101 Fold 18 Test Probability: 0.1072 (True Label: 0)
102 LOOCV Fold 19/103
103 [INFO] selected 7 principal components to retain 95.50% variance.
104 [INFO] Early stopping at epoch 172
105 Fold 19 Training AUC: 0.9540
106 Fold 19 Test Probability: 0.0456 (True Label: 0)
107 LOOCV Fold 20/103
108 [INFO] selected 7 principal components to retain 95.49% variance.
109 [INFO] Early stopping at epoch 152
110 Fold 20 Training AUC: 0.9520
111 Fold 20 Test Probability: 0.0168 (True Label: 0)
112 LOOCV Fold 21/103
113 [INFO] selected 7 principal components to retain 95.57% variance.
114 [INFO] Early stopping at epoch 235
115 Fold 21 Training AUC: 0.9508
116 Fold 21 Test Probability: 0.0642 (True Label: 0)
117 LOOCV Fold 22/103
118 [INFO] selected 7 principal components to retain 95.51% variance.
119 [INFO] Early stopping at epoch 230
120 Fold 22 Training AUC: 0.9548
121 Fold 22 Test Probability: 0.0020 (True Label: 0)
122 LOOCV Fold 23/103
123 [INFO] selected 7 principal components to retain 95.50% variance.
124 [INFO] Early stopping at epoch 185
125 Fold 23 Training AUC: 0.9540
126 Fold 23 Test Probability: 0.0545 (True Label: 0)
127 LOOCV Fold 24/103
128 [INFO] selected 7 principal components to retain 95.51% variance.
129 [INFO] Early stopping at epoch 292
130 Fold 24 Training AUC: 0.9540
131 Fold 24 Test Probability: 0.0091 (True Label: 0)
132 LOOCV Fold 25/103
133 [INFO] selected 7 principal components to retain 95.54% variance.
134 [INFO] Early stopping at epoch 223
135 Fold 25 Training AUC: 0.9392
136 Fold 25 Test Probability: 0.0454 (True Label: 0)
137 LOOCV Fold 26/103
138 [INFO] selected 7 principal components to retain 95.51% variance.
139 [INFO] Early stopping at epoch 249
140 Fold 26 Training AUC: 0.9528
141 Fold 26 Test Probability: 0.1990 (True Label: 0)
142 LOOCV Fold 27/103
143 [INFO] selected 7 principal components to retain 95.58% variance.
144 [INFO] Early stopping at epoch 171
145 Fold 27 Training AUC: 0.9544
146 Fold 27 Test Probability: 0.0399 (True Label: 0)
147 LOOCV Fold 28/103
148 [INFO] selected 7 principal components to retain 95.53% variance.
149 [INFO] Early stopping at epoch 216
150 Fold 28 Training AUC: 0.9520
151 Fold 28 Test Probability: 0.1211 (True Label: 0)
152 LOOCV Fold 29/103
153 [INFO] selected 7 principal components to retain 95.52% variance.
154 [INFO] Early stopping at epoch 250
155 Fold 29 Training AUC: 0.9528
156 Fold 29 Test Probability: 0.0352 (True Label: 0)
157 LOOCV Fold 30/103
158 [INFO] selected 7 principal components to retain 95.50% variance.
159 [INFO] Early stopping at epoch 204
```

```
160 Fold 30 Training AUC: 0.9564
161 Fold 30 Test Probability: 0.3177 (True Label: 0)
162 LOOCV Fold 31/103
163 [INFO] selected 7 principal components to retain 95.49% variance.
164 [INFO] Early stopping at epoch 163
165 Fold 31 Training AUC: 0.9548
166 Fold 31 Test Probability: 0.0239 (True Label: 0)
167 LOOCV Fold 32/103
168 [INFO] selected 7 principal components to retain 95.50% variance.
169 [INFO] Early stopping at epoch 184
170 Fold 32 Training AUC: 0.9528
171 Fold 32 Test Probability: 0.4003 (True Label: 0)
172 LOOCV Fold 33/103
173 [INFO] selected 7 principal components to retain 95.50% variance.
174 [INFO] Early stopping at epoch 158
175 Fold 33 Training AUC: 0.9528
176 Fold 33 Test Probability: 0.3620 (True Label: 0)
177 LOOCV Fold 34/103
178 [INFO] selected 7 principal components to retain 95.48% variance.
179 [INFO] Early stopping at epoch 199
180 Fold 34 Training AUC: 0.9532
181 Fold 34 Test Probability: 0.0275 (True Label: 0)
182 LOOCV Fold 35/103
183 [INFO] selected 7 principal components to retain 95.61% variance.
184 [INFO] Early stopping at epoch 187
185 Fold 35 Training AUC: 0.9520
186 Fold 35 Test Probability: 0.1162 (True Label: 0)
187 LOOCV Fold 36/103
188 [INFO] selected 7 principal components to retain 95.48% variance.
189 [INFO] Early stopping at epoch 200
190 Fold 36 Training AUC: 0.9532
191 Fold 36 Test Probability: 0.1004 (True Label: 0)
192 LOOCV Fold 37/103
193 [INFO] selected 7 principal components to retain 95.50% variance.
194 [INFO] Early stopping at epoch 208
195 Fold 37 Training AUC: 0.9540
196 Fold 37 Test Probability: 0.3671 (True Label: 0)
197 LOOCV Fold 38/103
198 [INFO] selected 7 principal components to retain 95.50% variance.
199 [INFO] Early stopping at epoch 235
200 Fold 38 Training AUC: 0.9532
201 Fold 38 Test Probability: 0.9977 (True Label: 1)
202 LOOCV Fold 39/103
203 [INFO] selected 7 principal components to retain 95.54% variance.
204 [INFO] Early stopping at epoch 146
205 Fold 39 Training AUC: 0.9532
206 Fold 39 Test Probability: 0.9916 (True Label: 1)
207 LOOCV Fold 40/103
208 [INFO] selected 7 principal components to retain 95.49% variance.
209 [INFO] Early stopping at epoch 223
210 Fold 40 Training AUC: 0.9548
211 Fold 40 Test Probability: 0.7543 (True Label: 1)
212 LOOCV Fold 41/103
213 [INFO] selected 7 principal components to retain 95.54% variance.
214 [INFO] Early stopping at epoch 264
215 Fold 41 Training AUC: 0.9573
216 Fold 41 Test Probability: 0.1435 (True Label: 1)
217 LOOCV Fold 42/103
218 [INFO] selected 7 principal components to retain 95.44% variance.
```

```
219 [INFO] Early stopping at epoch 155
220 Fold 42 Training AUC: 0.9512
221 Fold 42 Test Probability: 0.9991 (True Label: 1)
222 LOOCV Fold 43/103
223 [INFO] selected 7 principal components to retain 95.37% variance.
224 [INFO] Early stopping at epoch 185
225 Fold 43 Training AUC: 0.9552
226 Fold 43 Test Probability: 0.9991 (True Label: 1)
227 LOOCV Fold 44/103
228 [INFO] selected 7 principal components to retain 95.51% variance.
229 [INFO] Early stopping at epoch 212
230 Fold 44 Training AUC: 0.9548
231 Fold 44 Test Probability: 0.7251 (True Label: 1)
232 LOOCV Fold 45/103
233 [INFO] selected 7 principal components to retain 95.48% variance.
234 [INFO] Early stopping at epoch 209
235 Fold 45 Training AUC: 0.9560
236 Fold 45 Test Probability: 0.2180 (True Label: 1)
237 LOOCV Fold 46/103
238 [INFO] selected 7 principal components to retain 95.47% variance.
239 [INFO] Early stopping at epoch 224
240 Fold 46 Training AUC: 0.9528
241 Fold 46 Test Probability: 0.8574 (True Label: 1)
242 LOOCV Fold 47/103
243 [INFO] selected 7 principal components to retain 95.53% variance.
244 [INFO] Early stopping at epoch 142
245 Fold 47 Training AUC: 0.9548
246 Fold 47 Test Probability: 0.7181 (True Label: 1)
247 LOOCV Fold 48/103
248 [INFO] selected 7 principal components to retain 95.55% variance.
249 [INFO] Early stopping at epoch 230
250 Fold 48 Training AUC: 0.9560
251 Fold 48 Test Probability: 0.9429 (True Label: 1)
252 LOOCV Fold 49/103
253 [INFO] selected 7 principal components to retain 95.50% variance.
254 [INFO] Early stopping at epoch 186
255 Fold 49 Training AUC: 0.9540
256 Fold 49 Test Probability: 0.6575 (True Label: 1)
257 LOOCV Fold 50/103
258 [INFO] selected 7 principal components to retain 95.24% variance.
259 [INFO] Early stopping at epoch 205
260 Fold 50 Training AUC: 0.9536
261 Fold 50 Test Probability: 0.9999 (True Label: 1)
262 LOOCV Fold 51/103
263 [INFO] selected 7 principal components to retain 95.43% variance.
264 [INFO] Early stopping at epoch 195
265 Fold 51 Training AUC: 0.9605
266 Fold 51 Test Probability: 0.1117 (True Label: 1)
267 LOOCV Fold 52/103
268 [INFO] selected 7 principal components to retain 95.52% variance.
269 [INFO] Early stopping at epoch 210
270 Fold 52 Training AUC: 0.9540
271 Fold 52 Test Probability: 0.0589 (True Label: 0)
272 LOOCV Fold 53/103
273 [INFO] selected 7 principal components to retain 95.49% variance.
274 [INFO] Early stopping at epoch 214
275 Fold 53 Training AUC: 0.9520
276 Fold 53 Test Probability: 0.0112 (True Label: 0)
277 LOOCV Fold 54/103
```

```
278 [INFO] selected 7 principal components to retain 95.43% variance.  
279 [INFO] Early stopping at epoch 237  
280 Fold 54 Training AUC: 0.9548  
281 Fold 54 Test Probability: 0.9914 (True Label: 1)  
282 LOOCV Fold 55/103  
283 [INFO] selected 7 principal components to retain 95.50% variance.  
284 [INFO] Early stopping at epoch 221  
285 Fold 55 Training AUC: 0.9580  
286 Fold 55 Test Probability: 0.3679 (True Label: 0)  
287 LOOCV Fold 56/103  
288 [INFO] selected 7 principal components to retain 95.55% variance.  
289 [INFO] Early stopping at epoch 154  
290 Fold 56 Training AUC: 0.9581  
291 Fold 56 Test Probability: 0.1884 (True Label: 1)  
292 LOOCV Fold 57/103  
293 [INFO] selected 7 principal components to retain 95.49% variance.  
294 [INFO] Early stopping at epoch 174  
295 Fold 57 Training AUC: 0.9528  
296 Fold 57 Test Probability: 0.8059 (True Label: 1)  
297 LOOCV Fold 58/103  
298 [INFO] selected 7 principal components to retain 95.59% variance.  
299 [INFO] Early stopping at epoch 220  
300 Fold 58 Training AUC: 0.9560  
301 Fold 58 Test Probability: 0.3477 (True Label: 1)  
302 LOOCV Fold 59/103  
303 [INFO] selected 7 principal components to retain 95.40% variance.  
304 [INFO] Early stopping at epoch 147  
305 Fold 59 Training AUC: 0.9544  
306 Fold 59 Test Probability: 0.9994 (True Label: 1)  
307 LOOCV Fold 60/103  
308 [INFO] selected 7 principal components to retain 95.45% variance.  
309 [INFO] Early stopping at epoch 204  
310 Fold 60 Training AUC: 0.9411  
311 Fold 60 Test Probability: 0.9862 (True Label: 1)  
312 LOOCV Fold 61/103  
313 [INFO] selected 7 principal components to retain 95.49% variance.  
314 [INFO] Early stopping at epoch 228  
315 Fold 61 Training AUC: 0.9540  
316 Fold 61 Test Probability: 0.1002 (True Label: 0)  
317 LOOCV Fold 62/103  
318 [INFO] selected 7 principal components to retain 95.54% variance.  
319 [INFO] Early stopping at epoch 193  
320 Fold 62 Training AUC: 0.9516  
321 Fold 62 Test Probability: 0.0734 (True Label: 0)  
322 LOOCV Fold 63/103  
323 [INFO] selected 7 principal components to retain 95.50% variance.  
324 [INFO] Early stopping at epoch 233  
325 Fold 63 Training AUC: 0.9540  
326 Fold 63 Test Probability: 0.4440 (True Label: 0)  
327 LOOCV Fold 64/103  
328 [INFO] selected 7 principal components to retain 95.48% variance.  
329 [INFO] Early stopping at epoch 168  
330 Fold 64 Training AUC: 0.9556  
331 Fold 64 Test Probability: 0.1343 (True Label: 0)  
332 LOOCV Fold 65/103  
333 [INFO] selected 7 principal components to retain 95.49% variance.  
334 [INFO] Early stopping at epoch 127  
335 Fold 65 Training AUC: 0.9540  
336 Fold 65 Test Probability: 0.0068 (True Label: 0)
```

```
337 LOOCV Fold 66/103
338 [INFO] selected 7 principal components to retain 95.53% variance.
339 [INFO] Early stopping at epoch 210
340 Fold 66 Training AUC: 0.9536
341 Fold 66 Test Probability: 0.1788 (True Label: 0)
342 LOOCV Fold 67/103
343 [INFO] selected 7 principal components to retain 95.52% variance.
344 [INFO] Early stopping at epoch 163
345 Fold 67 Training AUC: 0.9536
346 Fold 67 Test Probability: 0.1447 (True Label: 0)
347 LOOCV Fold 68/103
348 [INFO] selected 7 principal components to retain 95.50% variance.
349 [INFO] Early stopping at epoch 199
350 Fold 68 Training AUC: 0.9544
351 Fold 68 Test Probability: 0.2332 (True Label: 0)
352 LOOCV Fold 69/103
353 [INFO] selected 7 principal components to retain 95.46% variance.
354 [INFO] Early stopping at epoch 253
355 Fold 69 Training AUC: 0.9544
356 Fold 69 Test Probability: 0.1420 (True Label: 0)
357 LOOCV Fold 70/103
358 [INFO] selected 7 principal components to retain 95.55% variance.
359 [INFO] Early stopping at epoch 200
360 Fold 70 Training AUC: 0.9508
361 Fold 70 Test Probability: 0.0489 (True Label: 0)
362 LOOCV Fold 71/103
363 [INFO] selected 7 principal components to retain 95.52% variance.
364 [INFO] Early stopping at epoch 239
365 Fold 71 Training AUC: 0.9504
366 Fold 71 Test Probability: 0.0188 (True Label: 0)
367 LOOCV Fold 72/103
368 [INFO] selected 7 principal components to retain 95.52% variance.
369 [INFO] Early stopping at epoch 268
370 Fold 72 Training AUC: 0.9536
371 Fold 72 Test Probability: 0.1592 (True Label: 0)
372 LOOCV Fold 73/103
373 [INFO] selected 7 principal components to retain 95.52% variance.
374 [INFO] Early stopping at epoch 224
375 Fold 73 Training AUC: 0.9548
376 Fold 73 Test Probability: 0.3159 (True Label: 0)
377 LOOCV Fold 74/103
378 [INFO] selected 7 principal components to retain 95.54% variance.
379 [INFO] Early stopping at epoch 222
380 Fold 74 Training AUC: 0.9528
381 Fold 74 Test Probability: 0.1435 (True Label: 0)
382 LOOCV Fold 75/103
383 [INFO] selected 7 principal components to retain 95.49% variance.
384 [INFO] Early stopping at epoch 271
385 Fold 75 Training AUC: 0.9581
386 Fold 75 Test Probability: 0.1738 (True Label: 1)
387 LOOCV Fold 76/103
388 [INFO] selected 7 principal components to retain 95.50% variance.
389 [INFO] Early stopping at epoch 210
390 Fold 76 Training AUC: 0.9524
391 Fold 76 Test Probability: 0.0389 (True Label: 0)
392 LOOCV Fold 77/103
393 [INFO] selected 7 principal components to retain 95.52% variance.
394 [INFO] Early stopping at epoch 249
395 Fold 77 Training AUC: 0.9540
```

```
396 Fold 77 Test Probability: 0.0162 (True Label: 0)
397 LOOCV Fold 78/103
398 [INFO] selected 7 principal components to retain 95.48% variance.
399 [INFO] Early stopping at epoch 220
400 Fold 78 Training AUC: 0.9552
401 Fold 78 Test Probability: 0.0314 (True Label: 0)
402 LOOCV Fold 79/103
403 [INFO] selected 7 principal components to retain 95.45% variance.
404 [INFO] Early stopping at epoch 210
405 Fold 79 Training AUC: 0.9536
406 Fold 79 Test Probability: 0.9000 (True Label: 1)
407 LOOCV Fold 80/103
408 [INFO] selected 7 principal components to retain 95.48% variance.
409 [INFO] Early stopping at epoch 204
410 Fold 80 Training AUC: 0.9544
411 Fold 80 Test Probability: 0.9864 (True Label: 1)
412 LOOCV Fold 81/103
413 [INFO] selected 7 principal components to retain 95.51% variance.
414 [INFO] Early stopping at epoch 234
415 Fold 81 Training AUC: 0.9532
416 Fold 81 Test Probability: 0.2445 (True Label: 0)
417 LOOCV Fold 82/103
418 [INFO] selected 7 principal components to retain 95.48% variance.
419 [INFO] Early stopping at epoch 182
420 Fold 82 Training AUC: 0.9444
421 Fold 82 Test Probability: 0.0513 (True Label: 0)
422 LOOCV Fold 83/103
423 [INFO] selected 7 principal components to retain 95.48% variance.
424 [INFO] Early stopping at epoch 242
425 Fold 83 Training AUC: 0.9540
426 Fold 83 Test Probability: 0.9295 (True Label: 1)
427 LOOCV Fold 84/103
428 [INFO] selected 7 principal components to retain 95.46% variance.
429 [INFO] Early stopping at epoch 240
430 Fold 84 Training AUC: 0.9532
431 Fold 84 Test Probability: 0.9475 (True Label: 1)
432 LOOCV Fold 85/103
433 [INFO] selected 7 principal components to retain 95.50% variance.
434 [INFO] Early stopping at epoch 246
435 Fold 85 Training AUC: 0.9540
436 Fold 85 Test Probability: 0.9975 (True Label: 1)
437 LOOCV Fold 86/103
438 [INFO] selected 7 principal components to retain 95.48% variance.
439 [INFO] Early stopping at epoch 261
440 Fold 86 Training AUC: 0.9512
441 Fold 86 Test Probability: 0.8489 (True Label: 1)
442 LOOCV Fold 87/103
443 [INFO] selected 7 principal components to retain 95.54% variance.
444 [INFO] Early stopping at epoch 191
445 Fold 87 Training AUC: 0.9544
446 Fold 87 Test Probability: 0.7522 (True Label: 1)
447 LOOCV Fold 88/103
448 [INFO] selected 7 principal components to retain 95.50% variance.
449 [INFO] Early stopping at epoch 210
450 Fold 88 Training AUC: 0.9540
451 Fold 88 Test Probability: 0.9898 (True Label: 1)
452 LOOCV Fold 89/103
453 [INFO] selected 7 principal components to retain 95.48% variance.
454 [INFO] Early stopping at epoch 219
```

```
455 Fold 89 Training AUC: 0.9548
456 Fold 89 Test Probability: 0.0563 (True Label: 0)
457 LOOCV Fold 90/103
458 [INFO] selected 7 principal components to retain 95.52% variance.
459 [INFO] Early stopping at epoch 153
460 Fold 90 Training AUC: 0.9572
461 Fold 90 Test Probability: 0.9117 (True Label: 0)
462 LOOCV Fold 91/103
463 [INFO] selected 7 principal components to retain 95.49% variance.
464 [INFO] Early stopping at epoch 249
465 Fold 91 Training AUC: 0.9556
466 Fold 91 Test Probability: 0.0364 (True Label: 0)
467 LOOCV Fold 92/103
468 [INFO] selected 7 principal components to retain 95.49% variance.
469 [INFO] Early stopping at epoch 211
470 Fold 92 Training AUC: 0.9452
471 Fold 92 Test Probability: 0.9173 (True Label: 1)
472 LOOCV Fold 93/103
473 [INFO] selected 7 principal components to retain 95.44% variance.
474 [INFO] Early stopping at epoch 170
475 Fold 93 Training AUC: 0.9520
476 Fold 93 Test Probability: 0.9992 (True Label: 1)
477 LOOCV Fold 94/103
478 [INFO] selected 7 principal components to retain 95.40% variance.
479 [INFO] Early stopping at epoch 215
480 Fold 94 Training AUC: 0.9516
481 Fold 94 Test Probability: 0.9995 (True Label: 1)
482 LOOCV Fold 95/103
483 [INFO] selected 7 principal components to retain 95.41% variance.
484 [INFO] Early stopping at epoch 179
485 Fold 95 Training AUC: 0.9548
486 Fold 95 Test Probability: 0.9999 (True Label: 1)
487 LOOCV Fold 96/103
488 [INFO] selected 7 principal components to retain 95.50% variance.
489 [INFO] Early stopping at epoch 288
490 Fold 96 Training AUC: 0.9544
491 Fold 96 Test Probability: 0.8059 (True Label: 1)
492 LOOCV Fold 97/103
493 [INFO] selected 7 principal components to retain 95.60% variance.
494 [INFO] Early stopping at epoch 191
495 Fold 97 Training AUC: 0.9532
496 Fold 97 Test Probability: 0.4043 (True Label: 1)
497 LOOCV Fold 98/103
498 [INFO] selected 7 principal components to retain 95.50% variance.
499 [INFO] Early stopping at epoch 244
500 Fold 98 Training AUC: 0.9520
501 Fold 98 Test Probability: 0.4137 (True Label: 1)
502 LOOCV Fold 99/103
503 [INFO] selected 7 principal components to retain 95.47% variance.
504 [INFO] Early stopping at epoch 224
505 Fold 99 Training AUC: 0.9512
506 Fold 99 Test Probability: 0.9840 (True Label: 1)
507 LOOCV Fold 100/103
508 [INFO] selected 7 principal components to retain 95.53% variance.
509 [INFO] Early stopping at epoch 246
510 Fold 100 Training AUC: 0.9516
511 Fold 100 Test Probability: 0.8754 (True Label: 1)
512 LOOCV Fold 101/103
513 [INFO] selected 7 principal components to retain 95.48% variance.
```

```

514 [INFO] Early stopping at epoch 165
515 Fold 101 Training AUC: 0.9532
516 Fold 101 Test Probability: 0.9773 (True Label: 1)
517 LOOCV Fold 102/103
518 [INFO] selected 7 principal components to retain 95.53% variance.
519 [INFO] Early stopping at epoch 196
520 Fold 102 Training AUC: 0.9560
521 Fold 102 Test Probability: 0.9277 (True Label: 1)
522 LOOCV Fold 103/103
523 [INFO] selected 7 principal components to retain 95.51% variance.
524 [INFO] Early stopping at epoch 286
525 Fold 103 Training AUC: 0.9738
526 Fold 103 Test Probability: 0.0150 (True Label: 1)
527
528 [INFO] LOOCV Finished
529
530 - Overall Model Performance (from LOOCV posteriors)
531 [INFO] ROC Curve is saved as roc_curve_ldf.png
532
533 Metrics (using threshold = 0.5):
534     Accuracy: 0.8738 (90/103)
535     Sensitivity: 0.7805 (32/41)
536     Specificity: 0.9355 (58/62)
537 Test AUC: 0.9284
538 Train AUC: 0.9538

```

---

## C Train Logs of SVM

```

1 [INFO] Data loaded successfully:
2     SeqNum GroundTruth Gender ... NoseSurfA NoseW NasoFacialA
3 0      1          0      2 ... 3972.311567 34.479069 32.325195
4 1      2          0      2 ... 4217.911999 38.170299 41.061411
5 2      3          0      2 ... 4010.477059 36.962578 36.151195
6 3      4          0      2 ... 3796.839953 38.330882 32.658731
7 4      5          0      2 ... 4011.612497 35.772898 36.637580
8
9 [5 rows x 22 columns]
10 [INFO] Starting Leave-One-Out Cross-Validation...
11 start with thresh=0.95
12 LOOCV Fold 1/103
13 [INFO] selected 7 principal components to retain 95.39% variance.
14 Fold 1 Training AUC: 0.9992
15 Fold 1 Test Score: -0.0406 (True Label: 0)
16 LOOCV Fold 2/103
17 [INFO] selected 7 principal components to retain 95.47% variance.
18 Fold 2 Training AUC: 0.9992
19 Fold 2 Test Score: 0.0677 (True Label: 0)
20 LOOCV Fold 3/103
21 [INFO] selected 7 principal components to retain 95.48% variance.
22 Fold 3 Training AUC: 0.9992
23 Fold 3 Test Score: -0.8235 (True Label: 0)
24 LOOCV Fold 4/103
25 [INFO] selected 7 principal components to retain 95.48% variance.
26 Fold 4 Training AUC: 0.9992
27 Fold 4 Test Score: -0.5338 (True Label: 0)

```

```
28 LOOCV Fold 5/103
29 [INFO] selected 7 principal components to retain 95.43% variance.
30 Fold 5 Training AUC: 0.9992
31 Fold 5 Test Score: -0.0312 (True Label: 0)
32 LOOCV Fold 6/103
33 [INFO] selected 7 principal components to retain 95.48% variance.
34 Fold 6 Training AUC: 0.9992
35 Fold 6 Test Score: -0.3885 (True Label: 0)
36 LOOCV Fold 7/103
37 [INFO] selected 7 principal components to retain 95.48% variance.
38 Fold 7 Training AUC: 0.9992
39 Fold 7 Test Score: -0.2422 (True Label: 0)
40 LOOCV Fold 8/103
41 [INFO] selected 7 principal components to retain 95.46% variance.
42 Fold 8 Training AUC: 0.9992
43 Fold 8 Test Score: -0.2012 (True Label: 0)
44 LOOCV Fold 9/103
45 [INFO] selected 7 principal components to retain 95.52% variance.
46 Fold 9 Training AUC: 0.9992
47 Fold 9 Test Score: -0.1302 (True Label: 0)
48 LOOCV Fold 10/103
49 [INFO] selected 7 principal components to retain 95.50% variance.
50 Fold 10 Training AUC: 0.9996
51 Fold 10 Test Score: 0.6758 (True Label: 0)
52 LOOCV Fold 11/103
53 [INFO] selected 7 principal components to retain 95.49% variance.
54 Fold 11 Training AUC: 0.9992
55 Fold 11 Test Score: -0.0070 (True Label: 0)
56 LOOCV Fold 12/103
57 [INFO] selected 7 principal components to retain 95.51% variance.
58 Fold 12 Training AUC: 0.9992
59 Fold 12 Test Score: -0.0049 (True Label: 0)
60 LOOCV Fold 13/103
61 [INFO] selected 7 principal components to retain 95.52% variance.
62 Fold 13 Training AUC: 0.9992
63 Fold 13 Test Score: -0.1452 (True Label: 0)
64 LOOCV Fold 14/103
65 [INFO] selected 7 principal components to retain 95.51% variance.
66 Fold 14 Training AUC: 0.9992
67 Fold 14 Test Score: -0.7896 (True Label: 0)
68 LOOCV Fold 15/103
69 [INFO] selected 7 principal components to retain 95.47% variance.
70 Fold 15 Training AUC: 0.9992
71 Fold 15 Test Score: -0.1342 (True Label: 0)
72 LOOCV Fold 16/103
73 [INFO] selected 7 principal components to retain 95.53% variance.
74 Fold 16 Training AUC: 0.9992
75 Fold 16 Test Score: -0.9641 (True Label: 0)
76 LOOCV Fold 17/103
77 [INFO] selected 7 principal components to retain 95.49% variance.
78 Fold 17 Training AUC: 0.9992
79 Fold 17 Test Score: -0.3388 (True Label: 0)
80 LOOCV Fold 18/103
81 [INFO] selected 7 principal components to retain 95.49% variance.
82 Fold 18 Training AUC: 0.9992
83 Fold 18 Test Score: -0.2360 (True Label: 0)
84 LOOCV Fold 19/103
85 [INFO] selected 7 principal components to retain 95.50% variance.
86 Fold 19 Training AUC: 0.9992
```

```
87 Fold 19 Test Score: -0.3663 (True Label: 0)
88 LOOCV Fold 20/103
89 [INFO] selected 7 principal components to retain 95.49% variance.
90 Fold 20 Training AUC: 0.9992
91 Fold 20 Test Score: -0.4682 (True Label: 0)
92 LOOCV Fold 21/103
93 [INFO] selected 7 principal components to retain 95.57% variance.
94 Fold 21 Training AUC: 0.9992
95 Fold 21 Test Score: -0.7286 (True Label: 0)
96 LOOCV Fold 22/103
97 [INFO] selected 7 principal components to retain 95.51% variance.
98 Fold 22 Training AUC: 0.9992
99 Fold 22 Test Score: -0.2457 (True Label: 0)
100 LOOCV Fold 23/103
101 [INFO] selected 7 principal components to retain 95.50% variance.
102 Fold 23 Training AUC: 0.9992
103 Fold 23 Test Score: -0.5574 (True Label: 0)
104 LOOCV Fold 24/103
105 [INFO] selected 7 principal components to retain 95.51% variance.
106 Fold 24 Training AUC: 0.9992
107 Fold 24 Test Score: -0.4387 (True Label: 0)
108 LOOCV Fold 25/103
109 [INFO] selected 7 principal components to retain 95.54% variance.
110 Fold 25 Training AUC: 0.9992
111 Fold 25 Test Score: -0.2239 (True Label: 0)
112 LOOCV Fold 26/103
113 [INFO] selected 7 principal components to retain 95.51% variance.
114 Fold 26 Training AUC: 0.9992
115 Fold 26 Test Score: -0.8905 (True Label: 0)
116 LOOCV Fold 27/103
117 [INFO] selected 7 principal components to retain 95.58% variance.
118 Fold 27 Training AUC: 0.9992
119 Fold 27 Test Score: -0.2199 (True Label: 0)
120 LOOCV Fold 28/103
121 [INFO] selected 7 principal components to retain 95.53% variance.
122 Fold 28 Training AUC: 0.9992
123 Fold 28 Test Score: -0.9958 (True Label: 0)
124 LOOCV Fold 29/103
125 [INFO] selected 7 principal components to retain 95.52% variance.
126 Fold 29 Training AUC: 0.9992
127 Fold 29 Test Score: -1.2568 (True Label: 0)
128 LOOCV Fold 30/103
129 [INFO] selected 7 principal components to retain 95.50% variance.
130 Fold 30 Training AUC: 0.9992
131 Fold 30 Test Score: -0.1156 (True Label: 0)
132 LOOCV Fold 31/103
133 [INFO] selected 7 principal components to retain 95.49% variance.
134 Fold 31 Training AUC: 0.9992
135 Fold 31 Test Score: -0.2388 (True Label: 0)
136 LOOCV Fold 32/103
137 [INFO] selected 7 principal components to retain 95.50% variance.
138 Fold 32 Training AUC: 0.9992
139 Fold 32 Test Score: -0.1532 (True Label: 0)
140 LOOCV Fold 33/103
141 [INFO] selected 7 principal components to retain 95.50% variance.
142 Fold 33 Training AUC: 0.9992
143 Fold 33 Test Score: -0.2210 (True Label: 0)
144 LOOCV Fold 34/103
145 [INFO] selected 7 principal components to retain 95.48% variance.
```

```
146 Fold 34 Training AUC: 0.9992
147 Fold 34 Test Score: -0.1097 (True Label: 0)
148 LOOCV Fold 35/103
149 [INFO] selected 7 principal components to retain 95.61% variance.
150 Fold 35 Training AUC: 0.9992
151 Fold 35 Test Score: -0.4836 (True Label: 0)
152 LOOCV Fold 36/103
153 [INFO] selected 7 principal components to retain 95.48% variance.
154 Fold 36 Training AUC: 0.9992
155 Fold 36 Test Score: -0.2592 (True Label: 0)
156 LOOCV Fold 37/103
157 [INFO] selected 7 principal components to retain 95.50% variance.
158 Fold 37 Training AUC: 0.9992
159 Fold 37 Test Score: -0.3584 (True Label: 0)
160 LOOCV Fold 38/103
161 [INFO] selected 7 principal components to retain 95.50% variance.
162 Fold 38 Training AUC: 0.9992
163 Fold 38 Test Score: -0.0196 (True Label: 1)
164 LOOCV Fold 39/103
165 [INFO] selected 7 principal components to retain 95.54% variance.
166 Fold 39 Training AUC: 0.9992
167 Fold 39 Test Score: 0.0532 (True Label: 1)
168 LOOCV Fold 40/103
169 [INFO] selected 7 principal components to retain 95.49% variance.
170 Fold 40 Training AUC: 0.9992
171 Fold 40 Test Score: -0.0408 (True Label: 1)
172 LOOCV Fold 41/103
173 [INFO] selected 7 principal components to retain 95.54% variance.
174 Fold 41 Training AUC: 0.9992
175 Fold 41 Test Score: -0.2046 (True Label: 1)
176 LOOCV Fold 42/103
177 [INFO] selected 7 principal components to retain 95.44% variance.
178 Fold 42 Training AUC: 0.9992
179 Fold 42 Test Score: 0.1923 (True Label: 1)
180 LOOCV Fold 43/103
181 [INFO] selected 7 principal components to retain 95.37% variance.
182 Fold 43 Training AUC: 0.9992
183 Fold 43 Test Score: 0.0786 (True Label: 1)
184 LOOCV Fold 44/103
185 [INFO] selected 7 principal components to retain 95.51% variance.
186 Fold 44 Training AUC: 0.9992
187 Fold 44 Test Score: -0.0163 (True Label: 1)
188 LOOCV Fold 45/103
189 [INFO] selected 7 principal components to retain 95.48% variance.
190 Fold 45 Training AUC: 0.9992
191 Fold 45 Test Score: -0.0674 (True Label: 1)
192 LOOCV Fold 46/103
193 [INFO] selected 7 principal components to retain 95.47% variance.
194 Fold 46 Training AUC: 0.9992
195 Fold 46 Test Score: 0.0974 (True Label: 1)
196 LOOCV Fold 47/103
197 [INFO] selected 7 principal components to retain 95.53% variance.
198 Fold 47 Training AUC: 0.9992
199 Fold 47 Test Score: -0.0060 (True Label: 1)
200 LOOCV Fold 48/103
201 [INFO] selected 7 principal components to retain 95.55% variance.
202 Fold 48 Training AUC: 0.9992
203 Fold 48 Test Score: -0.0238 (True Label: 1)
204 LOOCV Fold 49/103
```

```
205 [INFO] selected 7 principal components to retain 95.50% variance.  
206 Fold 49 Training AUC: 0.9992  
207 Fold 49 Test Score: 0.1197 (True Label: 1)  
208 LOOCV Fold 50/103  
209 [INFO] selected 7 principal components to retain 95.24% variance.  
210 Fold 50 Training AUC: 0.9992  
211 Fold 50 Test Score: -0.0635 (True Label: 1)  
212 LOOCV Fold 51/103  
213 [INFO] selected 7 principal components to retain 95.43% variance.  
214 Fold 51 Training AUC: 0.9992  
215 Fold 51 Test Score: -0.0588 (True Label: 1)  
216 LOOCV Fold 52/103  
217 [INFO] selected 7 principal components to retain 95.52% variance.  
218 Fold 52 Training AUC: 0.9992  
219 Fold 52 Test Score: -0.9616 (True Label: 0)  
220 LOOCV Fold 53/103  
221 [INFO] selected 7 principal components to retain 95.49% variance.  
222 Fold 53 Training AUC: 0.9992  
223 Fold 53 Test Score: -0.9535 (True Label: 0)  
224 LOOCV Fold 54/103  
225 [INFO] selected 7 principal components to retain 95.43% variance.  
226 Fold 54 Training AUC: 0.9992  
227 Fold 54 Test Score: 0.0925 (True Label: 1)  
228 LOOCV Fold 55/103  
229 [INFO] selected 7 principal components to retain 95.50% variance.  
230 Fold 55 Training AUC: 0.9992  
231 Fold 55 Test Score: -0.2981 (True Label: 0)  
232 LOOCV Fold 56/103  
233 [INFO] selected 7 principal components to retain 95.55% variance.  
234 Fold 56 Training AUC: 0.9992  
235 Fold 56 Test Score: -0.3941 (True Label: 1)  
236 LOOCV Fold 57/103  
237 [INFO] selected 7 principal components to retain 95.49% variance.  
238 Fold 57 Training AUC: 0.9992  
239 Fold 57 Test Score: -0.0527 (True Label: 1)  
240 LOOCV Fold 58/103  
241 [INFO] selected 7 principal components to retain 95.59% variance.  
242 Fold 58 Training AUC: 0.9996  
243 Fold 58 Test Score: -0.6814 (True Label: 1)  
244 LOOCV Fold 59/103  
245 [INFO] selected 7 principal components to retain 95.40% variance.  
246 Fold 59 Training AUC: 0.9992  
247 Fold 59 Test Score: -0.0721 (True Label: 1)  
248 LOOCV Fold 60/103  
249 [INFO] selected 7 principal components to retain 95.45% variance.  
250 Fold 60 Training AUC: 0.9992  
251 Fold 60 Test Score: 0.0152 (True Label: 1)  
252 LOOCV Fold 61/103  
253 [INFO] selected 7 principal components to retain 95.49% variance.  
254 Fold 61 Training AUC: 0.9992  
255 Fold 61 Test Score: -0.5653 (True Label: 0)  
256 LOOCV Fold 62/103  
257 [INFO] selected 7 principal components to retain 95.54% variance.  
258 Fold 62 Training AUC: 0.9992  
259 Fold 62 Test Score: -0.8051 (True Label: 0)  
260 LOOCV Fold 63/103  
261 [INFO] selected 7 principal components to retain 95.50% variance.  
262 Fold 63 Training AUC: 0.9992  
263 Fold 63 Test Score: -0.1374 (True Label: 0)
```

```
264 LOOCV Fold 64/103
265 [INFO] selected 7 principal components to retain 95.48% variance.
266 Fold 64 Training AUC: 0.9992
267 Fold 64 Test Score: -0.0970 (True Label: 0)
268 LOOCV Fold 65/103
269 [INFO] selected 7 principal components to retain 95.49% variance.
270 Fold 65 Training AUC: 0.9992
271 Fold 65 Test Score: -0.2668 (True Label: 0)
272 LOOCV Fold 66/103
273 [INFO] selected 7 principal components to retain 95.53% variance.
274 Fold 66 Training AUC: 0.9992
275 Fold 66 Test Score: -0.4900 (True Label: 0)
276 LOOCV Fold 67/103
277 [INFO] selected 7 principal components to retain 95.52% variance.
278 Fold 67 Training AUC: 0.9992
279 Fold 67 Test Score: -0.0944 (True Label: 0)
280 LOOCV Fold 68/103
281 [INFO] selected 7 principal components to retain 95.50% variance.
282 Fold 68 Training AUC: 0.9992
283 Fold 68 Test Score: -0.6893 (True Label: 0)
284 LOOCV Fold 69/103
285 [INFO] selected 7 principal components to retain 95.46% variance.
286 Fold 69 Training AUC: 0.9992
287 Fold 69 Test Score: -0.1977 (True Label: 0)
288 LOOCV Fold 70/103
289 [INFO] selected 7 principal components to retain 95.55% variance.
290 Fold 70 Training AUC: 0.9992
291 Fold 70 Test Score: -0.6227 (True Label: 0)
292 LOOCV Fold 71/103
293 [INFO] selected 7 principal components to retain 95.52% variance.
294 Fold 71 Training AUC: 0.9992
295 Fold 71 Test Score: -0.3707 (True Label: 0)
296 LOOCV Fold 72/103
297 [INFO] selected 7 principal components to retain 95.52% variance.
298 Fold 72 Training AUC: 0.9992
299 Fold 72 Test Score: -0.3025 (True Label: 0)
300 LOOCV Fold 73/103
301 [INFO] selected 7 principal components to retain 95.52% variance.
302 Fold 73 Training AUC: 0.9992
303 Fold 73 Test Score: -0.3760 (True Label: 0)
304 LOOCV Fold 74/103
305 [INFO] selected 7 principal components to retain 95.54% variance.
306 Fold 74 Training AUC: 0.9992
307 Fold 74 Test Score: -0.5257 (True Label: 0)
308 LOOCV Fold 75/103
309 [INFO] selected 7 principal components to retain 95.49% variance.
310 Fold 75 Training AUC: 0.9992
311 Fold 75 Test Score: 0.1101 (True Label: 1)
312 LOOCV Fold 76/103
313 [INFO] selected 7 principal components to retain 95.50% variance.
314 Fold 76 Training AUC: 0.9992
315 Fold 76 Test Score: -1.1055 (True Label: 0)
316 LOOCV Fold 77/103
317 [INFO] selected 7 principal components to retain 95.52% variance.
318 Fold 77 Training AUC: 0.9992
319 Fold 77 Test Score: -0.4589 (True Label: 0)
320 LOOCV Fold 78/103
321 [INFO] selected 7 principal components to retain 95.48% variance.
322 Fold 78 Training AUC: 0.9992
```

```
323 Fold 78 Test Score: -1.2687 (True Label: 0)
324 LOOCV Fold 79/103
325 [INFO] selected 7 principal components to retain 95.45% variance.
326 Fold 79 Training AUC: 0.9992
327 Fold 79 Test Score: -0.0725 (True Label: 1)
328 LOOCV Fold 80/103
329 [INFO] selected 7 principal components to retain 95.48% variance.
330 Fold 80 Training AUC: 0.9992
331 Fold 80 Test Score: -0.0024 (True Label: 1)
332 LOOCV Fold 81/103
333 [INFO] selected 7 principal components to retain 95.51% variance.
334 Fold 81 Training AUC: 0.9992
335 Fold 81 Test Score: -0.2229 (True Label: 0)
336 LOOCV Fold 82/103
337 [INFO] selected 7 principal components to retain 95.48% variance.
338 Fold 82 Training AUC: 0.9992
339 Fold 82 Test Score: -1.0062 (True Label: 0)
340 LOOCV Fold 83/103
341 [INFO] selected 7 principal components to retain 95.48% variance.
342 Fold 83 Training AUC: 0.9992
343 Fold 83 Test Score: -0.0515 (True Label: 1)
344 LOOCV Fold 84/103
345 [INFO] selected 7 principal components to retain 95.46% variance.
346 Fold 84 Training AUC: 0.9992
347 Fold 84 Test Score: -0.0066 (True Label: 1)
348 LOOCV Fold 85/103
349 [INFO] selected 7 principal components to retain 95.50% variance.
350 Fold 85 Training AUC: 0.9992
351 Fold 85 Test Score: 0.2166 (True Label: 1)
352 LOOCV Fold 86/103
353 [INFO] selected 7 principal components to retain 95.48% variance.
354 Fold 86 Training AUC: 0.9992
355 Fold 86 Test Score: 0.0011 (True Label: 1)
356 LOOCV Fold 87/103
357 [INFO] selected 7 principal components to retain 95.54% variance.
358 Fold 87 Training AUC: 0.9992
359 Fold 87 Test Score: 0.4264 (True Label: 1)
360 LOOCV Fold 88/103
361 [INFO] selected 7 principal components to retain 95.50% variance.
362 Fold 88 Training AUC: 0.9992
363 Fold 88 Test Score: 0.1245 (True Label: 1)
364 LOOCV Fold 89/103
365 [INFO] selected 7 principal components to retain 95.48% variance.
366 Fold 89 Training AUC: 0.9992
367 Fold 89 Test Score: -0.2606 (True Label: 0)
368 LOOCV Fold 90/103
369 [INFO] selected 7 principal components to retain 95.52% variance.
370 Fold 90 Training AUC: 0.9996
371 Fold 90 Test Score: 0.6651 (True Label: 0)
372 LOOCV Fold 91/103
373 [INFO] selected 7 principal components to retain 95.49% variance.
374 Fold 91 Training AUC: 0.9992
375 Fold 91 Test Score: -0.6217 (True Label: 0)
376 LOOCV Fold 92/103
377 [INFO] selected 7 principal components to retain 95.49% variance.
378 Fold 92 Training AUC: 0.9992
379 Fold 92 Test Score: 0.4049 (True Label: 1)
380 LOOCV Fold 93/103
381 [INFO] selected 7 principal components to retain 95.44% variance.
```

```
382 Fold 93 Training AUC: 0.9992
383 Fold 93 Test Score: 0.0272 (True Label: 1)
384 LOOCV Fold 94/103
385 [INFO] selected 7 principal components to retain 95.40% variance.
386 Fold 94 Training AUC: 0.9992
387 Fold 94 Test Score: -0.0621 (True Label: 1)
388 LOOCV Fold 95/103
389 [INFO] selected 7 principal components to retain 95.41% variance.
390 Fold 95 Training AUC: 0.9992
391 Fold 95 Test Score: -0.0567 (True Label: 1)
392 LOOCV Fold 96/103
393 [INFO] selected 7 principal components to retain 95.50% variance.
394 Fold 96 Training AUC: 0.9992
395 Fold 96 Test Score: -0.0004 (True Label: 1)
396 LOOCV Fold 97/103
397 [INFO] selected 7 principal components to retain 95.60% variance.
398 Fold 97 Training AUC: 0.9992
399 Fold 97 Test Score: -0.0844 (True Label: 1)
400 LOOCV Fold 98/103
401 [INFO] selected 7 principal components to retain 95.50% variance.
402 Fold 98 Training AUC: 0.9992
403 Fold 98 Test Score: -0.0622 (True Label: 1)
404 LOOCV Fold 99/103
405 [INFO] selected 7 principal components to retain 95.47% variance.
406 Fold 99 Training AUC: 0.9992
407 Fold 99 Test Score: 0.0365 (True Label: 1)
408 LOOCV Fold 100/103
409 [INFO] selected 7 principal components to retain 95.53% variance.
410 Fold 100 Training AUC: 0.9992
411 Fold 100 Test Score: 0.0196 (True Label: 1)
412 LOOCV Fold 101/103
413 [INFO] selected 7 principal components to retain 95.48% variance.
414 Fold 101 Training AUC: 0.9992
415 Fold 101 Test Score: -0.0525 (True Label: 1)
416 LOOCV Fold 102/103
417 [INFO] selected 7 principal components to retain 95.53% variance.
418 Fold 102 Training AUC: 0.9992
419 Fold 102 Test Score: -0.2064 (True Label: 1)
420 LOOCV Fold 103/103
421 [INFO] selected 7 principal components to retain 95.51% variance.
422 Fold 103 Training AUC: 1.0000
423 Fold 103 Test Score: -1.2055 (True Label: 1)
424
425 [INFO] LOOCV Finished
426
427 - Overall Model Performance (from LOOCV posteriors)
428 [INFO] ROC Curve is saved as roc_curve_svm.png
429
430 Metrics (using threshold = 0):
431     Accuracy: 0.7282 (75/103)
432     Sensitivity: 0.3902 (16/41)
433     Specificity: 0.9516 (59/62)
434 Test AUC: 0.8666
435 Train AUC: 0.9992
```

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