

Image Representation - Binarization

The functions cvLoadImage() and cvtColor() are integrated in OpenCV.

```
1 tmpImg = cvLoadImage(c);
2 tmpImgCopy = cvLoadImage(c);
3
4 Mat matTmpImgCopy(tmpImgCopy,0);
5 Mat frame_gray(matTmpImgCopy.rows, matTmpImgCopy.cols, matTmpImgCopy.depth());
6 cvtColor( matTmpImgCopy, frame_gray, CV_BGR2GRAY );
7 tmpImgCopy2 = frame_gray;
```

Image Representation - Normalization

The function normalize() is integrated in OpenCV.

```
1 Mat CPPPCA::normalize( const Mat& src ) {
2     Mat srcnorm;
3     cv::normalize(src, srcnorm, 0, 255, NORM_MINMAX, CV_8UC1);
4     return srcnorm;
5
6 } // end of void CPPPCA::normalize()
```

Face Detection

The parameter strClassifierFileName reads in the file path of the classifier file. Then function detect_and_draw() configures the classifier.

```
1 BOOL CPPPCA::FaceProc( IplImage* imgSource)
2 {
3     const char* strClassifierFileName = "";
4     static CvHaarClassifierCascade* cascade = 0;
5
6     cascade = (CvHaarClassifierCascade*)cvLoad(strClassifierFileName);
7
8     CvMemStorage* storage = cvCreateMemStorage(0);
9     detect_and_draw(imgSource, storage, cascade);
10
11    if(m_faces->total != 0){
12        m_FaceRect.x = (*(CvRect*)cvGetSeqElem( m_faces, 0)).x;
13        m_FaceRect.y = (*(CvRect*)cvGetSeqElem( m_faces, 0)).y;
14        m_FaceRect.width = (*(CvRect*)cvGetSeqElem( m_faces, 0)).width;
15        m_FaceRect.height = (*(CvRect*)cvGetSeqElem( m_faces, 0)).height;
16
17        cvClearMemStorage( storage );
18
19        return TRUE;
20    }
21    else
22        return FALSE;
23
24 } // end of void CPPPCA::FaceProc()
25
26 void CPPPCA::detect_and_draw( IplImage* img, CvMemStorage* storage,
27                             CvHaarClassifierCascade* cascade )
28 {
29     static CvScalar colors[] =
30     {
31         {{0,0,255}},
32         {{0,128,255}},
```

```

32         {{0,255,255}} ,
33         {{0,255,0}} ,
34         {{255,128,0}} ,
35         {{255,255,0}} ,
36         {{255,0,0}} ,
37         {{255,0,255}} }
38     };
39
40     double scale = 1;
41     IplImage* gray = cvCreateImage( cvSize(img->width ,img->height ) , 8 , 1 )
42         ;
43     IplImage* small_img = cvCreateImage( cvSize( cvRound ( img-> width /scale
44         ) ,
45         cvRound ( img-> height /scale ) ) ,
46         8 , 1 );
47     int i;
48
49     cvResize( img , small_img , CV_INTER_LINEAR );
50     cvClearMemStorage( storage );
51
52     if( cascade )
53     {
54         double t = (double)cvGetTickCount();
55         m_faces = cvHaarDetectObjects( small_img , cascade , storage ,
56             1.1 , 2 , 0
57             cvSize(30 , 30 ) );
58
59         t = (double)cvGetTickCount() - t;
60         printf( "detection time = %gms\n" , t /((double)cvGetTickFrequency()
61             *1000.) );
62         for( i = 0; i < (m_faces ? m_faces->total : 0); i++ )
63         {
64             CvRect* r = (CvRect*)cvGetSeqElem( m_faces , i );
65             CvPoint center;
66             int radius;
67             center.x = cvRound((r->x + r-> width *0.5)*scale);
68             center.y = cvRound((r->y + r-> height *0.5)*scale);
69             radius = cvRound((r-> width + r-> height )*0.25*scale);
70         }
71
72     }
73 } // end of void CPPPCA::detect_and_draw()

```

Pre-processing - Face Separation

The four Rect type parameters roi, eyesRoi, mouthRoi, NoseRoi define the face area, eyes area, mouth area, and nose area respectively.

```

1 Mat warp_dst = GetAffinedMat(tmpImgCopy2, frame_gray);
2
3 IplImage *imgLbpSrc = (&(IplImage)warp_dst);
4 IplImage *imgLbpDst = cvCreateImage(cvGetSize(imgLbpSrc), IPL_DEPTH_8U,1)
5     ;
6 m_lbpInst.CreatLBP(imgLbpSrc, imgLbpDst);
7
8 Mat lbp_dst(imgLbpDst);
9
10 Rect roi(51, 19, 80, 89);
11 Mat matRoi = lbp_dst(roi);
12 m_vmatLbpFace.push_back(matRoi);

```

```

13
14 Rect eyesRoi(46, 22, 84, 38);
15 Mat matEyes = lbp_dst(eyesRoi);
16 m_vmatLbpEyes.push_back(matEyes);
17
18 Rect mouthRoi(69, 102, 38, 22);
19 Mat matMouth = lbp_dst(mouthRoi);
20 m_vmatLbpMouth.push_back(matMouth);
21
22 Rect NoseRoi(71, 57, 39, 37);
23 Mat matNose = lbp_dst(NoseRoi);
24 m_vmatLbpNose.push_back(matNose);

```

Pre-processing - LBP

```

1 void CLBP::CreatLBP(IplImage *src, IplImage *dst)
2 {
3     int iTemp[8] = {0};
4     CvScalar s;
5
6     IplImage *ImgTemp = cvCreateImage(cvGetSize(src), IPL_DEPTH_8U, 1);
7     uchar *data = (uchar*)src->imageData;
8     int iStep = src->widthStep;
9
10    for (int i=1;i<src->height-1;i++)
11        for (int j=1;j<src->width-1;j++) {
12
13        int sum=0;
14        if (data[(i-1)*iStep+j-1]>data[i*iStep+j])
15            iTemp[0]=1;
16        else
17            iTemp[0]=0;
18        if (data[i*iStep+(j-1)]>data[i*iStep+j])
19            iTemp[1]=1;
20        else
21            iTemp[1]=0;
22        if (data[(i+1)*iStep+(j-1)]>data[i*iStep+j])
23            iTemp[2]=1;
24        else
25            iTemp[2]=0;
26        if (data[(i+1)*iStep+j]>data[i*iStep+j])
27            iTemp[3]=1;
28        else
29            iTemp[3]=0;
30        if (data[(i+1)*iStep+(j+1)]>data[i*iStep+j])
31            iTemp[4]=1;
32        else
33            iTemp[4]=0;
34        if (data[i*iStep+(j+1)]>data[i*iStep+j])
35            iTemp[5]=1;
36        else
37            iTemp[5]=0;
38        if (data[(i-1)*iStep+(j+1)]>data[i*iStep+j])
39            iTemp[6]=1;
40        else
41            iTemp[6]=0;
42        if (data[(i-1)*iStep+j]>data[i*iStep+j])
43            iTemp[7]=1;
44        else
45            iTemp[7]=0;
46        s.val[0] = (iTemp[0]*1+iTemp[1]*2+iTemp[2]*4+iTemp[3]*8+iTemp
47

```

```

48         cvSet2D( dst , i , j , s ) ;
49     }
50 }
51 } // end of CLBP::CreatLBP()

```

PCA

The function InitPCA() sets up the PCA instance for further use. The function GetEigenValues() obtains the eigenvalue of a corresponding eigenvector.

```

1 void CPPPCA::InitPCA( String strDirName , Mat matSrc , vector<Mat> vmatSrc )
2 {
3     double dbnumber_principal_comtent = 0.95;
4     Mat pcaImg , projectImg ;
5
6     PCA pca( matSrc , Mat() , CV_PCA_DATA_AS_COL , dbnumber_principal_comtent )
7         ;
8     Mat EigenVectors = pca.eigenvectors ;
9
10    pcaImg = normalize( pca.eigenvectors.row(0) ).reshape(1 , vmatSrc[0].rows
11        );
12    //      pcaFace = pca.eigenvectors.row(0).reshape(1 , src[0].rows);
13    imwrite(((“\\”) + strDirName + (“\\Pca.jpg”)) , pcaImg );
14
15    Mat EigenValues = pca.eigenvalues ;
16
17    Mat dst ;
18    dst = pca.project( matSrc.col(0) );
19    projectImg = normalize( pca.backProject( dst ).col(0) ).reshape(1 , vmatSrc
20        [0].rows );
21    imwrite(((“”) + strDirName + (“\\Project.jpg”)) , projectImg );
22
23    m_pcaTrain = pca ;
24 }
25 // end of CPPPCA::InitPCA()
26
27 void CPPPCA::GetEigenValues( String strDirName , Mat matSrc , vector<Mat>
28 vmatSrc , int iImgNum )
29 {
30     string strInt ;
31     Mat dst , projectImg ;
32     const string strEigenValue = "D:\\Summer Project\\EigenValue\\
33         FaceEigenValues.xml";
34     FileStorage fs( strEigenValue , FileStorage::WRITE );
35
36     for( int i = 0; i < iImgNum ; i++ ){
37         strInt = inttostring( i );
38         dst = m_pcaTrain.project( matSrc.col(i) );
39
40         //      projectImg = normalize( m_pcaTrain.backProject( dst ).col
41             (0) ).reshape(1 , vmatSrc[0].rows );
42         //      imwrite(((“D:\\Summer Project\\”) + strDirName + (“\\
43             Project”) + strInt + (”.jpg”)) , projectImg );
44         fs << "eigenvalue" + strInt << dst ;
45     }
46     fs.release();
47 }
48 // end of CPPPCA::GetEigenValues()

```

Face Representation - Gabor Wavelet

The function WDT() implements Wavelet transformation. The function IWDT() implements inverse Wavelet transformation. The function Wavelet() generates different types of Wavelet. Currently only haar and sym2 Wavelet are implemented. The function WaveletDecompose() implements Wavelet decomposition. The function WaveletReconstruct() implements Wavelet reconstruction.

```
1 Mat WDT( const Mat &_src , const string _wname, const int _level )const
2 {
3     int reValue = THID_ERR_NONE;
4     Mat src = Mat<float>(_src);
5     Mat dst = Mat::zeros( src.rows, src.cols, src.type() );
6     int N = src.rows;
7     int D = src.cols;
8
9     Mat lowFilter;
10    Mat highFilter;
11    wavelet( _wname, lowFilter, highFilter );
12
13    int t=1;
14    int row = N;
15    int col = D;
16
17    while( t<=_level )
18    {
19        for( int i=0; i<row; i++ )
20        {
21            Mat oneRow = Mat::zeros( 1,col, src.type() );
22            for ( int j=0; j<col; j++ )
23            {
24                oneRow.at<float>(0,j) = src.at<float>(i,j);
25            }
26            oneRow = waveletDecompose( oneRow, lowFilter, highFilter );
27            for ( int j=0; j<col; j++ )
28            {
29                dst.at<float>(i,j) = oneRow.at<float>(0,j);
30            }
31        }
32
33        #if 0
34        //normalize( dst, dst, 0, 255, NORM_MINMAX );
35        IplImage dstImg1 = IplImage(dst);
36        cvSaveImage( "dst.jpg" , &dstImg1 );
37        #endif
38        for ( int j=0; j<col; j++ )
39        {
40            Mat oneCol = Mat::zeros( row, 1, src.type() );
41            for ( int i=0; i<row; i++ )
42            {
43                oneCol.at<float>(i,0) = dst.at<float>(i,j);
44            }
45            oneCol = ( waveletDecompose( oneCol.t(), lowFilter, highFilter
46                                ) .t() );
47            for ( int i=0; i<row; i++ )
48            {
49                dst.at<float>(i,j) = oneCol.at<float>(i,0);
50            }
51        }
52
53        #if 0
54        //normalize( dst, dst, 0, 255, NORM_MINMAX );
55        IplImage dstImg2 = IplImage(dst);
56        cvSaveImage( "dst.jpg" , &dstImg2 );
57    }
```

```

57         #endif
58
59         row /= 2;
60         col /=2;
61         t++;
62         src = dst;
63     }
64
65     return dst;
66 }
67 Mat IWDT( const Mat &_src , const string _wname, const int _level )const
68 {
69     int reValue = THID.ERR_NONE;
70     Mat src = Mat<float>(_src);
71     Mat dst = Mat::zeros( src.rows , src.cols , src.type() );
72     int N = src.rows;
73     int D = src.cols;
74
75     Mat lowFilter;
76     Mat highFilter;
77     wavelet( _wname, lowFilter , highFilter );
78
79     int t=1;
80     int row = N/std::pow( 2., _level -1 );
81     int col = D/std::pow(2., _level -1 );
82
83     while ( row<=N && col<=D )
84     {
85         for ( int j=0; j<col; j++ )
86         {
87             Mat oneCol = Mat::zeros( row , 1 , src.type() );
88             for ( int i=0; i<row; i++ )
89             {
90                 oneCol.at<float>(i ,0) = src.at<float>(i ,j );
91             }
92             oneCol = ( waveletReconstruct( oneCol.t() , lowFilter ,
93                                           highFilter ) ).t();
94
95             for ( int i=0; i<row; i++ )
96             {
97                 dst.at<float>(i ,j ) = oneCol.at<float>(i ,0 );
98             }
99         }
100
101 #if 0
102 //normalize( dst , dst , 0 , 255 , NORMMINMAX );
103 IplImage dstImg2 = IplImage(dst);
104 cvSaveImage( "dst.jpg" , &dstImg2 );
105#endif
106         for( int i=0; i<row; i++ )
107         {
108             Mat oneRow = Mat::zeros( 1,col , src.type() );
109             for ( int j=0; j<col; j++ )
110             {
111                 oneRow.at<float>(0,j) = dst.at<float>(i ,j );
112             }
113             oneRow = waveletReconstruct( oneRow , lowFilter , highFilter );
114             for ( int j=0; j<col; j++ )
115             {
116                 dst.at<float>(i ,j ) = oneRow.at<float>(0,j );
117             }
118
119 #if 0
120 //normalize( dst , dst , 0 , 255 , NORMMINMAX );
121 IplImage dstImg1 = IplImage(dst);

```

```

122             cvSaveImage( "dst.jpg" , &dstImg1 );
123 #endif
124
125         row *= 2;
126         col *= 2;
127         src = dst;
128     }
129
130     return dst;
131 }
132 void wavelet( const string _wname, Mat &_lowFilter, Mat &_highFilter )
133 {
134     if ( _wname=="haar" || _wname=="db1" )
135     {
136         int N = 2;
137         _lowFilter = Mat::zeros( 1, N, CV_32F );
138         _highFilter = Mat::zeros( 1, N, CV_32F );
139
140         _lowFilter.at<float>(0, 0) = 1/sqrtnf(N);
141         _lowFilter.at<float>(0, 1) = 1/sqrtnf(N);
142
143         _highFilter.at<float>(0, 0) = -1/sqrtnf(N);
144         _highFilter.at<float>(0, 1) = 1/sqrtnf(N);
145     }
146     if ( _wname == "sym2" )
147     {
148         int N = 4;
149         float h [] = { -0.483, 0.836, -0.224, -0.129 };
150         float l [] = { -0.129, 0.224, 0.837, 0.483 };
151
152         _lowFilter = Mat::zeros( 1, N, CV_32F );
153         _highFilter = Mat::zeros( 1, N, CV_32F );
154
155         for ( int i=0; i<N; i++ )
156         {
157             _lowFilter.at<float>(0, i) = l[i];
158             _highFilter.at<float>(0, i) = h[i];
159         }
160     }
161 }
162 }
163 Mat waveletDecompose( const Mat &_src, const Mat &_lowFilter, const Mat &
164 _highFilter )const
165 {
166     assert( _src.rows==1 && _lowFilter.rows==1 && _highFilter.rows==1 );
167     assert( _src.cols>=_lowFilter.cols && _src.cols>=_highFilter.cols );
168     Mat &src = Mat<float>(_src);
169
170     int D = src.cols;
171
172     Mat &lowFilter = Mat<float>(_lowFilter);
173     Mat &highFilter = Mat<float>(_highFilter);
174
175     Mat dst1 = Mat::zeros( 1, D, src.type() );
176     Mat dst2 = Mat::zeros( 1, D, src.type() );
177
178     filter2D( src, dst1, -1, lowFilter );
179     filter2D( src, dst2, -1, highFilter );
180
181     Mat downDst1 = Mat::zeros( 1, D/2, src.type() );
182     Mat downDst2 = Mat::zeros( 1, D/2, src.type() );
183
184     resize( dst1, downDst1, downDst1.size() );
185     resize( dst2, downDst2, downDst2.size() );

```

```

186     for ( int i=0; i<D/2; i++ )
187     {
188         src.at<float>(0, i) = downDst1.at<float>( 0, i );
189         src.at<float>(0, i+D/2) = downDst2.at<float>( 0, i );
190     }
191
192     return src;
193 }
194 Mat waveletReconstruct( const Mat &_src , const Mat &_lowFilter , const Mat
195 &_highFilter )const
196 {
197     assert( _src.rows==1 && _lowFilter.rows==1 && _highFilter.rows==1 );
198     assert( _src.cols>=_lowFilter.cols && _src.cols>=_highFilter.cols );
199     Mat &src = Mat<float>(_src);
200
201     int D = src.cols;
202
203     Mat &lowFilter = Mat<float>(_lowFilter);
204     Mat &highFilter = Mat<float>(_highFilter);
205
206     Mat Up1 = Mat::zeros( 1, D, src.type() );
207     Mat Up2 = Mat::zeros( 1, D, src.type() );
208
209     Mat roi1( src, Rect(0, 0, D/2, 1) );
210     Mat roi2( src, Rect(D/2, 0, D/2, 1) );
211     resize( roi1, Up1, Up1.size(), 0, 0, INTER_CUBIC );
212     resize( roi2, Up2, Up2.size(), 0, 0, INTER_CUBIC );
213
214     Mat dst1 = Mat::zeros( 1, D, src.type() );
215     Mat dst2= Mat::zeros( 1, D, src.type() );
216     filter2D( Up1, dst1, -1, lowFilter );
217     filter2D( Up2, dst2, -1, highFilter );
218
219     dst1 = dst1 + dst2;
220
221     return dst1;
222 }

```

Face Detection

The parameter params contains all set up information of the BP network. The parameter layerSizes stands for the number of layers in the network. Here, the network has three hidden layers with an input layer and an output layer. The function predict() enables predicting new nodes in the network.

```

1 int main()
2 {
3     CvANN_MLP bp;
4     CvANN_MLP_TrainParams params;
5
6     params.train_method=CvANN_MLP_TrainParams::BACKPROP;
7     params.bp_dw_scale=0.1;
8     params.bp_moment_scale=0.1;
9     float labels[3][5] = {{0,0,0,0,0},{1,1,1,1,1},{0,0,0,0,0}};
10    Mat labelsMat(3, 5, CV_32FC1, labels);
11
12    float trainingData[3][5] = { {1,2,3,4,5},{111,112,113,114,115},
13                                {21,22,23,24,25} };
14    Mat trainingDataMat(3, 5, CV_32FC1, trainingData);
15    Mat layerSizes=(Mat<int>(1,5) << 5,2,2,2,5);
16    bp.create(layerSizes,CvANN_MLP::SIGMOID_SYM); //CvANN_MLP::SIGMOID_SYM
17    //CvANN_MLP::GAUSSIAN
18    //CvANN_MLP::IDENTITY

```

```

18     bp.train(trainingDataMat, labelsMat, Mat(), Mat(), params);
19
20
21     int width = 512, height = 512;
22     Mat image = Mat::zeros(height, width, CV_8UC3);
23     Vec3b green(0,255,0), blue (255,0,0);
24
25     for (int i = 0; i < image.rows; ++i)
26     for (int j = 0; j < image.cols; ++j)
27     {
28         Mat sampleMat = (Mat<float>(1,5) << i,j,0,0,0);
29         Mat responseMat;
30         bp.predict(sampleMat, responseMat);
31         float* p=responseMat.ptr<float>(0);
32         float response=0.0f;
33         for(int k=0;k<5;i++){
34             // cout<<p[k]<<" ";
35             response+=p[k];
36         }
37         if (response >2)
38             image.at<Vec3b>(j, i) = green;
39         else
40             image.at<Vec3b>(j, i) = blue;
41     }
42
43     // Show the training data
44     int thickness = -1;
45     int lineType = 8;
46     circle( image, Point(501, 10), 5, Scalar( 0, 0, 0), thickness,
47             lineType);
48     circle( image, Point(255, 10), 5, Scalar(255, 255, 255), thickness,
49             lineType);
50     circle( image, Point(501, 255), 5, Scalar(255, 255, 255), thickness,
51             lineType);
52     circle( image, Point( 10, 501), 5, Scalar(255, 255, 255), thickness,
53             lineType);
54
55     imwrite("result.png", image);           // save the image
56     imshow("BP Simple Example", image); // show it to the user
57     waitKey(0);
58 }
```

PCA - Kernel PCA

The function `kernel()` works as a switch of two types of mainstream kernels, which are RBF and Polynomial. The function `run_pca()` implements all main steps of kernel PCA which are calculating the kernel matrix, centering the kernel matrix, and obtaining eigenvectors and eigenvalues.

```

1 void PCA::load_data(const char* data, char sep){
2
3     unsigned int row = 0;
4     ifstream file(data);
5     if(file.is_open()){
6         string line,token;
7         while(getline(file, line)){
8             stringstream tmp(line);
9             unsigned int col = 0;
10            while(getline(tmp, token, sep)){
11                if(X.rows() < row+1){
12                    X.conservativeResize(row+1,X.cols());
13                }
14            }
15        }
16    }
17 }
```

```

13
14         }
15         if(X.cols() < col+1){
16             X.conservativeResize(X.rows(), col+1);
17         }
18         X(row, col) = atof(token.c_str());
19         col++;
20     }
21     row++;
22 }
23 Xcentered.resize(X.rows(), X.cols());
24 } else{
25     cout << "Failed to read file " << data << endl;
26 }
27
28 }
29
30 double PCA::kernel(const VectorXd& a, const VectorXd& b){
31
32     switch(kernel_type){
33         case 2 :
34             return(pow(a.dot(b)+constant, order));
35         default :
36             return(exp(-gamma*((a-b).squaredNorm())));
37     }
38 }
39
40 }
41
42 void PCA::run_kpca(){
43
44     K.resize(X.rows(), X.rows());
45     for(unsigned int i = 0; i < X.rows(); i++){
46         for(unsigned int j = i; j < X.rows(); j++){
47             K(i, j) = K(j, i) = kernel(X.row(i), X.row(j));
48             //printf("k(%i,%i) = %f\n", i, j, K(i, j));
49         }
50     }
51
52     EigenSolver<MatrixXd> edecom(K);
53     eigenvalues = edecom.eigenvalues().real();
54     eigenvectors = edecom.eigenvectors().real();
55     cumulative.resize(eigenvalues.rows());
56     vector<pair<double, VectorXd>> eigen_pairs;
57     double c = 0.0;
58     for(unsigned int i = 0; i < eigenvectors.cols(); i++){
59         if(normalise){
60             double norm = eigenvectors.col(i).norm();
61             eigenvectors.col(i) /= norm;
62         }
63         eigen_pairs.push_back(make_pair(eigenvalues(i), eigenvectors.col(i)));
64     }
65     sort(eigen_pairs.begin(), eigen_pairs.end(), [](<const pair<double,
66         VectorXd> a, const pair<double, VectorXd> b) -> bool {return (a.
67         first > b.first);});
68     for(unsigned int i = 0; i < eigen_pairs.size(); i++){
69         eigenvalues(i) = eigen_pairs[i].first;
70         c += eigenvalues(i);
71         cumulative(i) = c;
72         eigenvectors.col(i) = eigen_pairs[i].second;
73     }
74     transformed.resize(X.rows(), components);
75
76     for(unsigned int i = 0; i < X.rows(); i++){
77         for(unsigned int j = 0; j < components; j++){
78
79
80
81
82
83
84
85
86
87
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89
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92
93
94
95
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```

```

76         for (int k = 0; k < K.rows(); k++){
77             transformed(i,j) += K(i,k) * eigenvectors(k,j);
78         }
79     }
80 }
81 cout << "Sorted eigenvalues:" << endl;
82 for(unsigned int i = 0; i < eigenvalues.rows(); i++){
83     if(eigenvalues(i) > 0){
84         cout << "PC " << i+1 << ": Eigenvalue: " << eigenvalues(i);
85         printf("\t(%3.3f of variance, cumulative = %3.3f)\n",
86               eigenvalues(i)/eigenvalues.sum(),cumulative(i)/eigenvalues
87               .sum());
88     }
89 }
90 //cout << "Sorted eigenvectors:" << endl << eigenvectors << endl <<
91 //endl;
92 //cout << "Transformed data:" << endl << transformed << endl << endl;
93 }
94 void PCA::print(){
95
96     cout << "Input data:" << endl << X << endl << endl;
97     cout << "Centered data:" << endl << Xcentered << endl << endl;
98     cout << "Covariance matrix:" << endl << C << endl << endl;
99     cout << "Eigenvalues:" << endl << eigenvalues << endl << endl;
100    cout << "Eigenvectors:" << endl << eigenvectors << endl << endl;
101    cout << "Sorted eigenvalues:" << endl;
102    for(unsigned int i = 0; i < eigenvalues.rows(); i++){
103        if(eigenvalues(i) > 0){
104            cout << "PC " << i+1 << ": Eigenvalue: " << eigenvalues(i);
105            printf("\t(%3.3f of variance, cumulative = %3.3f)\n",
106                  eigenvalues(i)/eigenvalues.sum(),cumulative(i)/eigenvalues
107                  .sum());
108        }
109    }
110    cout << endl;
111    cout << "Sorted eigenvectors:" << endl << eigenvectors << endl << endl
112    ;
113    cout << "Transformed data:" << endl << X * eigenvectors << endl <<
114    endl;
115    //cout << "Transformed centred data:" << endl << transformed << endl
116    << endl;
117 }
118 void PCA::write_transformed(string file){
119
120     ofstream outfile(file);
121     for(unsigned int i = 0; i < transformed.rows(); i++){
122         for(unsigned int j = 0; j < transformed.cols(); j++){
123             outfile << transformed(i,j);
124             if(j != transformed.cols()-1) outfile << ",";
125         }
126         outfile << endl;
127     }
128     outfile.close();
129     cout << "Written file " << file << endl;
130 }
131 void PCA::write_eigenvectors(string file){
132
133     ofstream outfile(file);
134     for(unsigned int i = 0; i < eigenvectors.rows(); i++){

```

```

134         for( unsigned int j = 0; j < eigenvectors.cols(); j++){
135             outfile << eigenvectors(i,j);
136             if(j != eigenvectors.cols()-1) outfile << ",";
137         }
138         outfile << endl;
139     }
140     outfile.close();
141     cout << "Written file " << file << endl;
142 }
143 }
```

Verification - Mahalanobis Distance

The function calcCovarMatrix() calculates the covariance matrix between two vectors. The calculation function cvMahalonobis() is integrated in OpenCV.

```

1 double CPPPCA::CalMahDistance(Mat matSrc, Mat matTest)
2 {
3     Mat matCovar, matMean;
4     CvMat cvmatSrc, cvmatTest, cvmatCovar;
5     cvmatSrc = matSrc;
6     cvmatTest = matTest;
7
8     calcCovarMatrix(&matSrc, 1, matCovar, matMean, CV_COVAR_NORMAL);
9     cvmatCovar = matCovar;
10
11    double dbMahDistance = cvMahalonobis(&cvmatSrc, &cvmatTest, &
12        cvmatCovar);
13
14 } // end of CPPPCA::CalMahDistance()
```

Verification - Correlation

```

1 double CPPPCA::GetCorelation( uchar *v1, uchar *v2, int n)
2 {
3     double dSignal = 0, dNoise = 0;
4     int i;
5     double e1 = 0, e2 = 0, e12 = 0, c1 = 0, c2 = 0;
6
7     //calculate the expectations of V1, V2 and V1 x V2
8     for (i = 0; i < n; i++){
9         e1 += v1[i];
10        e2 += v2[i];
11        e12 += v1[i] * v2[i];
12    }
13
14    e1 = e1 / n;
15    e2 = e2 / n;
16    e12 = e12 / n;
17
18    //calulate the variances of R1 and R2
19    for (i = 0; i < n; i++){
20        c1 += (e1 - v1[i]) * (e1 - v1[i]);
21        c2 += (e2 - v2[i]) * (e2 - v2[i]);
22    }
23
24    c1 = sqrt(c1 / n);
25    c2 = sqrt(c2 / n);
```

```
26      // calculate the correlation
27      return IsZero(c1) || IsZero(c2)? 0.0 : fabs((e12 - e1 * e2) / (c1 * c2
28          ));
29 }
30 } //end of CPPPCA::GetCorelation()
```
