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INTERACTIVE Embedded FACE RECOGNITION

Douglas A. Lyon
Fairfield University, dlyon@fairfield.edu

Nishanth Vincent

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By Douglas Lyon and Nishanth Vincent

Abstract

This paper describes the design and construction of a prototype for embedded face detection and recognition algorithms. The test-bed is called the PITS (Portable Interactive Terrorist Identification System). It makes use of a hand-held device called the *Sharp Zaurus*. The embedded device has a processor, camera, color display, and wireless networking. This system is different from existing systems because of its embedded nature and its' use of Java technologies. The embedded device performs both detection and recognition. We present a skin color approach in the YCbCr color space for fast and accurate skin detection. We then process this image using a combination of morphological operators and elliptical shape of faces to segment faces from the other skin colored regions. An eigenface algorithm processes the segmented faces and matches the face to a face database.

1   INTRODUCTION

Face detection locates and segments face regions in cluttered images. It has numerous applications in areas like surveillance and security control systems, content-based image retrieval, video conferencing and intelligent human-computer interfaces. Some of the current face-recognition systems assume that faces are isolated in a scene. We do not make that assumption. Our system segments faces in cluttered images [2].

With a portable system, we can ask the user to pose for the face identification task. This can simplify the face-detection algorithm. In addition to creating a more cooperative target, we can interact with the system in order to improve and monitor its detection. The task of face detection is seemingly trivial for the human brain, yet it remains a challenging and difficult problem to enable a computer /mobile phone/PDA to do face detection. The human face changes with respect to internal factors like facial expression, beard, mustache, glasses, etc. is sensitive to external factors like scale, lighting conditions, and contrast between face, background and orientation of face. Thus, face detection remains an open problem. Many researchers have proposed different methods for addressing the problem of face detection. Face detection is classified into feature-based and image-based techniques. The feature-based techniques use edge information, skin color, motion, symmetry, feature analysis, snakes, deformable templates and point distribution. Image-based techniques include neural networks, linear subspace methods, like eigen faces [1], fisher faces etc. The problem of face detection in still images is more challenging and difficult when

compared to the problem of face detection in video, since motion information can lead to probable regions where faces could be located.

1.1 Problem definition

We are given an input scene and a suspect database. The goal is to find a set of possible candidates, subject to the constraint that we are able to match the faces from the scene in an interactive time on embedded hardware.

1.2 Motivation

Face detection plays an important role in today's world. It has many real-world applications like human/computer interface, surveillance, authentication and video indexing.

Interactive Face Recognition (IFR) can benefit the areas of: Law Enforcement, Airport Security, Access Control, Driver's Licenses & Passports, Homeland Defense, Customs & Immigration and Scene Analysis. The following paragraphs detail each of these topics, in turn.

Law Enforcement: Today's law enforcement agencies are looking for innovative technologies to help them stay one step ahead of the world's ever-advancing terrorists.

Airport Security: IFR can enhance security efforts already underway at most airports and other major transportation hubs (seaports, train stations, etc.). This includes the identification of known terrorists before they get onto an airplane or into a secure location.

Access Control: IFR can enhance security efforts considerably. Biometric identification ensures that a person is who they claim to be, eliminating any worry of someone using illicitly obtained keys or access cards.

Driver's Licenses & Passports: IFR can leverage the existing identification infrastructure. This includes, using existing photo databases and the existing enrollment technology (e.g. cameras and capture stations); and integrate with terrorist watch lists, including regional, national, and international "most-wanted" databases.

Homeland Defense: IFR can help in the war on terrorism, enhancing security efforts. This includes scanning passengers at ports of entry; integrating with CCTV cameras for "out-of-the-ordinary" surveillance of buildings and facilities; and more.

Customs & Immigration: New laws require advanced submission of manifests from planes and ships arriving from abroad; this should enable the system to assist in identification of individuals who should, and should not be there.

1.3 Approach

We define the face segmentation problem as: given a scene that may contain one or more faces, create sub-images that crop out individual faces. After face segmentation, the device enters the *face identification mode*.

```
(small)              Face              Feature
Suspect database  →  Data Base   →     Data Base
                                          │
                                          ↓
Face              Feature
Segmentation  →   Extraction   →      classifier
                                          │
                                          ↓
                                       matches
                                          │
                                          ↓
                                       GUI
                                       Displays possible
                                       candidates for selection
```
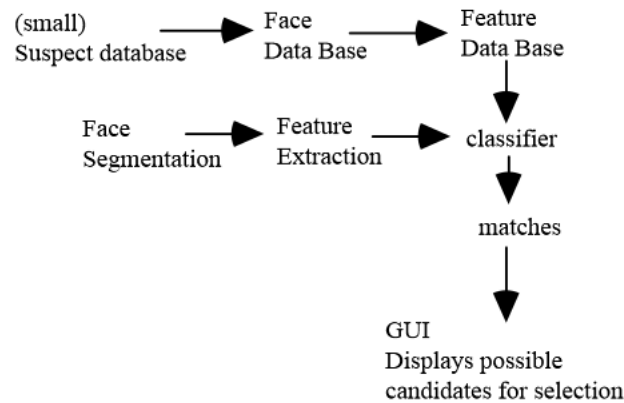
Fig 1.3 Face Identification System

Human skin is hard to detect in uncontrolled settings and remains an open problem [6]. Many approaches to face detection are only applicable to static images assumed to contain a single face in a particular part of the image. Additional assumptions are placed on pose, lighting, and facial expression. When confronted with a scene containing an unknown number of faces, at unknown locations, they are prone to high false detection rates and computational inefficiency. Real-world images have many sources of corruption (noise, background activity, and lighting variation) where objects of interest, such as people, may only appear at low resolution. An earlier generation of such a system has already been used for the purpose of flower identification by [7, 8].

2   LITERATURE SURVEY

Face detection is impacted by lot of external and internal factors that affect the detection. Even if a subject's face is stored in the database, a disguise or even a minor change in appearance, like wearing sunglasses or wearing or growing a mustache can often fool the system. Even an unusual facial expression can confuse the software. Facial identifiers often cannot distinguish twins. Different illuminations deform faces significantly. There are several algorithms available in the literature that can solve this problem. A survey on face detection with more than 150 references appears in [29]. There are two categories of algorithms in face detection, a feature-based approach [13] and an image-based approach [4].

A feature-based approach requires prior information of the face. It makes an explicit use of facial features include color, shape and component features.

Image-based approach does direct classification without any face knowledge derivation and analysis. It incorporates facial features implicitly into the system through training. Once skin color based face detection algorithm claims an accuracy of 95.18% [2]. Another face detection algorithm uses color images in the presence of varying lighting conditions as well as complex backgrounds. The method detects skin regions over the entire image, and then generates face candidates based on the spatial arrangement of these skin patches. The algorithm constructs eye, mouth, and

boundary by using a transfer of color space from RGB to YCbCr maps for verifying each face candidate [13].

Edge-detection algorithms

Edge detection detects outlines of an object and boundaries between objects and the background in the image. The Roberts algorithm performs is an edge detection using a two dimensional spatial gradient convolution. It detects horizontal and vertical edges [19].

The Sobel edge detector is similar to the Roberts algorithm. Both former and the latter use two kernels to determine edges running in different directions. The main difference is the kernels that each of these operator uses to obtain these initial images. Roberts kernels are designed to detect edges that run along the vertical axis of 45 degrees and the axis of 135 degrees whereas the Sobel kernels are more apt to detect edges along the horizontal axis and vertical axis [19]

Template matching algorithms

Cross correlation is a template-matching algorithm that estimates the correlation between two shapes that have a similar orientation and scale. Consider two series x(i) and y(i) where i=0,1,2...N-1. The cross correlation r at delay d is defined as

$$ r = \frac{\sum_i [\,(x(i) - mx) * (y(i-d) - my)\,]}{\sqrt{\sum_i (x(i) - mx)^2}\,\sqrt{\sum_i (y(i-d) - my)^2}} $$

Where *mx* and *my* are the means of the corresponding series. If the above is computed for all delays d=0, 1, 2,.. N-1 then it results in a cross correlation series of twice the length as the original series.

$$ r(d) = \frac{\sum_i [\,(x(i) - mx) * (y(i-d) - my)\,]}{\sqrt{\sum_i (x(i) - mx)^2}\,\sqrt{\sum_i (y(i-d) - my)^2}} $$

There is the issue of what to do when the index into the series is less than 0 or greater than or equal to the number of points. *(i-d < 0 or i-d >= N)* The most common approaches are to either ignore these points or assuming the series *x* and *y* are zero for *i < 0* and *i >= N*. In many signal processing applications the series is assumed to be circular in which case the out of range indexes are "wrapped" back within range, i.e.: *x(-1) = x(N-1), x(N+5) = x(5)* etc.

The range of delays d and thus the length of the cross correlation series can be less than N, for example the aim may be to test correlation at short delays only. The denominator in the expression above serves to normalize the correlation coefficients such that *-1 <= r(d) <= 1*, the bounds indicating maximum correlation and *0* indicating no correlation. A high negative correlation indicates a high correlation but have the inverse of one of the series but of the inverse of one of the series. It is quite robust to noise, and can be normalized to allow pattern matching independent of brightness and offset in the images [3].

The cross-correlation algorithm to be of limited utility because of its assumption on geometric scale and orientation of the templates.

Gray-scale algorithms

This gray-scale algorithm was suggested by Yang and Huang [33], who observed that when the resolution of a face image is reduced gradually either by sub sampling or averaging, macroscopic features of the face will disappear and that at low resolution, face region will become uniform.

Image based algorithms

- Statistical approach
- Neural networks[4]

Many commercial applications of face recognition are also available such as security system, criminal identification, and film processing. Like face detection face recognition can also be categorized into three types, a feature-based approach, a holistic approach and a hybrid approach.

Feature-based Approach

In feature-based methods, local features such as eyes, nose, and lips are segmented which is then used as an input data for structural classifier. Hidden Markov model and dynamic link architecture fall under this category.

Holistic Approach

In holistic methods, the face as a whole is taken as input data. One of the main algorithms that fall under this category is the eigenface method

Eigenface method is based on the implementation of Principal Component Analysis (PCA) over images. In this method, the features of the studied images are obtained by looking for the maximum deviation of each image from the mean image. This variance is obtained by getting the eigenvectors of the covariance matrix of all the images. The eigenface space is obtained by applying the eigenface method to the training images. Later, the training images are projected into the eigenface space. Next, the test image is projected into this new space and the distance of the projected test image to the training images is used to classify the test image [1]. Other examples of holistic methods are fisherfaces and support vector machines [1] [16] [17].

Hybrid Approach

The idea of this method comes from how human vision system sees both face and local features (includes nose, lips and eyes). Some of the examples in hybrid approach are modular eigenfaces and component-based methods [6].

Even though there is a wide range of algorithms available for both face detection and recognition. Tuning these algorithms on to our embedded system will be a real challenge [5].

3   HARDWARE AND SOFTWARE

The IFR system is a stand-alone GUI implementation on the Sharp Zaurus SL-6000L. The Zaurus is provided with a 400MHz processor, 64 MB RAM, and Compact Flash and Serial Device ports. It is equipped with a Sharp CE-AG06 camera attachment,

which is inserted into the Compact Flash port. The operating system is embedded Linux with Personal Java support. All code was written to Personal Java specifications. The code was migrated from a laptop to the Zaurus. In addition to that, the embedded device is provided with color display, wireless networking card and a QWERTY keyboard.

Fig 3-1 Sharp Zaurus and camera

Fig 3-2 GUI for Zaurus

4   EXPERIMENTS ON IMAGES

The Sharp Zaurus SL-6000L is provided with CE-AG06 camera attachment is inserted into the Compact Flash port which allows direct capture of images. The source code for the camera is in C so we call the executable at runtime using java.

There is a scan option in our GUI menu which will load the image that is being recently captured. The source code for calling the executable is given below.
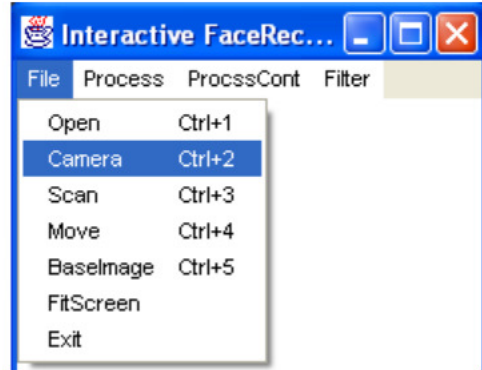
Figure 4-1. The Interface

```
private void camera() {
    try {
Runtime.getRuntime ().
    exec ("/home/QtPalmtop/bin/./sq_camera");
    } catch (IOException ioe) {
    ioe.printStackTrace ();
    }
}
```

4.1 Face Detection

The first stage in face detection is to perform skin detection. Skin detection can be performed in a number of color models. To name a few are RGB, YCbCr, HSV, YIQ, YUV, CIE, XYZ, etc. An efficient skin detection algorithm is one that should be able to cover all the skin colors like black, brown, white, etc. and should account for varying lighting conditions. Experiments were performed in YIQ and YCbCr color models to find out the robust skin color model.

4.2 YIQ Color Model

YIQ color model belongs to the family of television transmission color models. This color model is defined by the National Television Systems Committee (NTSC). This color space is used in televisions in the United States. The main advantages of this format is that grayscale information is separated from color data, so the same signal can be used for both color and black and white sets. In this color model, image data consists of three components: luminance (Y) which represents grayscale information, while hue (I) and saturation (Q) represents the color information. The following conversion is used to segment the RGB image into Y, I and Q components. Fig 4.2.1 shows the conversion of a RGB color model in to a YIQ color model and Fig 4.2.2 shows the skin threshold in the YIQ color model.

$$(1) \quad \begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.212 & -0.523 & -0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$
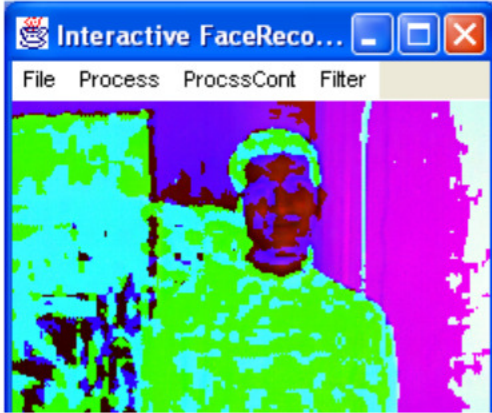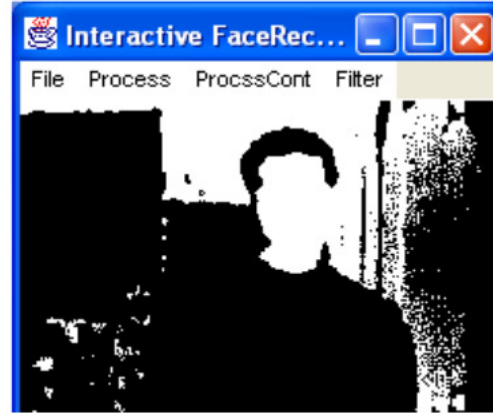

Fig 4.2-1 RGB□ YIQ

Fig 4.2-2 Skin threshold in YIQ

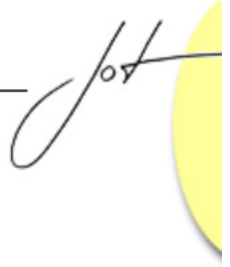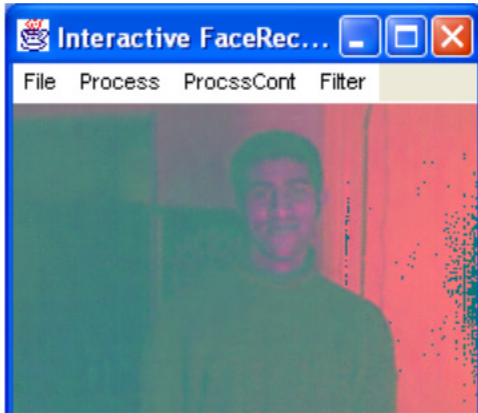The thresholds are selected by repeated experimentations. We have arrived at the following code:

```
if (    (Y[x][y] < 223) &&
     (Y[x][y] > 44) &&
     (I[x][y] < 0) &&
     (I[x][y] > 64)
  )
     setPixel(x, y, 255);
       else
          setPixel(x, y, 0);
}
```

4.3 YCbCr Color Model

YCbCr color model also belongs to the family of television transmission color models. In this color model, the luminance component is separated from the color components. Component (*Y*) represents luminance, and chrominance information is stored as two color-difference components. Color component *Cb* represent the difference between the blue component and a reference value and the color component *Cr* represents the difference between the red component and a reference value. The following conversion is used to segment the *RGB* image into *Y, Cb* and *Cr* components:

$$(2) \quad \begin{bmatrix} Y \\ C_b \\ C_r \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.5 \\ 0.5 & -0.419 & -0.081 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix}$$

Among all the color models found, *YCbCr* seems to be better for skin detection since the Colors in *YCbCr* are specified in terms of luminance (Y channel) and chrominance

(*Cb* and *Cr* channels). The main advantage of converting the image from *RGB* color model to the *YCbCr* color model is the influence of luminance can be removed during our image processing. We deal only with *Cb* and *Cr* components to perform skin detection. From analysis, we found that the *Cb* and *Cr* components give a good indication on whether a pixel is part of the skin or not. . Fig 4.3-1 shows the conversion of a RGB color model in to a *YCbCr* color model. Fig 4.3-2 shows the skin threshold in the *YCbCr* color model
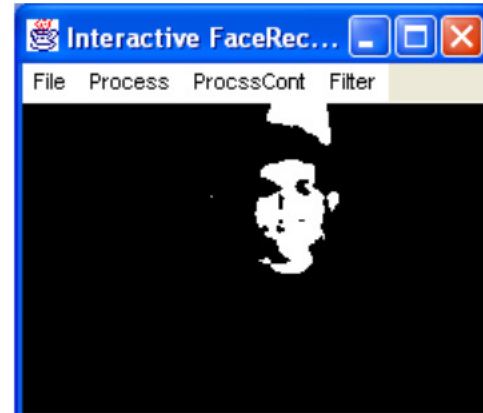

Fig 4.3-1 *RGB* □ *YCbCr*   Fig 4.3-2 Skin threshold in *YCbCr*

The thresholds are selected by repeated experimentations. We have arrived at the following code

```
if (   (Cb[x][y] < 173) &&
    (Cb[x][y] > 133) &&
    (Cr[x][y] < 127) &&
    (Cr[x][y] > 77)
 )
    setPixel(x, y, 255);
      else
        setPixel(x, y, 0);
}
```

From the above figures, we found that YCbCr color model is more efficient that YIQ color model for skin detection.

4.4 Binary Image Processing

Depending on the Cb and Cr threshold values a binary image is obtained with the skin regions masked in white and the non skin regions masked in black. This mask is further refined through morphological operators. The two basic morphological operators used are erosion and dilation.

Erosion is defined as a morphological operator which is usually applied to binary images. It is used to erode away the boundaries of regions of foreground pixels. Thus the areas of foreground pixels shrink in size, and holes within those areas become larger [18] [22]. Equation 3 defines the basic morphological operator erosion on sets A and B

$$erosion: \quad A \ominus B = \bigcap_{b \in B} T_{-b}(A) \tag{3}$$

Dilation is defined as a morphological operator, which is usually applied to binary images. The basic effect of the operator on a binary image is to gradually enlarge the boundaries of regions of foreground pixels [18] [22]. Equation 4 defines the basic morphological operator dilation on sets A and B

$$dilation: \quad A \oplus B = \bigcup_{b \in B} T_{-b}(A) \tag{4}$$

The image is first eroded to eliminate small background objects and separate individual faces.

This eroded image is then dilated to refill gaps within the faces. The blobs that are elliptical in shape are termed as faces while the other blobs are rejected.
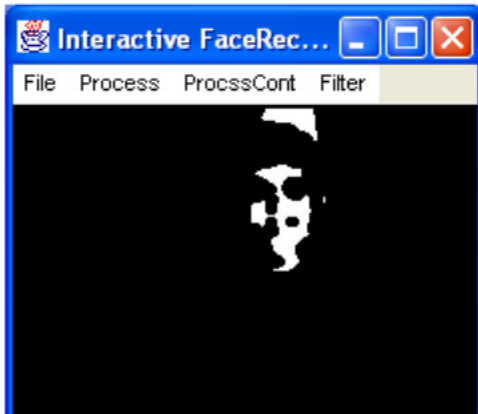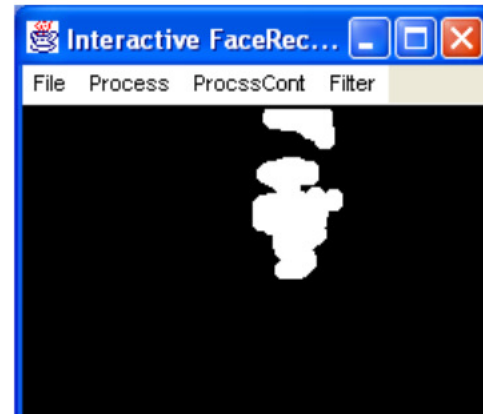

Fig 4.4-1 Eroded Image   Fig 4.4-2 Dilated Image

4.5 Blob detection

We used an open GL blob detection library. This library designed for finding 'blobs' in an image, i.e. areas whose luminosity is above or below a particular value. In our case it is just a binary image (black and white). It computes their edges and their bounding box. This library does not perform blob tracking; it only tries to find all blobs in each frame it was fed with.

Blobs in the image which are elliptical in shape are detected as faces. The blob detection algorithm draws a rectangle around those blobs by calculating information such as position and center.
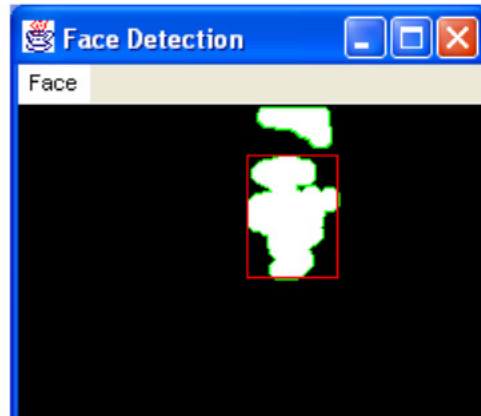
Fig 4.5-1 Blob detected Image.

4.6 Face Recognition

Principal component analysis (PCA), also known as Karthunen-Loéve's transform, is a well-known face recognition algorithm [1]. It is mainly useful in expressing the data in such a way that will highlight their similarities and differences. Since patterns in data can be hard to find in data of high dimension, where the luxury of graphical representation is not available, PCA is a powerful tool for analyzing data.

A small database is created with images. Each of these images are m pixels high and n pixels wide For each image in the database an image vector is created and are put in a matrix form which gives a start point for PCA. Covariance is found from the matrix of images and from the covariance the eigenvectors are found for the original set of images. The way this algorithm works is by treating face recognition as a "two-dimensional recognition problem, taking advantage of the fact that faces are normally upright and thus may be described by a small set of 2-D characteristics views. Face images are projected onto a feature space ('face space') that best encodes the variation among known face images. The face space is defined by the eigenfaces, which are the eigenvectors of the set of faces; they do not necessarily correspond to isolated features such as eyes, ears, and noses. So when a new image is passed from the blob detected image, the algorithm measures the difference between the new image and the original images, not along the original axes, but along the new axes derived from the PCA analysis [18] [36].
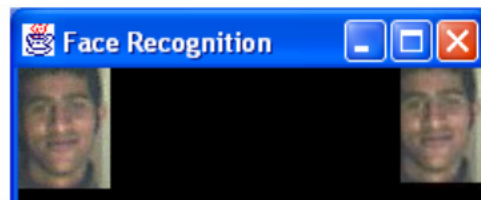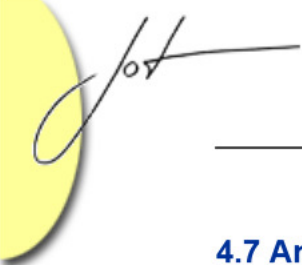

Fig 4.6.1 Face Recognized Image

4.7 Analysis

Face detection was tried on different complex images. The algorithm works fairly well in detecting faces. The performance of the algorithm in detecting faces is above 85%. Few of the images that were tried are shown below. Fig 4.7.1, fig 4.7.4 and fig 4.7.9 show the input images fed in to the GUI. Fig 4.7.8 shows the database used for face recognition. Fig 4.7.2, fig 4.7.5 and fig 4.7.10 show's the image after skin segmentation and binary image processing. Fig 4.7.3, fig 4.7.6 and fig 4.7.11 show's the face detected image. Fig 4.7.7 and fig 4.7.12 show's the face recognized image. The performance of recognizing 50x60 face images using PCA is approximately 76%.
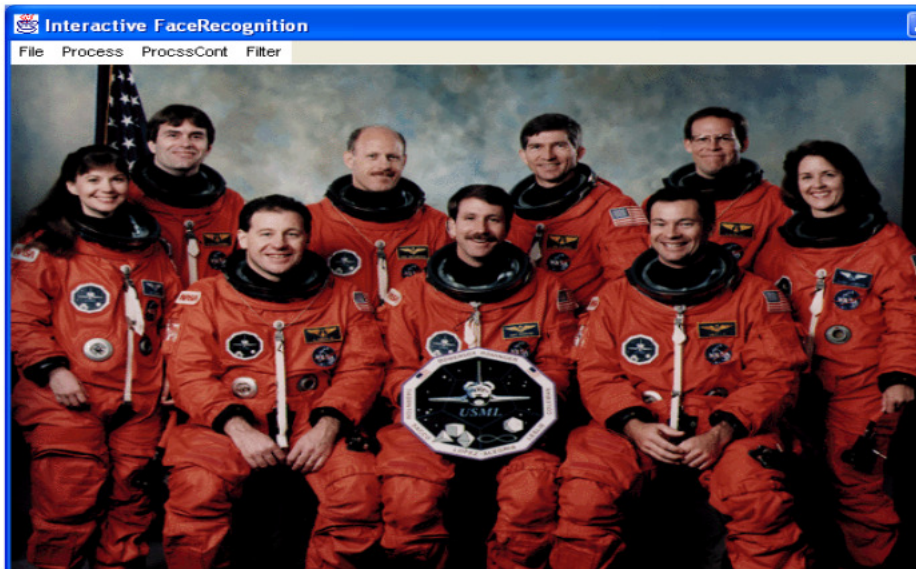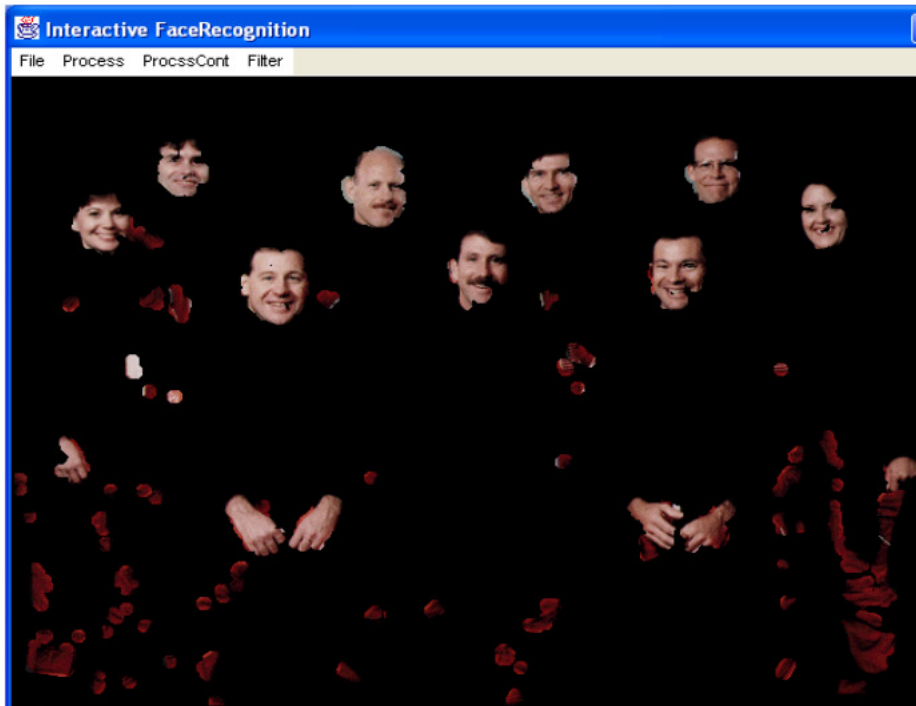
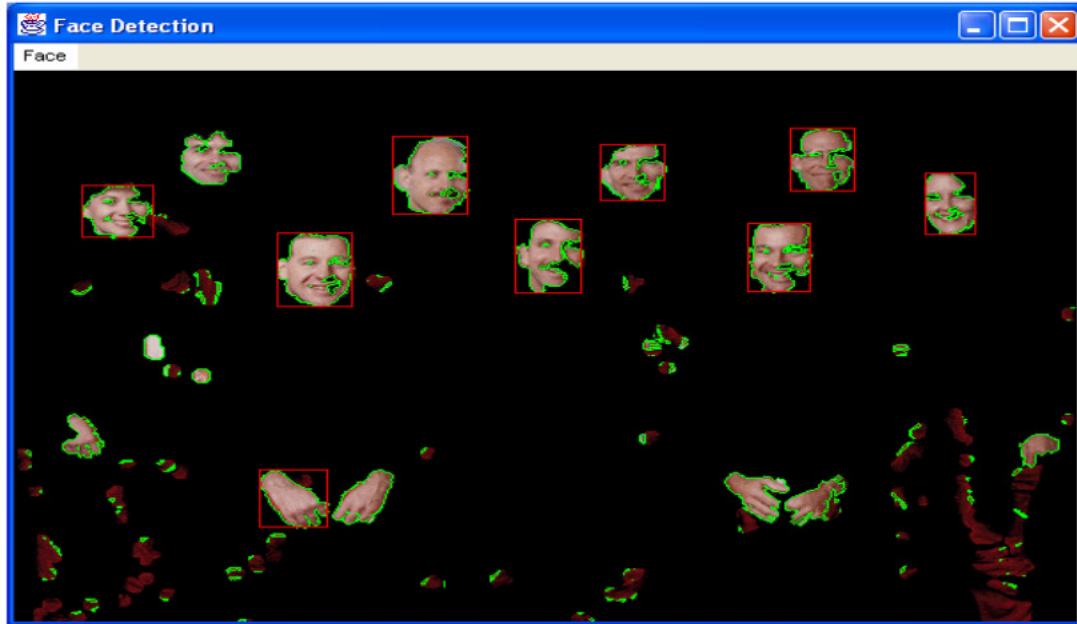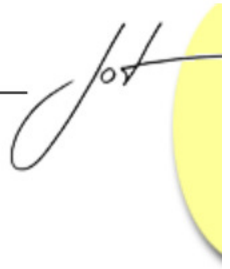Fig. 4.7-1 Input image

Fig. 4.7-2 Skin detected image

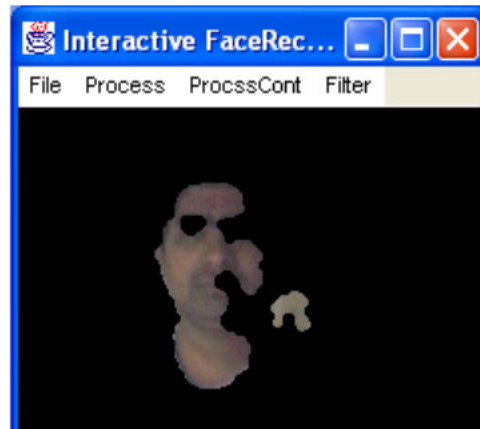Fig. 4.7-3 Face detected image

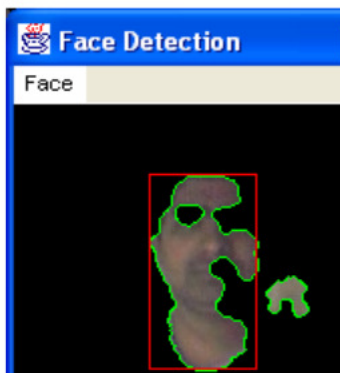Fig. 4.7-4 Input image

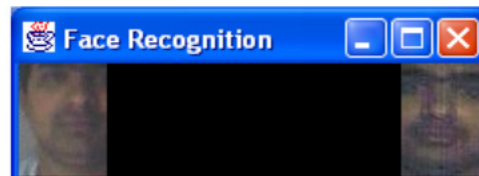Fig. 4.7-5 skin detection

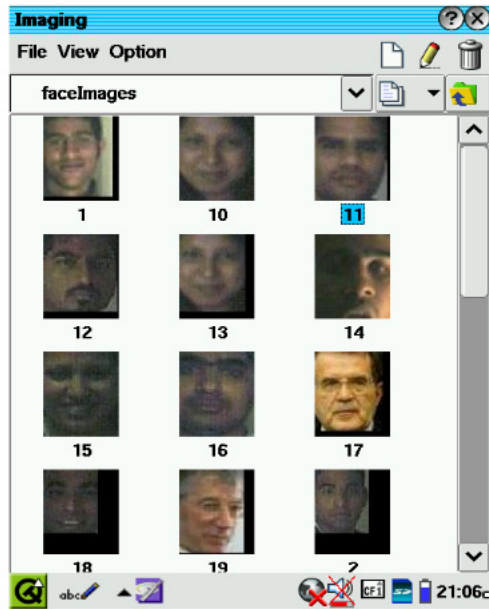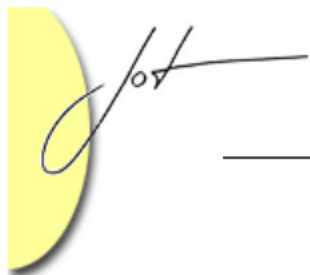Fig 4.7-6 Face detection

Fig 4.7-7 Face recognition

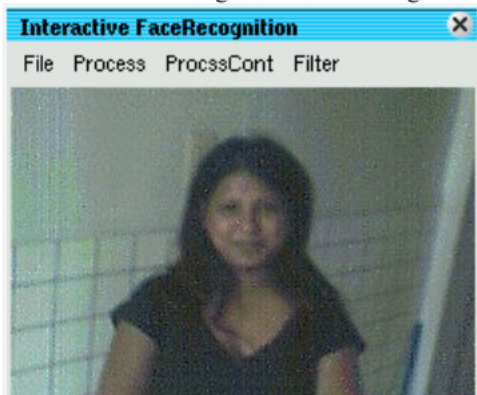Fig 4.7.8 Face Recognition database created in the Zaurus.
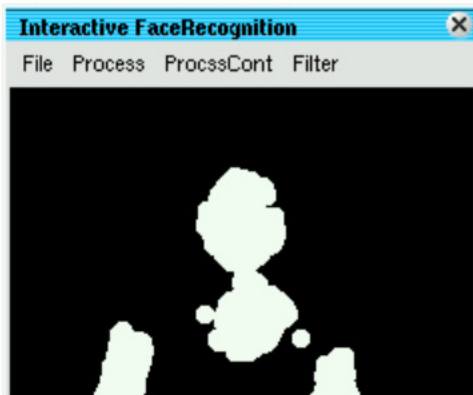

Fig 4.7-9 Input image
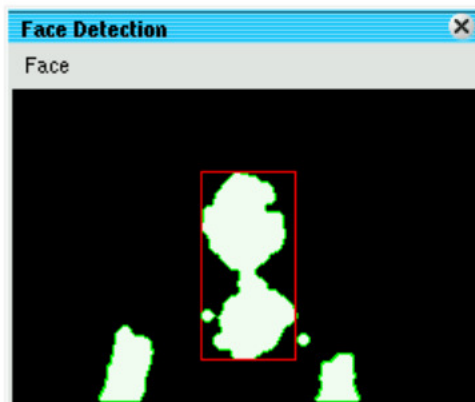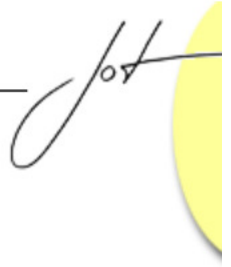

Fig 4.7-10 skin detection

Fig 4.7-11 Face detection

Fig 4.7-12 Face recognition

5   CONCLUSION

This paper shows an interactive face recognition algorithm on an embedded device. The device performs both face detection and recognition for color images. Face detection is performed in the *YCbCr* color space to provide a fast and accurate detection. The performance of the algorithm in detecting faces is over 85% correct. Face recognition is performed using PCA and the performance is found to be approximately 76% accurate. Our work is novel in that we are able to match the faces from the scene in an interactive time and that our algorithm is able to run on the given embedded hardware. Our future work will focus on improving the efficiency of the algorithm. Finally, we conclude saying that the Interactive Face Recognition device is a test bed for embedded face recognition research. As such, it contributes toward building a general infrastructure for research into embedded vision, further benefiting society.

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APPENDIX A

YIQ Color Model

```
public class Yiq extends FloatPlane {
// Matrix used for conversion from RGB to YIQ
  double A[][] = {
    {0.2989, 0.5866, 0.1144},
    {0.5959, -0.2741, -0.3218},
    {0.2113, -0.5227, 0.3113}
  };
//Constructor that takes an image
  public Yiq(Image img) {
    super(img);
  }


//  Mat3 is a math utility class for processing 3X3
matrices
  Mat3 rgbn2yiqMat = new Mat3(A);
//Method used to convert RGB to YIQ color space
  public void fromRgb() {
    convertSpaceYiq(rgbn2yiqMat);
    System.out.println("yiq");
    rgbn2yiqMat.print();
  }
/*Method that is used for skin detection in the YIQ color
*space
* if ((44 < Y < 223) && (0 < I  < 64))
* then we have skin
*/
  public void skinChromaKey() {
    for (int x = 0; x < r.length; x++)
    for (int y = 0; y < r[0].length; y++) {
      if (
        (r[x][y] < 223) &&
        (r[x][y] > 44) &&
        (g[x][y] > 0) &&
        (g[x][y] < 64)
      )
        setPixel(x, y, 255);
      else
```
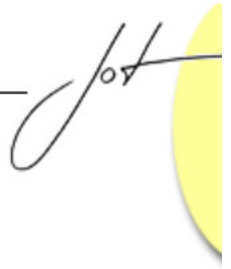
```java
            setPixel(x, y, 0);
        }
    }
//Method used to set pixel to binary in an image
    public void setPixel(int x, int y, int v) {
        r[x][y] = v;
        g[x][y] = v;
        b[x][y] = v;
    }
}
```

YCbCr Color Model

```java
public class Ycbcr extends FloatPlane{
//Matrix used for conversion from RGB to YCbCr
    double A[][] = {
        {0.299, 0.587, 0.114},
        {-0.16874, -0.33126, 0.50000},
        {0.50000, -0.41869, -0.08131}
    };
//  Mat3 is a math utility class for processing 3X3
matrices
    Mat3 rgb2yuvMat = new Mat3(A);

//Constructor that takes an image
public Ycbcr(Image img) {
    super(img);
    }
//Method used to convert RGB to YCbCr color space
    public void fromRgb() {
        convertSpace(rgb2yuvMat);
        System.out.println("ycbcr");
        rgb2yuvMat.print();
    }

//Method used for skin detection in the YIQ color
//space
    public void skinChromaKey() {
        for (int x = 0; x < r.length; x++)
        for (int y = 0; y < r[0].length; y++) {
            if (
(b[x][y] < 173) &&
```

```
(b[x][y] > 133) &&
(g[x][y] < 127) &&
(g[x][y] > 77)
  )
        setPixel(x, y, 255);
      else
        setPixel(x, y, 0);
    }
  }
//Method used to set pixel to binary in an image
  public void setPixel(int x, int y, int v) {
    r[x][y] = v;
    g[x][y] = v;
    b[x][y] = v;
  }
}
```

Morphological Operators

```
public class MorphUtils {
//Method to perform dilation in an image whose
functionality is to
//is to gradually enlarge the boundaries of regions of
foreground
//pixels
  public static short[][] dilate(short f[][], float k[][])
{
    int uc = k.length / 2;
    int vc = k[0].length / 2;
    int w = f.length;
    int h = f[0].length;
    short o[][] = new short[w][h];
    short sum;
    for (int x = uc; x < w - uc; x++) {
    for (int y = vc; y < h - vc; y++) {
      sum = 0;
      for (int v = -vc; v <= vc; v++)
        for (int u = -uc; u <= uc; u++)
          if (k[u + uc][v + vc] == 1)
            if (f[x - u][y - v] > sum)
sum = f[x - u][y - v];
      o[x][y] = sum;
    }
```

```
        }
      return o;
    }


    //Method to perform erosion in an image whose functionality
    is
    //to erode away the boundaries of regions of foreground
    pixels.
    //Thus the areas of foreground pixels shrink in size and
    holes
    //within those areas become larger.
      public  short[][] erode(short f[][], float k[][]) {
        int uc = k.length / 2;
        int vc = k[0].length / 2;
        int w = f.length;
        int h = f[0].length;
        short o[][] = new short[w][h];
        short sum = 0;

        for (int x = uc; x < w - uc; x++) {
        for (int y = vc; y < h - vc; y++) {
          sum = 255;
          for (int v = -vc; v <= vc; v++)
            for (int u = -uc; u <= uc; u++)
            if (k[u + uc][v + vc] == 1)
              if (f[x - u][y - v] < sum)
    sum = f[x - u][y - v];
          o[x][y] = sum;
        }
        }
      return o;
    }
  }
  }
```

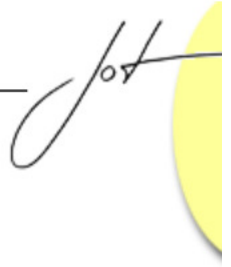## Face Detection and Face Recognition

```
  public class FaceDetectionFrame extends Frame implements
  ActionListener {
  //This object is used to display the graphics of the image
  on the
  //frame
    Display d = new Display();
```

```java
//vectors are declared to get the X-coordinate, Y-
coordinate,
//height and width of the blob
  Vector locationX = new Vector();
  Vector locationY = new Vector();
  Vector imageWidth = new Vector();
  Vector imageHeight = new Vector();


//Blob detection object initialized to find the blobs in
the image
//after processing
  BlobDetection theBlobDetection;
 //constructor that takes two images as argument
  FaceDetectionFrame(Image img, Image image) {
    super("Face Detection");
    this.rawImg = img;
    this.baseImage = image;
    Menu face = new Menu("Face");
    MenuItem mi1 = new MenuItem("Detect");
    mi1.setShortcut(new MenuShortcut(KeyEvent.VK_0));
    mi1.addActionListener(new ActionListener() {
public void actionPerformed(ActionEvent e) {

faceRecognition();
        }
      }
);
    face.add(mi1);

    MenuBar mb = new MenuBar();
    setMenuBar(mb);
    mb.add(face);
    setSize(240, 320);
    setVisible(true);
    this.add(d);
    face.addActionListener(this);
    addWindowListener(
      new WindowAdapter() {
        public void windowClosing(WindowEvent e) {
          theBlobDetection = null;
          setVisible(false);
```

```
        //terminate the program
      }//end windowClosing()
    }//end WindowAdapter
  );//end addWindowListener
  }
}
//Method used to detect blobs in the image areas whose luminosity
//is above or below a particular value. In our case it is just a
//binary image (black and white). It computes their edges and
//their bounding box
  public void detectBlob() {
    ImageBean ib = new ImageBean(rawImg);
theBlobDetection = new BlobDetection(ib.getWidth(),
ib.getHeight());
    theBlobDetection.setPosDiscrimination(false);
   // will detect bright areas whose luminosity < 0.38f;
    theBlobDetection.setThreshold(0.38f);
      theBlobDetection.computeBlobs(ib.getPels());
    blobNb = theBlobDetection.getBlobNb();
    rawImg = ib.getImage();
    d. update(this.getGraphics());
    this.add(d);
    setVisible(true);
    repaint();

}
//Method for performing face recognition uses principal component
//analysis. This algorithm treats face recognition as a two-
//dimensional recognition problem, taking advantage of the fact
//that faces are normally upright and thus may be described by a
//small set of 2-D characterisits views. Face images are projected
//onto a feature space ('face space') that best encodes the
//variation among known face images. The face space is defined by
```

```java
//the eigenfaces, which are the eigenvectors of the set of
faces;
public void faceRecognition() {
    try {
    for (int i = 0; i < locationX.size(); i++) {
ImageBean ib = new  ImageBean(Integer.parseInt
(String.valueOf(imageWidth.elementAt(i))),

Integer.parseInt(String.valueOf(imageHeight.elementAt(i))))
;
        Image faceDetectedImage = ib.getImage();
ImageBean ib1 = new ImageBean(faceDetectedImage,
baseImage);

ib1.imageRenewed(Integer.parseInt(String.valueOf(locationX.
elementAt(i))),

Integer.parseInt(String.valueOf(locationY.elementAt(i))),

Integer.parseInt(String.valueOf(imageHeight.elementAt(i))),

Integer.parseInt(String.valueOf(imageWidth.elementAt(i))));
ImageBean ib2 = new ImageBean(50, 60);
        Image finalTemp = ib2.getImage();
ImageBean ib3 = new ImageBean(finalTemp ,ib1.getImage());
            ib3.imageReCon();
    try {
EigenFaceCreator creator = new EigenFaceCreator();
creator.readFaceBundles("/usr/mnt.rom/card/faceImages");

String result = creator.checkAgainstNew(ib3.getImage());
System.out.println("Most closly reseambling: "+result+"
with "+creator.DISTANCE+" distance.");

    if(result == null){
new FaceRecognitionFrame(ib3.getImage());
    }
    else
    {
File f = new File("/usr/mnt.rom/card/faceImages/" +
result);
Image  faceRecognizedImage = Toolkit.getDefaultToolkit().
        getImage(f.toString());
```

```java
MediaTracker mediatracker = new MediaTracker(new Canvas());
        mediatracker.addImage(faceRecognizedImage, 1);
    try {
         mediatracker.waitForAll();
    }
   catch (
InterruptedException e1) {
        e1.printStackTrace();
    }
        mediatracker.removeImage(faceRecognizedImage);
           ImageBean ib4 = new ImageBean(240, 200);
ImageBean ib5 = new
ImageBean(ib4.getImage(),ib3.getImage());
ib5.imageAddAndDisplay();
ImageBean ib6 = new
ImageBean(ib5.getImage(),faceRecognizedImage);
ib6.imageAddFinalDisplay();
new FaceRecognitionFrame(ib6.getImage());
        }
   } catch (Exception e) { e.printStackTrace(); }
        }
    } catch (Exception e) {
    e.printStackTrace();
    }
   }
//Override the paint method to display the rawImg on the
same //Canvas object, separated by one row of pixels in the
background //color. Also draws a rectangle around the blob
by calculating //blob information such as position and
center.
   public class Display extends Canvas {
     .
    public void paint(Graphics g) {
    g.drawImage(rawImg, 0, 0, this);
    PGraphics pg = new PGraphics();
    Blob b;
    float eA, eB, eC, eD = 0;
    ImageBean sib = new ImageBean(rawImg);
    for (int n = 0; n < blobNb; n++) {
      b = theBlobDetection.getBlob(n);
      if (b != null) {
```

```
// Edges
        if (true) {
        pg.strokeWeight(2);
        pg. stroke(0, 255, 0);
        for (int m = 0; m < b.getEdgeNb(); m++) {
eA = b.getEdgeVertexAX(m);
eB = b.getEdgeVertexBX(m);
eC = b.getEdgeVertexAY(m);
eD = b.getEdgeVertexBY(m);
if (eA != 0 && eB != 0 && eC != 0 && eD != 0)
g.setColor(Color.green);
g.drawLine((int) (b.getEdgeVertexAX(m) * sib.getWidth()),
(int) (b.getEdgeVertexAY(m) * sib.getHeight()), (int)
(b.getEdgeVertexBX(m) * sib.getWidth()),
(int) (b.getEdgeVertexBY(m) * sib.getHeight()));
            }
            }
// Blob
pg. strokeWeight(1);
pg. stroke(255, 0, 0);
g.setColor(Color.red);
g.drawRect((int) (b.xMin * sib.getWidth()), (int) (b.yMin *
sib.getHeight()), (int) (b.w * sib.getWidth()), (int) (b.h
* sib.getHeight()));
        }

    }
    }
    }
}
```

Image Utility

```
public class ImageBean implements Serializable {
//Initialization of 2D arrays for red, blue and green
component in //an image.
 public  short r[][];
 public  short g[][];
 public  short b[][];
 public  short r1[][];
 public  short g1[][];
 public  short b1[][];
//constructor that takes two images as parameters
```

```java
public ImageBean(Image img1, Image img2) {
    final Frame f = new Frame();
    int w1 = img1.getWidth(f);
    int h1 = img1.getHeight(f);
    int w2 = img2.getWidth(f);
    int h2 = img2.getHeight(f);
    if (w1 == -1) return;
    r = new short[w1][h1];
    g = new short[w1][h1];
    b = new short[w1][h1];
    r1 = new short[w2][h2];
    g1 = new short[w2][h2];
    b1 = new short[w2][h2];
    pelsToShort(r, g, b,
      getPels(img1,
        w1,
        h1),
      w1, h1);
    pelsToShort(r1, g1, b1,
      getPels(img2,
        w2,
        h2),
      w2, h2);
}
//Method gets an image from the 2D red, green and blue
arrays
  public static Image getImage(short r[][], short g[][],
short b[][]) {
    int w = r.length;
    int h = r[0].length;
    int pels[] = new int[w * h];
    for (int x = 0; x < w; x++)
    for (int y = 0; y < h; y++)
      pels[x + y * w]
        = 0xFF000000
        | ((0xFF & r[x][y]) << 16)
        | ((0xFF & g[x][y]) << 8)
        | (0xFF & b[x][y]);
    return Toolkit.getDefaultToolkit().createImage(new
MemoryImageSource(w,
```

```
            h,
            ColorModel.getRGBdefault(),
            pels, 0,
            w));
    }


//method gets pixel array from an image
public int[] getPels(Image img, int width, int height) {
    pels = new int[width * height];
      PixelGrabber grabber =
        new PixelGrabber(img, 0, 0,
          width, height, pels, 0, width);
      try {
      grabber.grabPixels();
      } catch (InterruptedException e) {
      e.printStackTrace();
      }
      return pels;
    }
//method converts the pixel array in to 2D array of red,
blue and //green
public  void pelsToShort(short r[][], short g[][], short
b[][],
  int[] pels, int width, int height) {
      int i;
      ColorModel cm = getRgbColorModel();
      for (int x = 0; x < width; x++)
      for (int y = 0; y < height; y++) {
        i = x + y * width;
        b[x][y] = (short) cm.getBlue(pels[i]);
        g[x][y] = (short) cm.getGreen(pels[i]);
        r[x][y] = (short) cm.getRed(pels[i]);
      }
    }
//method clips the image to 255 if the rgb value exceeds
255 and //makes it to 0 if it is negative
public void clip(ImageBean ib) {
      int w = ib.getWidth();
      int h = ib.getHeight();
      for (int x = 0; x < w; x++)
      for (int y = 0; y < h; y++) {
```
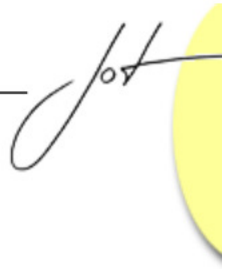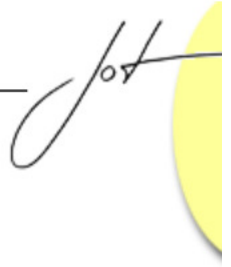
```java
        if (r[x][y] > 255) r[x][y] = 255;
        if (g[x][y] > 255) g[x][y] = 255;
        if (b[x][y] > 255) b[x][y] = 255;
        if (r[x][y] < 0) r[x][y] = 0;
        if (g[x][y] < 0) g[x][y] = 0;
        if (b[x][y] < 0) b[x][y] = 0;
      }
   }
//method reconstructs the skin detected image from the
binary //image
   public void SkinReCon() {
      for (int x = 0; x < getWidth(); x++)
      for (int y = 0; y < getHeight(); y++) {
        if (r[x][y] == 255) {
           if (g[x][y] == 255) {
           if (b[x][y] == 255) {
             r[x][y] = r1[x][y];
             g[x][y] = g1[x][y];
             b[x][y] = b1[x][y];
           }
           }
        }
      }
   }
//convert the image to gray scale by taking the average of
the //red, green and blue colors.
   public void gray() {
      for (int x = 0; x < getWidth(); x++)
      for (int y = 0; y < getHeight(); y++) {
        r[x][y] = (short)
           ((r[x][y] + g[x][y] + b[x][y]) / 3);
        g[x][y] = r[x][y];
        b[x][y] = r[x][y];
      }
   }
//method used to negate an image
public void negate() {
      for (int x = 0; x < getWidth(); x++)
      for (int y = 0; y < getHeight(); y++) {
        r[x][y] = (short) (255 - r[x][y]);
```

```java
            g[x][y] = (short) (255 - g[x][y]);
            b[x][y] = (short) (255 - b[x][y]);
        }
        clip(this);
    }
}
//Method used to display the final facerecognized image on
the //frame
public void imageAddFinalDisplay() {
int m = getWidthOne()-1;
    for (int x = getWidth()-1; x > getWidth() -
getWidthOne(); x--) {
        for (int y = 0 ; y < getHeightOne() ; y++){
        r[x][y] = r1[m][y] ;
        g[x][y] = g1[m][y] ;
        b[x][y] = b1[m][y] ;
      }
    m--;
    }
}
//Method tries to invoke the camera in the Zaurus
  private void camera() {
    try {
Runtime.getRuntime ().
    exec ("/home/QtPalmtop/bin/./sq_camera");
    } catch (IOException ioe) {
    ioe.printStackTrace ();
    }
  }
//Getters and Setters declared for r,g and b
public short[][] getR() {
    return r;
  }
  public void setR(short[][] r) {
    this.r = r;
  }
  public short[][] getG() {
    return g;
  }
  public void setG(short[][] g) {
    this.g = g;
```

```
    }
    public short[][] getB() {
      return b;
    }
    public void setB(short[][] b) {
      this.b = b;
    }
  }
```

About the author

Douglas A. Lyon (M'89-SM'00) received the Ph.D., M.S. and B.S. degrees in computer and systems engineering from Rensselaer Polytechnic Institute (1991, 1985 and 1983). Dr. Lyon has worked at AT&T Bell Laboratories at Murray Hill, NJ and the Jet Propulsion Laboratory at the California Institute of Technology, Pasadena, CA. He is currently the Chairman of the Computer Engineering Department at Fairfield University, in Fairfield CT, a senior member of the IEEE and President of DocJava, Inc., a consulting firm in Connecticut. Dr. Lyon has authored or co-authored three books (Java, Digital Signal Processing, Image Processing in Java and Java for Programmers). He has authored over 30 journal publications. Email: lyon@docjava.com. Web: http://www.DocJava.com.

Nishanth Vincent ('03-'06) recieved the M.S. degree in Electrical and computer engineering from Fairfield University, CT and received the B.E. degree in Instrumentation and control systems from Madras University ('99 - '03). Nishanth has worked at Pitney Bowes as an intern in their Mixed Media Network labs. He is currently working as a web developer at Zentechinc, in Norwalk CT email: nishanth.vincent@zentechinc.com