Personal identification system using unimodal and multimodal biometrics operates in two modes namely enrolment phase and identification phase. During the enrolment phase, several imprints of the persons obtained from the sensor or scanner are passed to the system. The samples captured by these scanner are passed through pre-processing and feature extraction to produce the templates which are then stored in the database. The identification/recognition mode involves passing the query imprint image to the system. This query imprint is passed through pre-processing and feature extraction block. The extracted features from the query imprint are then compared with templates stored in the database in order to find the correct match. The distance measure finds the close match between the query imprint and the template imprints stored in the database. It is necessary for a practical biometric system that it should provide acceptable recognition accuracy and speed accepted by the user and it should be robust to various fraudulent attacks. Number of biometric identifiers has been in use for various applications. Each of one has its strengths and weaknesses and its choice typically depends on the application. Although each of these biometrics to a certain extent, satisfies the desirable requirements and has been used in practical systems or has the potential to become a valid biometric technique, not many of them are acceptable as indisputable evidence of identity as the biometrics community is slow in establishing benchmarks for biometrics systems. A hand based biometrics has a good balance of all desirable properties. Hence we propose a multi-resolution framework for fingerprint and palm-print as multimodal biometrics.

This chapter of the thesis describes the proposed system for personnel identification using the unimodal and multimodal biometrics namely palmprint and fingerprint along with the region of interest (ROI) extraction from the imprint images captured with the help of scanners. Extraction of ROI is an important step prior to extract the various textural features from the individual biometric used for personal identification or system authentication.
3.1 Proposed unimodal biometric system for personal identification

Figure 3.1 shows the block diagram of the proposed unimodal personal identification system. The five modules of system are acquisition of image using sensor or scanner, preprocessing of the image like region of interest (ROI) extraction, extracting feature using subspace analysis or multi-resolution multi-scale transform techniques, to find match using Euclidian distance and storing the templates in the database.

The image is initially captured by the scanner and converted into a digital form. The image is then transmitted to a computer for further processing. In pre-processing extraction of the central part called as ROI of the image as explained in subsequent Sections.

![Figure 3.1 Block diagram of the unimodal personal identification system.](image)

Textural information from the central part of the digital image has been extracted by applying a multi-resolution multi-scale transform or subspace analysis methods. These textural features are then stored in the database as the templates of images during enrolment phase. When a query hand is placed on the sensor, the whole process is repeated to extract the features from the query imprint image. These textural features of query image are then compared with the templates. During enrolment phase the features are stored in the database as the templates of the images. In terms of distance a close match for the imprint at crime site can be found by comparing it with template stored in database.

3.2 Proposed multimodal biometric system for personal identification

Multimodal biometric system involves utilization of more than one modality for identification purpose. The basic requirement for multimodal biometric system is the fusion of these modalities using sum rule. The fusion may be carried out sensor level, feature level, match level or decision level. In this work, we have used fingerprint and palmprint as two modalities and the fusion has been carried out at feature level. Block diagram of the proposed personal identification system using multimodal biometrics is as shown in Figure
3.2. During enrollment phase, the fused features from fingerprint and palmprint images have been stored in the database. With application of a query image, the features of individual image are extracted. The features are summed up and matched with the feature vectors from database to find a suitable match.

![Block diagram of the multimodal personal identification system.](image)

**3.3 Extraction of ROI from the palmprint image**

In order to make the proposed system rotation and translation invariant, it is necessary to obtain a ROI from the captured palmprint image, prior to feature extraction. Five major steps of palmprint image pre-processing to extract the ROI are as follows and illustrated in Figure 3.3:

1. **Step 1**: Convolve the captured palmprint image with a low-pass filter. Figure 3.3(b) shows the binary image formed by applying a threshold value for this convolved imprint. This transformation can be represented as,

   \[
   B(x,y) = \begin{cases} 
   1, & \text{if } O(x,y) * L(x,y) \geq T \\
   0, & \text{if } O(x,y) * L(x,y) < T
   \end{cases}
   \]  

   where,

   \[O(x,y)\] and \[B(x,y)\]- the original image and the binary image respectively,
   \[L(x,y)\] - lowpass filter such as Gaussian and
   \[*\] -convolution operator.
Figure 3.3 Steps demonstrating pre-processing: (a) original image (b) binary image (c) boundary tracking (d) key points ($k_1$ and $k_3$) detecting (e) coordinate system and (f) the central part of a palmprint.
Step 2: Extract the boundaries of holes, \((F_i x_j,F_i y_j)\) \((i=1,2)\), between fingers by using boundary-tracking algorithm. Start points \((Sx_i, Sy_i)\), and end points \((Ex_i, Ey_i)\) of holes are then marked in the process (Figure 3.3(c)).

Step 3: For each hole, compute the center of gravity \((C_x, C_y)\), with the following equations:

\[
C_{x_i} = \frac{\sum_{j=1}^{M(i)} F_i x_j}{M(i)}, \quad \text{and} \\
C_{y_i} = \frac{\sum_{j=1}^{M(i)} F_i y_j}{M(i)}
\]  \((3.2)\)

where,

\(M(i)\) represents the number of boundary points in the hole, \(i\).

Then construct a line that passes through \((C_x, C_y)\) and the midpoint of \((Sx_i, Sy_i)\) and \((Ex_i, Ey_i)\). The line equation is defined as,

\[
y = x \frac{(C_y - M y_i)}{(C_x - M x_i)} + \frac{(M y_i C x_i - M x_i C y_i)}{(C x_i - M x_i)}
\]  \((3.3)\)

where,

\((M x_i, M y_i)\) is the midpoint of \((Sx_i, Sy_i)\) and \((Ex_i, Ey_i)\).

Based on these lines, two key points, \((k_1, k_2)\), can easily be detected (Figure 3.3(d)).

Step 4: Line up \(k_1\) and \(k_2\) to get the \(Y\)-axis of the palmprint coordinate system and make a line through their midpoint which is perpendicular to \(Y\)-axis, for determining the origin of the coordinate system (see Figure 3.3(e)). This coordinate system can align different palmprint images.

Step 5: Extract a sub-image with the fixed size on the basis of coordinate system located at the certain part of the palmprint for feature extraction (Figure 3.3(f)).

### 3.4 Extraction of ROI from the fingerprint image

Fingerprint and position of finger with scanner may differ every time. Also size of all the fingerprints may not be uniform. For achieving the translation and rotation invariance for the proposed model, ROI is extracted from the captured images before feature extraction. This requires location of a core point in every fingerprint which will act as reference point for that fingerprint. Using its core point as the center, crop the fingerprint image into a fixed size of pixels. In order to find the center point location following steps have been performed:

Step 1: Divide the input image, into non-overlapping blocks of size \(8 \times 8\).
Step 2: Compute the gradients $\partial_x(i, j)$ and $\partial_y(i, j)$ at each pixel $(i, j)$. Depending on the computational requirement, gradient operator may vary from simple Sobel operator to the more complex Marr-Hildreth operator.

Step 3: For each block compute local orientation centered at pixel $(i, j)$ using

$$o(i, j) = \frac{1}{2} \tan^{-1} \left( \frac{V_x(i, j)}{V_y(i, j)} \right)$$  \hspace{1cm} (3.4)

where,

$$V_x(i, j) = \sum_{u=-4}^{i+4} \sum_{v=-4}^{j+4} 2 \partial_x(u, v) \partial_y(u, v)$$

$$V_y(i, j) = \sum_{u=-4}^{i+4} \sum_{v=-4}^{j+4} (\partial_x^2(u, v) - \partial_y^2(u, v))$$

The value of $o(i, j)$ is least square estimate of the local ridge orientation in the block centered at pixel $(i, j)$. It represents mathematically, the direction orthogonal to the dominant direction of the Fourier spectrum of the $8 \times 8$ window.

Step 4: Smooth out the orientation field in a local neighborhood. For smoothing means low pass filtering, the orientation image requires conversion into a continuous vector field and is defined as,

$$\phi_{1x}(i, j) = \cos \left( 2 \, o(i, j) \right)$$  \hspace{1cm} (3.5)

and

$$\phi_{1y}(i, j) = \sin \left( 2 \, o(i, j) \right)$$  \hspace{1cm} (3.6)

where, $\phi_{1x}$ and $\phi_{1y}$, are the vector field components in $x$ and $y$ direction respectively.

With the resulting vector field, low pass filtering can be performed as,

$$\phi_x(i, j) = \sum_{u=-w/2}^{w/2} \sum_{v=-w/2}^{w/2} W(u, v) \phi_{1x}(i - wu, j - wv)$$  \hspace{1cm} (3.7)

and

$$\phi_y(i, j) = \sum_{u=-w/2}^{w/2} \sum_{v=-w/2}^{w/2} W(u, v) \phi_{1y}(i - wu, j - wv)$$  \hspace{1cm} (3.8)

where,

$W(.)$ is a two dimensional low pass filter with unit integral and $w \times w$ specifies filter size.
Note that smoothing operation is performed at the block level. A 5×5 mean filter has been used in our experimentation. The smoothed orientation field $O$ at $(i, j)$ is computed as,

$$O(i, j) = \frac{1}{2} \tan^{-1}\left(\frac{\phi_x(i, j)}{\phi_y(i, j)}\right)$$  \hspace{1cm} (3.9)

**Step 5:** Initialize $R$, a label image used to indicate the core point.

**Step 6:** For each pixel $(i, j)$ in $O$, compute the Poincare index and assign the corresponding pixels in $R$. The poincare index at pixel $(i, j)$ enclosed by a digital curve that consists of a sequence of pixels that are on or within a distance of one pixel apart from the corresponding curve, is computed as,

$$Poincare(i, j) = \frac{1}{2\pi} \sum_{k=0}^{2} \Delta(k)$$  \hspace{1cm} (3.10)

where,

$$\Delta(k) = \begin{cases} 
\delta(k), & \text{if } |\delta(k)| < \frac{\pi}{2} \\
\pi + \delta(k), & \text{if } \delta(k) \leq -\frac{\pi}{2} \\
\pi - \delta(k), & \text{otherwise,} \end{cases}$$

$$\delta(k) = O(j' - i') - O(i, j)$$

$i = (i + 1) \mod (8)$

$j' = (j + 1) \mod (8)$

Here $i'$ and $j'$ are the $x$ and $y$ co-ordinates of the closed digital curve with 8 surrounding pixels of 3×3 mask.

**Step 7:** Find the connected components in $R$. For connected component area larger than seven, a core is detected at the centroid of the connected component. For the area of a connected component larger than 20, two cores are detected at the centroid of the connected component.

**Step 8:** If two cores are detected, center is assigned the co-ordinates of the core point with the lower $y$ value (the upper core). If only one core is detected, the center is assigned to the co-ordinates of the core point. Detected core points on fingerprint sample images have been shown in Figure 3.4.
Figure 3.4 Core point detection in fingerprint images (a) images with one core point detected, (b) two core points detected on images.

*Step 9:* Compute covariance matrix of the vector field in a local neighborhood \((q \times q)\) of each point in the orientation field, if no core point is detected. Define a feature image \(F\) with the largest Eigen value of the covariance matrix for each element in the orientation image. Core is detected at centroid of the largest connected component in the threshold image of \(F\) and the center is assigned to the co-ordinates of the core.

*Step 10:* Finally crop the fingerprint image into 128×128 pixels using its core point as the center as shown in Figure 3.5.

Figure 3.5 Cropped fingerprint image to 128×128 pixels using its core point as the center.