# List of Figures

<table>
<thead>
<tr>
<th>Fig. No.</th>
<th>Description</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Iris image examples</td>
<td>10</td>
</tr>
<tr>
<td>2.2</td>
<td>Anatomy of the human eye</td>
<td>14</td>
</tr>
<tr>
<td>2.3</td>
<td>Morphology of the human iris (Iris Image 4_S1_L_9 from COEP Dataset. Elements seen in a typical iris images are labeled here)</td>
<td>16</td>
</tr>
<tr>
<td>3.1</td>
<td>Iris image acquisition set up using $I$ – Scan 2</td>
<td>35</td>
</tr>
<tr>
<td>3.2</td>
<td>Examples of iris images (a) Iris image 1_S1_R_3   (b) Iris image 1_S1_L_3</td>
<td>35</td>
</tr>
<tr>
<td>3.3</td>
<td>Iris image acquisition set up using Mobile Eyes</td>
<td>36</td>
</tr>
<tr>
<td>3.4</td>
<td>Examples of iris images (a) Iris image 7_S1_R_6   (b) Iris image 7_S1_L_7</td>
<td>37</td>
</tr>
<tr>
<td>3.5</td>
<td>(a) Huvitz HS 5000   (b) GUI for iris image acquisition</td>
<td>39</td>
</tr>
<tr>
<td>4.1</td>
<td>Iris images with artifacts (a) Eyelid &amp; eyelashes, (b) Isolated eyelashes obstructions, (c) Lighting reflection, (d) Specular reflection, (e) Partially captured, (f) Out of iris, (g) Off angle iris, (h) Motion blur (i) Poor focus</td>
<td>47</td>
</tr>
<tr>
<td>4.2</td>
<td>Iris images with artifacts (a) Defocus image, (b) High specular reflection, (c) High pigmentation, (d) Off-angle image, (e) Occluded image, (f) Lighting variation</td>
<td>48</td>
</tr>
<tr>
<td>4.3</td>
<td>Overall scheme for estimation of quality factors</td>
<td>51</td>
</tr>
<tr>
<td>4.4</td>
<td>Various stages of processed iris image</td>
<td>52</td>
</tr>
<tr>
<td>4.5</td>
<td>Dilation measure</td>
<td>53</td>
</tr>
<tr>
<td>4.6</td>
<td>Occlusion measure</td>
<td>53</td>
</tr>
<tr>
<td>4.7</td>
<td>Processable iris resolution assessments</td>
<td>55</td>
</tr>
<tr>
<td>4.8</td>
<td>Eccentric distance measure</td>
<td>55</td>
</tr>
<tr>
<td>4.9</td>
<td>Angular assessment</td>
<td>56</td>
</tr>
<tr>
<td>4.10</td>
<td>Separation between focus score in defocused version of NICE.I dataset</td>
<td>60</td>
</tr>
<tr>
<td>4.11</td>
<td>Flowchart for minimum radius detection of structuring element</td>
<td>60</td>
</tr>
</tbody>
</table>
4.12 Average focus score for image, iris and interior portion of iris for NICE.I dataset
4.13 Focus score values for NICE.I using (a) Kang & Park’s kernel (b) Daugman’s kernel
4.14 Occlusion assessment
4.15 Specular reflection assessment
4.16 Dilation score assessment
4.17 Pixel count assessment
4.18 Lighting variation assessment
4.19 Pigmentation score assessment
4.20 Eccentricity assessment
4.21 Comparison of pixel count for NICE.I and UBIRIS.v2
4.22 Comparison of pigmentation score for NICE.I and UBIRIS.v2
4.23 Comparison of occlusion score for NICE.I and UBIRIS.v2
4.24 Comparison of specular reflection for NICE.I, UBIRIS.v2 and CASIA.v3I
4.25 Comparison of dilation for NICE.I, UBIRIS.v2 and CASIA.v3I
5.1 Iris localization
5.2 Result of preprocessing (a) Original image, (b) Image histogram, (c) Thresholded image, (d) Hole filled image, (e) Complemented image (Ic)
5.3 Circular geometry concept
5.4 Left edge point detection on outer iris boundary
5.5 Position of 7 pixels on either side of SP
5.6 Detection of edge point (a) Right edge point, (b) Diagonal edge point on outer iris boundary
5.7 Result of edge detection process (a) Left edge points, (b) Diagonal edge points, (c) Right edge points
5.8 Results of proposed segmentation algorithm for CASIA.v1
5.9 Results of proposed segmentation algorithm for CASIA.v2
5.10 (a) Results of proposed segmentation algorithm for CASIA.v3 (CASIA-Iris-Interval)
5.10 (b) Results of proposed segmentation algorithm for CASIA.v3 (CASIA-Iris-Lamp)

5.11 Result of incorrect localisation

5.12 Color based clustering (a) Original image, (b) Clustered image, (c) Separated clustered iris portion based on thresholding – iris portion, (d) Skin region, and (e) Eyebrows

5.13 Coarse iris localization

5.14 Specular reflection map

5.15 Reflection removal (a) Original image having specular reflection, (b) Reflection removed image

5.16 Iris outer (limbic) boundary localisation (a) Original image, (b) Localised iris outer (limbic) boundary, (c) Final iris detected square box, (d) Image having iris portion

5.17 Pupil boundary detection (a) Square box area for pupil circle detection, (b) Increased-contrast for square box, (c) Pupil boundary detection

5.18 Examples of non-circular iris boundaries

5.19 Euclidean distance between the original center \( (x_0, y_0) \) and the pupil center \( (x_p, y_p) \)

5.20 Examples of non-circular boundary detection

5.21 Example of eyelid detection (a) Image having eyelids, (b) Upper eyelid detected, (c) Lower eyelid detected

5.22 Example of the square patch used to obtain the average gray intensity for eyelash detection

5.23 Sample images of UBIRIS.v2 database

5.24 (i) Sample result of successful iris segmentation for images from UBIRIS.v2, NICE.I and NICE.II databases (a) Original image, (b) Iris mask, (c) Segmented iris

5.24 (ii) Sample result of successful iris segmentation for images from UBIRIS.v2, NICE.I and NICE.II databases (a) Original image, (b) Iris mask, (c) Segmented iris

5.25 Sample results of failures of iris segmentation cases (a) and (b) Bright spot present on outer iris boundary and pupil part, (c) and
(d) Shadow of space and natural shadow present, (e) Eyebrow is detected as iris portion

5.26 Daugman’s Rubber Sheet model
5.27 Daugman’s Rubber Sheet model for non-concentric pupil
5.28 Normalisation of lower half of iris
5.29 Sector based normalisation
5.30 Sector dimensions
5.31 Effective iris region extraction from localized iris
5.32 Sample results of extracted side mapping of iris images

6.1 Gabor filter response at $\lambda = 3$ for $\theta = 0^\circ, 45^\circ, 90^\circ, 135^\circ$
6.2 Gabor filter response at $\lambda = 4$ for $\theta = 0^\circ, 45^\circ, 90^\circ, 135^\circ$
6.3 Gabor filter response at $\lambda = 8$ for $\theta = 0^\circ, 45^\circ, 90^\circ, 135^\circ$
6.4 Iris code generation using 2D Gabor filter
6.5 Feature encoding process using 1D Log Gabor filter
6.6 Iris code using 1D Log Gabor filter (a) Iris code ($N = 2, \lambda = 18, \sigma/\lambda = 0.3$) (b) Iris code ($N = 2, \lambda = 20, \sigma/\lambda = 0.5$)
6.7 Original POC function (a) Example of genuine matching (b) Example of imposter matching
6.8 Enhanced image in spatial and frequency domain
6.9 BLPOC function $(K_1/M_1, K_2/M_2) = (0.5, 0.2)$ (a) Example of genuine matching, (b) Example of imposter matching
6.10 Block partitioning and cross-phase spectrum calculation
6.11 Genuine matching of normalised image, lower iris and iris side image
6.12 ROC for Phase-Based matching approach – UBIIRS.v1 database
6.13 ROC curves and EER for UBIIRS, MMU, ND Iris 04 05 and COEP.v2 database
6.14 3D view of wavelet analysis
6.15 Implementation of DWT
6.16 DB$_1$ filter (a) DB$_1$ Wavelet function $\psi$, (b) Decomposition low-pass filter, (c) Decomposition high-pass filter
6.17 DB$_4$ filter (a) DB$_4$ Wavelet function $\psi$, (b) Decomposition low-pass filter, (c) Decomposition high-pass filter
6.18 Bior2.4 filter (a) Bior2.4 Wavelet function $\psi$, (b) Decomposition low pass filter, (c) Decomposition high-pass filter

6.19 2 D DWT applied on images

6.20 Flow diagram of wavelet encoding algorithm

6.21 Recommended Recognition Threshold (RRT) for CASIA.v1 using DB1 (a) Distribution of genuine and imposter matching scores, (b) Variation of FAR and FRR

6.22 ROC of Different Databases using DB1, DB4 and Bior2.4, (a) ROC for UBIIRIS.v1, (b) ROC for MMU.1, (c) ROC for MMU.2, (d) ROC for CASIA.v1, (e) ROC for CASIA.v2, (f) ROC for CASIA.v3L

6.23 Receiver Operating Characteristic curves for different transforms

6.24 Various steps in forming feature vector from normalized iris image

6.25 Receiver Operating Characteristic curves for 1 D DCT

6.26 Receiver Operating Characteristic curves for 1 D WHT

6.27 Receiver Operating Characteristic curves for 2 D DCT

6.28 Receiver Operating Characteristic curves for different databases

7.1 Iridology chart for left and right iris

7.2 Pancreas location for Diabetes Mellitus: Right Eye, Sec 38-39 (approx.)

7.3 Process for clinical feature extraction

7.4 Flow diagram for LabVIEW detect defect method

7.5 Differences in intensity in the resulting defect image

7.6 Block diagram of LabVIEW based detect object method

7.7 Normalised iris image

7.8 Iris normalisation (a) Original normalised image, (b) Histogram normalised image, (c) Adaptive histogram equalization of normalised image

7.9 Various sections of normalised iris image

7.10 Probability distribution functions for the subsection where there is maximum difference in pixel intensity

7.11 Selection of liver section from normalized iris image

7.12 Sections 4 as an input for training Neural Network
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.13</td>
<td>Subsection (10 × 10) input and output of Neural Network</td>
<td>181</td>
</tr>
<tr>
<td>7.14</td>
<td>Results of Neural Network output for different training algorithm</td>
<td>184</td>
</tr>
<tr>
<td></td>
<td>(a) Number of hidden neuron 10, (b) Number of hidden neuron 50,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(c) Number of hidden neuron 100</td>
<td></td>
</tr>
<tr>
<td>7.15</td>
<td>Confusion Matrix</td>
<td>186</td>
</tr>
<tr>
<td>7.16</td>
<td>Probability distribution function of output of neural network</td>
<td>189</td>
</tr>
</tbody>
</table>