3D Facial Model Construction and Expressions Synthesis using a Single Frontal Face Image

Narendra Patel, Mukesh Zaveri
Department of Computer Engg, BVM Engg. College, V.V.Nagar, India
Department of Computer Engg, SVNIT, Surat, Gujarat, India
bvm_nmp@yahoo.com, mazaveri@gmail.com

Abstract

In this paper we present a system which automatically generates a 3D face model from a single frontal image of a face with the help of generic 3D model and allow to synthesis various expressions. Our system consists of three components. The first component detects the features like eyes, mouth, eyebrow and contour of face. After detecting features the second component automatically adapts the generic 3D model into face specific 3D model using geometric transformations. Once the model is ready six basic facial expressions are generated with the help of MPEG-4 facial animation parameters (FAPs). To generate transitions between these facial expressions we use 3D shape morphing between the corresponding face models and blend the corresponding textures. Our system has the advantage that it is fully automatic, robust and fast. It can be used in a variety of applications for which the accuracy of depths are not critical such as games, avatars, face recognition etc. We have tested and evaluated our system using standard database namely, BU-3DFE.

Keywords: Generic 3d model, morphing, animation, MPEG-4, FAPs, texture etc.

1. Introduction

There has been a lot of work on face modeling from images. One technique which has been used in much commercial system is to use two orthogonal views [1]: one frontal view and one side view. Such systems require the users to manually specify the face features on the two images. Blanz and Vetter [2] developed a system to create face models from a single image. Their system uses both a geometry database and an image database. Their system is computationally more expensive. Feng and yuen [3] synthesized the face only from a single image, but this method needs to estimate head rotation parameters by using another reference image. Liu [4] also proposed a system to create face models from a single face image but they have used existing software to detect features.

After generation of 3D face model next important issue is synthesis human face with high degree of realism. Modeling of facial expressions for synthesis humans adds realism and achieves high levels of engagement and responsiveness. However, the task of modeling all human expressions on to a virtual character is complicated by the richness of human facial expressions and the fact that each individual has their unique way of expressing emotions facially.

Approaches that achieve high degree of realism required to manipulate the face mesh’s vertices. Face mesh manipulation of facial animation approaches includes Key
framing [5] which is one of the earliest approaches and involves linear transformations from one face mesh to another. This approach requires extensive computation and large data sets.

As a result new system was proposed which defines a set of expression parameters for different parts of the face [6]. Each expression parameter affects a set of vertices of the face model and generates key frame. The disadvantage of the parametric systems is that they cannot easily blend facial expressions since each parameter affects a disjoint set of vertices in the face model.

Terzopoulos and Waters [7] model the face in a layered fashion and incorporate an anatomically based muscle model with a physically based layered tissue model. They used a trilayer facial tissue concept modeled as a trilayer mesh of vertices connected by springs. Anatomically based muscle models [8] are first used by waters to animate major facial expressions. Later methods based on parameterization and muscle based modeling [6, 8] are proven to be efficient and provides the realistic view. The problem with these approaches is that the number of parameters is very large and the model is very complex because of muscle structure.

The establishment of the MPEG-4 standard facilities an alternate way of analyzing and modeling facial expressions [9 10].

We have proposed a system that automatically generate 3D face model from the given frontal image of the face and generates the universal six expressions of the face, such as fear, anger, happiness, surprise, disgust and sadness. In our proposed system these expressions are represented with the help of MPEG-4 facial animation parameters [9 10]. The MPEG-4 visual standard provides an alternative way of modeling facial expressions and the underlying emotion, which are strongly influenced by psychological studies such as Ekman’s [11] facial action coding system (FACS). The MPEG-4 visual standard specifies a set of facial definition parameters (FDPs) and facial animation parameters (FAPs) for facial animation. The FAPs are used to characterize the movements of facial features defined over jaw, lips, eyes, mouth, nose and cheek. Facial animation is produced by interpolation between two or more different models using 2D morphing techniques combined with 3D transformations of geometric model. Novelty of our system is automatic generation of texture corresponding to expression from neutral face. Our proposed system generate 3D face model and expressions from any frontal face image. We have used 3D facial expression database BU-3DFE [12] for texture mapping and to determine the values of FAPs. It is also possible to generate new expression through the blending of selected expressions.

The paper is organized as follows: Section 2 describes 3D face model reconstruction. It is followed by expressions generation and expression morphing in section 3 and 4 respectively. Section 5 describes animation. The simulation results and conclusions are discussed in section 6 and 7.

2. 3D face model reconstruction

The method which reconstructs the 3D face model from single frontal 2D face image consists of facial feature extraction, face model adaptation and texture mapping [13].

2.1 Facial feature extraction
Facial feature extraction comprises two phases: face detection and facial feature extraction. Face is detected by segmenting skin and non skin pixels. It is reported that YCbCr color model is more suitable for face detection than any other color model. It is also reported that the chrominance component Cb and Cr of the skin tone always have values between 77<=Cb<=127 and 133<=Cr<=173 respectively [14]. After detection of face the features like eyes, mouth and eyebrows are detected.

We first build two separate eye maps, one from the chrominance components and the other from the luminance component [15]. We have used upper half of the face region for preparation of eye maps to detect eyes. The eye map from the chroma is based on the observation that high Cb and low Cr values are found around the eyes. It is constructed using equation 1.

\[
\text{EyeMapC} = \frac{1}{3} \left\{ C_b^2 + \overline{C_r^2} + \frac{C_b}{C_r} \right\}
\]

(1)

Where \(C_b^2\), \(C_r^2\) and \(C_b / C_r\) all are normalized to the range [0 1] and \(Cr^2\) is the negative of Cr (i.e. 1-Cr).

The eyes usually contain both dark and bright pixels in the luma component so grayscale morphological operators dilation (\(\oplus\)) and erosion (\(\Theta\)) is used to emphasis brighter and darker pixels in the luma component around eye regions. We have used gray scale dilation and erosion with a structuring element of radius 5 to construct the eye map from the luma using equation 2.

\[
\text{EyeMapL}=Y(x, y) \oplus g(x, y) / Y(x, y) \Theta g(x, y)
\]

(2)

Where \(Y(x, y)\) is luma component of face region and \(g(x, y)\) is structuring element.

The eye map from the chroma is enhanced by histogram equalization and then combined with the eye map from the luma by an AND (multiplication) operation. The resulting Eyemap is dilated with same structuring element to brighten eyes and suppress other facial areas. The locations of the eyes are detected using appropriate value of threshold and finding maximum connected component. The color of mouth region contains stronger red component and weaker blue component than other facial regions. Mouth has a relatively low response in the \(C_r/C_b\) feature but it has a high response in \(C_r^2\) [15]. We construct mouth map using equation 3.

\[
\text{MouthMap}=C_r^2 \ast (C_r^2 - n*C_r/C_b)^2
\]

(3)

\[
n = 0.8 \frac{\sum C_r(x, y)^2}{\sum C_r(x, y)/C_b(x, y)}
\]

Where \(C_r^2\) and \(C_r / C_b\) are normalized to the range [0 1].

Eyebrows are detected with the help of edge detection in the region above the eyes. All the detected features are shown in Figure 1.
2.2 Face model adaptation

This is a process in which the generic 3D face model is deformed to fit a specific face. Our proposed generic model [16] is shown in Figure 2 and Figure 3 which is polygon-based (triangle mesh) and consists of 350 triangles and 215 vertices. We have also used Candide-3 face model [17] shown in Figure 4. Model is adapted to given frontal face with the help of two geometrical transformations scaling and translation. Assuming orthographic projection, the translation vector can be derived by calculating the distance between the 3D face model centre to the 2D face centre. Let $C_l$ indicate centre of left eye, $C_r$ indicate centre of right eye, $C_c$ indicate middle point between two eyes and $C_m$ indicate centre of mouth in given face. Similarly $C_l'$, $C_r'$, $C_c'$ and $C_m'$ are corresponding points in the 2D projection of the 3D face model. Model is scaled by an amount $S_x$, $S_y$ and $S_z$ using equation 4.

\[
S_x = \frac{|(C_l - C_r)|}{|(C_l' - C_r')|} \\
S_y = \frac{|(C_c - C_m)|}{|(C_c' - C_m')|} \\
S_z = \frac{(S_x + S_y)}{2}
\]
After global adaptation of model we perform local refinement of model eyes, eyebrows, mouth and contour with that of face features. Appropriate translation factor does local refinement of the model. After the 3D face geometry is reconstructed, it is rendered and appropriate texture is mapped to synthesis 2D face image which is shown in Figure 5 and Figure 6.
Figure 5. Model reconstruction

Figure 6. Model reconstruction
3. Expressions generation

Expressions are represented with the help of MPEG-4 facial animation parameters (FAPS). The FAPs are a set of parameters defined in the MPEG-4 visual standard for the animation of synthetic face models. There are 68 FAPs including 2 high-level FAPs used for visual phoneme and expression and 66 low level FAPs used to characterize the facial feature movements over jaw, lips, eyes, mouth, nose, cheek, ears etc. The expression parameter FAP-2 define the six primary facial expression as shown in Table-1. We have generated six basic expressions with the help of low level FAPs shown in Table 2. The FAPs are computed through tracking a set of facial features defined in Figure 7 and they are measured by facial animation parameter units (FAPUs) that permit us to place FAPs on any facial model in a consistent way [18]. The FAPUs are defined with respect to the distances between key facial features in their neutral state such as eyes (ES0), eyelids (IRDS0), eye-nose (ENS0), mouth-nose (MNS0) and lip corners (MW0) as shown in Figure 7.

![Neutral face model and feature points](image)

**Table 2:** Neutral face model and feature points

Table 2 gives the relations between the FAPS, and involved vertices of model shown in Figure 2 and Figure 3. Table 3 gives the relation between expressions and involved FAPS. Expressions are generated by moving and deforming various control vertices of face model according to FAPs shown in Table 2. Negative sign with FAPs indicate opposite direction motion. If \( V_m \) indicates the neutral coordinate of the \( m^{th} \) vertex in a certain dimension of the 3D space, its animated position \( V_m' \) in the same dimension can be expressed as

\[
V_m' = V_m + \omega_n * FAPU_n * i_n
\]

Where \( \omega_n \) is the weight of the \( n \)th FAP, \( FAP_n \) that affects \( V_m \); \( FAPU_n \) is the FAPU to \( FAP_n \); \( i_n \) is the amplitude of FAP ranging between \([0, 1]\). In fact, the term, \( \omega_n * FAPU_n \) defines the maximum displacement of \( FAP_n \), while coefficient \( i_n \) controls the intensity of \( FAP_n \). We have developed scan line algorithm to generate texture corresponding to expression from neutral face. Our algorithm establish corresponded between each triangle of neutral model and expression model for each scan line for each pixel.
4. Expression morphing

Expression morphing means the generation of continuous and realistic transitions between different facial expressions. We achieve these effects by morphing between corresponding face models. 3D morphing sequence can be obtained using simple linear interpolation between the geometric coordinates of corresponding vertices in each of the two face meshes. Together with the geometric interpolation, we need to blend the associated textures. When we morph two different expressions of the same face model then first intermediate face model is generated by geometric interpolation. Texture for this intermediate model is directly generated from neutral face by establishing corresponded between each triangle of neutral model and intermediate expression model for each scan line for each pixel. We have also developed algorithm which morph expressions of any two face models. We have used triangle based wrapping method [19-20]. Intermediate texture is generated using linear interpolation of respective source and destination triangle for each scan line. New expression can be generated by blending any two expressions from the six basic expressions with the help of morphing. Our proposed morphing algorithm is as follows

Step 1: For each value of interpolation factor t repeat

Step 2 to 5 (0<=t<=1)

Step 2: For each triangle of the model repeat step

3 to 5 to generate intermediate frame

Step 3: Sort triangle based on their Y\text{min}

Step 4: Generate the Intermediate Triangle of source and target model.

\text{Imtriangle} = (1 - t) * \text{source triangle} + t * \text{target Triangle}

Step 5: For each scan line from Y\text{min} to Y\text{max} repeat step 4

\text{Image}(x, y) = (1 - t) * \text{Image1}(x1, y1) + t * \text{Image2}(x2, y2)

Step 5 is generating texture for intermediate model from source and target image. For each scan line of the intermediate triangle, the y increment factors are as follow

\text{Yinc (Imtriangle)} = 1

\text{Yinc (source triangle)} = (\text{ysmax-ysmin})/ (\text{yimax- ymin})

\text{Yinc (target triangle)} = (\text{ytmax-ytmin})/ (\text{yimax - ymin})

ysmax and ysmin are maximum and minimum y-value of source triangle, yimax and yiminy are maximum and minimum y-value of intermediate triangle and ytmax and ytmin are maximum and minimum y-value of target triangle.

For each scan line, the x increment factors are as follows

\text{Xinc (Imtriangle)} = 1

\text{Xinc (source triangle)} = (xstart2-xstart1)/\text{width}. 
swidth = xend – xbegin of intermediate triangle and xstart1 and xstart2 are starting x values of source triangle corresponding to current scan line.

Xinc (target triangle) = (xstart4–xstart3)/swidth. xstart3 and xstart4 are starting x values of target triangle corresponding to current scan line.

Starting x value corresponding to next scan line=previous x start value+(1/slope) * yinc

**Table 1. Facial expressions defined by FAP-2**

<table>
<thead>
<tr>
<th>Facial-Animation Parameters (FAP)</th>
<th>Expressions</th>
</tr>
</thead>
<tbody>
<tr>
<td>The eyebrows are relaxed. The mouth is open and mouth corners pulled back towards the ears.</td>
<td>Happiness,</td>
</tr>
<tr>
<td>The inner eyebrows are bent upward. The eyes are slightly closed, the mouth is relaxed.</td>
<td>Sadness,</td>
</tr>
<tr>
<td>The inner eyebrows are pulled downward and together. The eyes are wide open. The lips are pressed against each other or opened to expose the teeth.</td>
<td>Anger</td>
</tr>
<tr>
<td>The eyebrows are raised and pulled together. The inner eyebrows are bent upward. The eyes are tense and alert.</td>
<td>Fear</td>
</tr>
<tr>
<td>The eyebrows and eyelids are relaxed. The upper lip is raised and curled, often asymmetrically</td>
<td>Disgust,</td>
</tr>
<tr>
<td>The eyebrows are raised. The upper eyelids are wide open, the lower relaxed. The jaw is opened.</td>
<td>surprise</td>
</tr>
</tbody>
</table>

**Table 2. Relation between FAPs and vertices**

<table>
<thead>
<tr>
<th>FAP No</th>
<th>FAP Name and FAPU</th>
<th>Description</th>
<th>Involved Vertices of model shown In Fig.3</th>
<th>Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>raise_l_i_eyebrow (ENS)</td>
<td>Vertical displacement of left inner eyebrow</td>
<td>28,27</td>
<td>Up</td>
</tr>
<tr>
<td>32</td>
<td>raise_r_i_eyebrow (ENS)</td>
<td>Vertical displacement of right inner eyebrow</td>
<td>33,32</td>
<td>Up</td>
</tr>
<tr>
<td>33</td>
<td>raise_l_m_eyebrow (ENS)</td>
<td>Vertical displacement of left middle eyebrow</td>
<td>26,29</td>
<td>Up</td>
</tr>
<tr>
<td>34</td>
<td>raise_r_m_eyebrow (ENS)</td>
<td>Vertical displacement of right middle eyebrow</td>
<td>31,34</td>
<td>Up</td>
</tr>
<tr>
<td>35</td>
<td>raise_l_o_eyebrow (ENS)</td>
<td>Vertical displacement of left outer eyebrow</td>
<td>25</td>
<td>Up</td>
</tr>
<tr>
<td>No.</td>
<td>Action</td>
<td>Description</td>
<td>Type</td>
<td>Direction</td>
</tr>
<tr>
<td>-----</td>
<td>---------</td>
<td>--------------------------------------</td>
<td>-------</td>
<td>-----------</td>
</tr>
<tr>
<td>36</td>
<td>raise_r_o_eyebrow (ENS)</td>
<td>Vertical displacement of right outer eyebrow</td>
<td>30</td>
<td>Up</td>
</tr>
<tr>
<td>37</td>
<td>squeeze_l_eyebrow (ES)</td>
<td>Horizontal displacement of left eyebrow</td>
<td>27,28</td>
<td>Right</td>
</tr>
<tr>
<td>38</td>
<td>squeeze_r_eyebrow (ES)</td>
<td>Horizontal displacement of right eyebrow</td>
<td>32,33</td>
<td>Left</td>
</tr>
<tr>
<td>19</td>
<td>close_t_l_eyelid (IRISD)</td>
<td>Vertical displacement of top left eyelid</td>
<td>2,3,4,5,6</td>
<td>Down</td>
</tr>
<tr>
<td>20</td>
<td>close_t_r_eyelid (IRISD)</td>
<td>Vertical displacement of top right eyelid</td>
<td>14,15,16,17,18</td>
<td>Down</td>
</tr>
<tr>
<td>41</td>
<td>lift_l_cheek (ENS)</td>
<td>Vertical displacement of left cheek</td>
<td>35,36,37,38,39,40,41,42</td>
<td>Up</td>
</tr>
<tr>
<td>42</td>
<td>lift_r_cheek (ENS)</td>
<td>Vertical displacement of right cheek</td>
<td>43,44,45,46,47,48,49,50</td>
<td>Up</td>
</tr>
<tr>
<td>59</td>
<td>raise_l_cornerlip (MNS)</td>
<td>Vertical displacement of left corner lip</td>
<td>a, p</td>
<td>Up</td>
</tr>
<tr>
<td>60</td>
<td>raise_r_cornerlip (MNS)</td>
<td>Vertical displacement of right corner lip</td>
<td>i, u</td>
<td>Up</td>
</tr>
<tr>
<td>6</td>
<td>stretch_l_cornerlip (MW)</td>
<td>Horizontal displacement of left lip corner</td>
<td>a, p</td>
<td>Left</td>
</tr>
<tr>
<td>7</td>
<td>stretch_r_cornerlip (MW)</td>
<td>Horizontal displacement of right lip corner</td>
<td>i, u</td>
<td>Right</td>
</tr>
<tr>
<td>4</td>
<td>lower_t_midlip (MNS)</td>
<td>Vertical displacement of top inner lip</td>
<td>q, r, s, t</td>
<td>Down</td>
</tr>
<tr>
<td>5</td>
<td>raise_b_midlip (MNS)</td>
<td>Vertical displacement of bottom inner lip</td>
<td>y, x, w, v</td>
<td>Up</td>
</tr>
<tr>
<td>51</td>
<td>lower_t_midlip_o (MNS)</td>
<td>Vertical displacement of top outer lip</td>
<td>b, c, d, e, f, g, h</td>
<td>Down</td>
</tr>
<tr>
<td>52</td>
<td>raise_b_midlip_o (MNS)</td>
<td>Vertical displacement of bottom outer lip</td>
<td>o, n, m, l, k, j</td>
<td>Up</td>
</tr>
<tr>
<td>61</td>
<td>stretch_l_nose (ENS)</td>
<td>Horizontal displacement of left side of nose</td>
<td>51,52,53,54,55,56,57</td>
<td>Left</td>
</tr>
<tr>
<td>62</td>
<td>stretch_r_nose</td>
<td>Horizontal displacement of right side of nose</td>
<td>58,59,60,61</td>
<td>Right</td>
</tr>
</tbody>
</table>
(ENS) displacement of right side of nose 1.62

<table>
<thead>
<tr>
<th>Expressions</th>
<th>FAPs no</th>
</tr>
</thead>
<tbody>
<tr>
<td>Happiness</td>
<td>Raise corner lip, stretch corner lip, lift cheek, mouth open 59,60,6,7, 41,42,4-,5-,51-,52-</td>
</tr>
<tr>
<td>Sadness</td>
<td>Lower corner lip, lower inner eyebrow, close eyelid 59-,60-,31-,32-,19,20</td>
</tr>
<tr>
<td>Disgust</td>
<td>Close eyelid, mouth open, stretch nose, raise corner lip 19,20, 4-,5,51-,52, 61,62,59,60</td>
</tr>
<tr>
<td>Surprise</td>
<td>Raise eyebrow, mouth open, open eyelid 31,32,33,34,35,36, 4-,5-,51-,52-,19-,20-</td>
</tr>
<tr>
<td>Anger</td>
<td>Open eyelid, lower eyebrow, squeeze eyebrow, mouth open 19-,20-,31-,32-,37,38, 4-,5,51-,52</td>
</tr>
<tr>
<td>Fear</td>
<td>Open eyelid, raise eyebrow, squeeze eyebrow, mouth open 19-,20-,31,32,33,34,35,36,37,38, 4-,5-,51-,52</td>
</tr>
</tbody>
</table>

Table 3. Facial expressions and FAPs

5. Animation

Once the expressions are modeled as described above, it is time to animate our character of interest. As mentioned earlier, we have used key-frame approach of animation. Every facial expression can be stored as key-frame by storing the values of parameters. After all key-frames are defined, animation can be created by generating intermediate frames. Intermediate frames are generated by interpolating the parameters values of successive key-frames. Our algorithm supports two types of interpolation: (i) Linear and (ii) Cardinal Spline. When number of key frames is more than two, with linear interpolation jerky and abrupt movement is observed at joint point of key frames but smooth animation is achieved with the help of non-linear animation (Cardinal Spline) [16]. Global animation of the face is of great importance in the implementation of facial animation when an animator manipulates a 3D face in terms of translation, rotation and zooming. We have rotated 3D model about three primary axes and our morphing algorithm automatically generate texture for rotated model. Same way 3D model is scaled to create effect of Zoom-in and Zoom-out.

6. Simulation results

The simulation results of model reconstruction from given frontal face image and generic 3d model are shown in Figure 5. Figure 6 shows the simulation result of model construction from given frontal image and Candide-3 generic model. Six basic expressions are generated once model is ready which is shown in Figure 8. Morphing between any two expressions are generated as shown in Figure 9. Figure 10 show the result of morphing between two different face models one with happy expression and other with angry expression. Figure 11 shows the result of morphing between two face models using linear interpolation. Result of eye animation, result of 3D rotation about three principle axes and result of Zoom-in and Zoom-out are shown in Figure 12, Figure 13 and figure 14 respectively. Figure 15 shows that expressions generated for one
person is mapped on the other person model. When key-frames are more than two non-linear interpolations give better result than linear interpolation. Non-linear interpolation does not retain values of adjacent key frames when these are equal. Figure 16 shows that one of the parameter values remains same during key frame 5 and 10 but Cardinal spline does not retain value. So we have modified Cardinal spline interpolation which dynamically make decision and retain value of parameters. Figure 16 shows the correct result for same. We have developed our algorithm in MATLAB and tested on PIV, 3 GHz, and 1GB RAM computer. The total time starting from feature detection to synthesis of image is 406msec for 512X512 images and 100msec for 128X128 images. In [4] time complexity is listed about 7 sec for 640X480 images on a 1.7GHZ PC. Our algorithm is faster than that in [4].

Figure 8. (A) Happy (B) Sad (C) Angry (D) Fear (E) Disgust (F) Surprise

Figure 9. Morphing between happy and angry expressions
Figure 10. Morphing between two different face models with different expressions

Figure 11. Morphing between A and B (linear interpolation)

Figure 12. Eye animation
Figure 13.  A) Zoom out \((S_x,S_y,S_z)=(0.8,0.8,0.8)\) (B) Zoom in \((S_x, S_y, S_z)=(1.1,1.1,1.1)\)

Figure 14.  (A) Rotation about x-axis (-10°) (B) Rotation about y-axis (-5°) (C) Rotation about Z-axis (-5°)

Figure 15.  Expressions Mapping
7. Conclusion

A 3D face reconstruction from single image is developed which is proved to be automatic, robust, fast and accurate. Our proposed algorithm constructing 3D face model using proposed generic model as well as using Candide-3 face model. Six universal expressions are generated with the help of MPEG-4 facial animation parameters. Our proposed morphing algorithm generates new expressions from the existing six basic expressions. Morphing result indirectly tell the accuracy of our algorithm because it only produce smooth result if features are properly align in the respective models. When number of key frames is more than two, with linear interpolation jerky and abrupt movement is observed at joint point of key frames. Smooth animation is achieved with the help of non linear interpolation. Combination of linear and non linear interpolation gives better result even though adjacent key frames retain value of parameters.

Acknowledgment

The authors would like thank to state university of New York at Binghamton for providing database BU-3DFE.
8. References


Authors

Narendra M.Patel received B.E. degree in electronics engineering from M.S. University, Baroda in 1993 and M.E. degree from M.S.University, Baroda in 1997. He is pursuing Ph.D. from SVNIT, Surat. He is currently Assistant Professor in Computer Engineering Department, B.V.M. Engineering College, V.V.Nagar, India. His research interests include Digital Image Processing, Real time operating systems and computer graphics.
Mukesh A. Zaveri received the B.E. degree in electronics engineering from Sardar Vallabhbhai Regional College of engineering and Technology, Surat, India in 1990, the M.E. degree from M.S. University, Baroda, India in 1993 and the Ph.D. degree in electrical engineering from the Indian Institute of Technology Bombay, in 2005. He is currently an Associate Professor in SVNIT, Surat. His current research interests include the area of signal and image processing, multimedia, sensor networks and wireless communication.