### List of Figures

<table>
<thead>
<tr>
<th>Fig. No.</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig. 2.1</td>
<td>Premise (for the partial data set {x_1-y} from Table 2-1) membership function on (x_1-y) plane</td>
</tr>
<tr>
<td>Fig. 2.2</td>
<td>(a) Data points plotted in (x_1-y), (x_2-y), and (x_3-y) space (b) fuzzy curves (y_1^o), (y_2^o), and (y_3^o)</td>
</tr>
<tr>
<td>Fig. 2.3</td>
<td>TS method of input selection</td>
</tr>
<tr>
<td>Fig. 2.4</td>
<td>Control action of an operator</td>
</tr>
<tr>
<td>Fig. 2.5</td>
<td>Model Performance vs Descending Order of (c_i) for Example 2.1 with noise free data</td>
</tr>
<tr>
<td>Fig. 2.6</td>
<td>Model Performance vs Descending Order of (c_i) for Example 2.1 with noisy data.</td>
</tr>
<tr>
<td>Fig. 2.7</td>
<td>Model Performance vs Descending Order of (c_i) for Gas furnace data (Example 2.2).</td>
</tr>
<tr>
<td>Fig. 2.8</td>
<td>Model Performance vs Descending Order of (c_i) for Human operation at a chemical plant (Example 2.3).</td>
</tr>
<tr>
<td>Fig. 2.9</td>
<td>Model Performance vs Descending Order of (c_i) for Daily price of a Stock market (Example 2.4).</td>
</tr>
<tr>
<td>Fig. 3.1</td>
<td>Membership function (\phi^k(y)) (white upper triangle and gray trapezoid) and (\phi^{*k}(y)) (only gray Trapezoid) corresponding to (B^k) and (B^{*k}) for the (k^{th}) rule of class II CRI-model.</td>
</tr>
<tr>
<td>Fig. 3.1A</td>
<td>Four classes of GFM under two types of T-norm (i.e. product and min) and S-norm (i.e., sum and max).</td>
</tr>
<tr>
<td>Fig. 3.2</td>
<td>Effect of (\nu_k) on overall defuzzified output.</td>
</tr>
<tr>
<td>Fig. 3.3</td>
<td>Ten input fuzzy membership functions generated by (\mu(x) = e^{-</td>
</tr>
</tbody>
</table>
Fig. 3.4. Different choices of consequent membership functions for the same centroid and area.

Fig. 3.5: GRBF network for normalized calculation.

Fig. 3.6: Generalized basis function network for non-normalized calculation.

Fig. 3.7: Results of Example 3.2 for (a) effect of $v_k$ on normalization of basis function (b) use of reactivation.

Fig. 3.8: Symmetry on error surface for three sets of values for $\sigma_k$'s and $l_k$'s over the span of $c_k$'s.

Fig. 3.9: Membership Function for Example 3.3.

Fig. 3.10: GRB Functions ---- unit 1-5 for Example 3.3.

Fig. 3.11: Initial Premise variable membership functions of Example 3.4.

Fig. 3.12: Final Premise variable membership functions for non-normalized network of Example 3.4.

Fig. 3.13: Final Premise variable membership functions for normalized network of Example 3.4.

Fig. 3.14: Learning pattern of normalized model (——) & non-normalized model (---) for Example 3.4.

Fig. 3.15: A comparative study of learning pattern of different models for Example 2.1-Example 2.4.

Fig. 4.1: Plots of (a) Average time/epoch ($T_{av}$) vs number of rules on linear scale (b) Logarithmic of average time/epoch ($T_{av}$) vs number of rules on linear scale (c) Natural logarithmic of average time/epoch ($T_{av}$) vs number of rules on linear scale (d) Average time/epoch ($T_{av}$) vs Decimal exponential of Number of rules on logarithmic scale.

Fig. 4.2: Initialization of membership functions (a) Lin method (b) proposed method.

Fig. 4.3: Grid points and data points in a normalized two-dimensional plot.
Fig. 4.4: Plots of (a) $J$ (b) $S$ (c) $SIC$ (d) $AIC$ for class I GFM for noise free data of Example 2.1 w.r.t. different number of RBF units with different methods of initialization of centers.

Fig. 4.5: Plots of (a) $J$ (b) $S$ (c) $SIC$ (d) $AIC$ for class II GFM for noise free data of Example 2.1 w.r.t. different number of RBF units with different methods of initialization of centers.

Fig. 4.6: Plots of (a) $y$ (solid line) and $y_o$ (dashed line) (b) model error for class I GFM for noise free data of Example 2.1 obtained from initialization of centers based on Modified Mountain clustering method with 3 RBF units.

Fig. 4.7: Plots of (a) $y$ (solid line) and $y_o$ (dashed line) (b) model error for class II GFM for noise free data of Example 2.1 obtained from initialization of centers based on Modified Mountain clustering method with 3 RBF units.

Fig. 4.8: Plots of (a) $J$ (b) $S$ (c) $SIC$ (d) $AIC$ for class I GFM for noisy data of Example 2.1 w.r.t. different number of RBF units with different methods of initialization of centers.

Fig. 4.9: Plots of (a) $J$ (b) $S$ (c) $SIC$ (d) $AIC$ for class II GFM for noisy data of Example 2.1 w.r.t. different number of RBF units with different methods of initialization of centers.

Fig. 4.10: Plots of (a) $y$ (solid line) and $y_o$ (dashed line) (b) model error for class I GFM for noisy data of Example 2.1 obtained from initialization of centers based on Modified Mountain clustering method with 3 RBF units.

Fig. 4.11: Plots of (a) $y$ (solid line) and $y_o$ (dashed line) (b) model error for class II GFM for noisy data of Example 2.1 obtained from initialization of centers based on Modified Mountain clustering method with 3 RBF units.

Fig. 4.12: Plots of (a) $J$ (b) $S$ (c) $SIC$ (d) $AIC$ for class I GFM of Example 2.2 w.r.t. different number of RBF units with different methods of initialization of centers.

Fig. 4.13: Plot of (a) $J$ (b) $S$ (c) $SIC$ (d) $AIC$ for class II GFM of Example 2.2 w.r.t. different number of RBF units with different methods of initialization of centers.
Fig. 4.14: Plots of (a) $y$ (solid line) and $y^0$ (dashed line) (b) model error for class I GFM of Example 2.2 obtained from initialization of centers based on Modified Mountain clustering method with 3 RBF units.

Fig. 4.15: Plots of (a) $y$ (solid line) and $y^0$ (dashed line) (b) model error for class II GFM of Example 2.2 obtained from initialization of centers based on Modified Mountain clustering method with 3 RBF units.

Fig. 4.16: Plots of (a) $J$ (b) $S$ (c) SIC (d) AIC for class I GFM of Example 2.3 w.r.t. different number of RBF units with different methods of initialization of centers.

Fig. 4.17: Plots of (a) $J$ (b) $S$ (c) SIC (d) AIC for class II GFM of Example 2.3 w.r.t. different number of RBF units with different methods of initialization of centers.

Fig. 4.18: Plots of (a) $y$ (solid line) and $y^0$ (dashed line) (b) model error for class I GFM of Example 2.3 obtained from initialization of centers based on Modified Mountain clustering method with 3 RBF units.

Fig. 4.19: Plots of (a) $y$ (solid line) and $y^0$ (dashed line) (b) model error for class II GFM of Example 2.3 obtained from initialization of centers based on Modified Mountain clustering method with 3 RBF units.

Fig. 4.20: Plots of (a) $J$ (b) $S$ (c) SIC (d) AIC for class I GFM of Example 2.4 w.r.t. different number of RBF units with different methods of initialization of centers.

Fig. 4.21: Plots of (a) $J$ (b) $S$ (c) SIC (d) AIC for class II GFM of Example 2.4 w.r.t. different number of RBF units with different methods of initialization of centers.

Fig. 4.22: Plots of (a) $y$ (solid line) and $y^0$ (dashed line) (b) model error for class I GFM of Example 2.4 obtained from initialization of centers based on Modified Mountain clustering method with 3 RBF units.

Fig. 4.23: Plots of (a) $y$ (solid line) and $y^0$ (dashed line) (b) model error for class II GFM of Example 2.4 obtained from initialization of centers based on Modified Mountain clustering method with 3 RBF units.
Fig. 5.1: Flow chart of Gradient Descent algorithm.

Fig. 5.2: A two-dimensional sketch of a search space depicts target islands $\zeta^*_i$, basins of attraction under local method L to those targets, $\beta_i$, and two types of dead zone, active and passive.

Fig. 5.3: Flow chart of a standard Genetic Algorithm.

Fig. 5.4: Flow chart of a hybrid of Genetic Algorithm and Gradient Descent.

Fig. 5.5: Number of innerloop as a function of outerloop_count.

Fig. 5.6: Cooling Schedule as a function of outerloop_count.

Fig. 5.7: $P_{accept}$ at different outerloop_count for different values of $\Delta J$.

Fig. 5.8: $P_{accept}$ at different temperature for different values of $\Delta J$.

Fig. 5.9: Band of $\Delta J$ at different temperature for $0.001 \leq P_{accept} \leq 0.99$.

Fig. 5.10: Initial membership functions for class II GFM rules, obtained from Modified Mountain clustering, for data 1 of Example 2.1.

Fig. 5.11: Final membership functions for class II GFM rules learned by GD, for data 1 of Example 2.1.

Fig. 5.12: Initial membership functions for class II GFM rules obtained from Modified Mountain clustering, for data 2 of Example 2.1.

Fig. 5.13: Final membership functions for class II GFM rules learned by GD, for data 2 of Example 2.1.

Fig. 5.14: Initial membership functions for class II GFM rules obtained from Modified Mountain clustering, of Example 2.2.

Fig. 5.15: Final membership functions for class II GFM rules learned by GD, of Example 2.2.

Fig. 5.16: Initial membership functions for class II GFM rules obtained from Modified Mountain clustering, of Example 2.3.
Fig. 5.17: Final membership functions for class II GFM rules learned by GD, of Example 2.3.

Fig. 5.18: Learning pattern of SA hybrid algorithm of Example 2.4.

Fig. 5.19: Initial membership functions for class II GFM rules obtained from fuzzy curve, of Example 2.4.

Fig. 5.20: Final membership functions for class II GFM rules learned by SA hybrid algorithm, of Example 2.4.

Fig. 5.21: Learning pattern of GA hybrid algorithm of Example 2.4.

Fig. 5.22: Final membership functions for class II GFM rules learned by GA hybrid algorithm, of Example 2.4.

Fig. 5.23: Plots of (a) $y$ (-----, solid line) and $y^o$ (-------, dashed line) (b) model error for class II GFM of Example 2.4 obtained from hybrid GA algorithm.

Fig. 6.1: A typical high conversion refinery.

Fig. 6.2: A Typical Reactor-Regenerator-Stripper Assembly.

Fig. 6.3: A typical FCC main fractionator circuit.

Fig. 6.4: Engineering & Operation Constraints of FCCU.

Fig. 6.5: Heat balance in Reactor Regenerator Stripper.

Fig. 6.6: Flow Diagram.

Fig. 6.7: Premise membership functions for class IGFMI rules, of $C_1(t)$ variable.

Fig. 6.8: Plots of (a) $y$ (-----, solid line) and $y^o$ (-------,dashed line) (b) model error for class II GFM of $C_1(t)$.

Fig. 6.9: Premise membership functions for class II GFM rules, of $C_2(t)$ variable.

Fig. 6.10: Plots of (a) $y$ (-----, solid line) and $y^o$ (-------,dashed line) (b) model error for class II GFM of $C_2(t)$. 

xviii
Fig. 6.11: Premise membership functions for class II GFM rules, of $C_3(t)$ variable.

Fig.6.12: Plots of (a) $y$ (———, solid line) and $y^o$ (---------,dashed line) (b) 
model error class II for GFM of $C_3(t)$

Fig. 6.13: Premise membership functions for class II GFM rules, of $C_4(t)$ variable

Fig.6.14: Plots of (a) $y$ (———, solid line) and $y^o$ (---------,dashed line) (b) 
model error for class II GFM of $C_4(t)$.

Fig. 6.15: Premise membership functions for class II GFM rules, of $C_5(t)$ variable

Fig.6.16: Plots of (a) $y$ (———, solid line) and $y^o$ (---------,dashed line) (b) 
model error for class II GFM of $C_5(t)$.

Fig. 6.17: Premise membership functions for class II GFM rules, of $C_6(t)$ variable

Fig.6.18: Plots of (a) $y$ (———, solid line) and $y^o$ (---------,dashed line) (b) 
model error for class II GFM of $C_6(t)$.

Fig. 6.19: Premise membership functions for class II GFM rules, of $C_7(t)$ variable

Fig.6.20: Plots of (a) $y$ (———, solid line) and $y^o$ (---------,dashed line) (b) 
model error for class II GFM of $C_7(t)$.

Fig. 6.21: Premise membership functions for class II GFM rules, of $C_8(t)$ variable

Fig.6.22: Plots of (a) $y$ (———, solid line) and $y^o$ (---------,dashed line) (b) 
model error for class II GFM of $C_8(t)$.

Fig. 6.23: Premise membership functions for class II GFM rules, of $C_9(t)$ variable.

Fig.6.24: Plots of (a) $y$ (———, solid line) and $y^o$ (---------,dashed line) (b) 
model error for class II GFM of $C_9(t)$.

Fig. 6.25: Premise membership functions for class II GFM rules, of $C_{10}(t)$ variable.

Fig.6.26: Plots of (a) $y$ (———, solid line) and $y^o$ (---------,dashed line) (b) 
model error for class II GFM of $C_{10}(t)$.

Fig. 6.27: Premise membership functions for class II GFM rules, of $M_1(t)$ variable.
Fig. 6.28: Plots of (a) $y$ (———, solid line) and $y^o$ (-------,dashed line) (b) model error for class II GFM of $M_1(t)$.

Fig. 6.29: Premise membership functions for class II GFM rules, of $M_2(t)$ variable.

Fig. 6.30: Plots of (a) $y$ (———, solid line) and $y^o$ (-------,dashed line) (b) model error for class II GFM of $M_2(t)$.

Fig. 6.31: Premise membership functions for class II GFM rules, of $M_3(t)$ variable.

Fig. 6.32: Plots of (a) $y$ (———, solid line) and $y^o$ (-------,dashed line) (b) model error for class II GFM of $M_3(t)$.

Fig. 6.33: Premise membership functions for class II GFM rules, of $M_4(t)$ variable.

Fig. 6.34: Plots of (a) $y$ (———, solid line) and $y^o$ (-------,dashed line) (b) model error for class II GFM of $M_4(t)$.

Fig. 6.35: Premise membership functions for class II GFM rules, of $M_5(t)$ variable.

Fig. 6.36: Plots of (a) $y$ (———, solid line) and $y^o$ (-------,dashed line) (b) model error for class II GFM of $M_5(t)$.

Fig. 6.37: Premise membership functions for class II GFM rules, of $M_6(t)$ variable.

Fig. 6.38: Plots of (a) $y$ (———, solid line) and $y^o$ (-------,dashed line) (b) model error for class II GFM of $M_6(t)$.

Fig. 6.39: Premise membership functions for class II GFM rules, of $M_7(t)$ variable.

Fig. 6.40: Plots of (a) $y$ (———, solid line) and $y^o$ (-------,dashed line) (b) model error for class II GFM of $M_7(t)$.

Fig. 6.41: Premise membership functions for class II GFM rules, of $M_8(t)$ variable.

Fig. 6.42: Plots of (a) $y$ (———, solid line) and $y^o$ (-------,dashed line) (b) model error for class II GFM of $M_8(t)$.

Fig. 6.43: Premise membership functions for GFM class II rules, of $M_9(t)$ variable.

Fig. 6.44: Plots of (a) $y$ (———, solid line) and $y^o$ (-------,dashed line) (b) model error for class II GFM of $M_9(t)$.
Fig. 6.45: Premise membership functions for class II GFM rules, of $M_{10}(t)$ variable.

Fig. 6.46: Plots of (a) $y$ (solid line) and $y^o$ (dashed line) (b) model error for class II GFM of $M_{10}(t)$. 