Estimation of Fat in Fresh Milk through Adaptive Neuro-Fuzzy Inference System

CHAPTER – 02

Literature Review
1. Literature survey – Fat detection in milk:

Milk is looked as main food as it contains fat, protein and other various minerals and vitamins. Relatively detecting fat and protein content in milk would decide the quality of milk. Normally milk consist almost 90% of water and rest of nutritional elements including fat and protein. The fat content in milk is measured using ultrasonic technique. Ultrasound signal is made to pass through the milk sample under controlled temperature condition. The velocity and attenuation of signal is measured, that are found to be linearly varying with fat content in milk sample. The detection of fat content in milk strongly depends on milk sample temperature. Its needs to be controlled precisely or it becomes a bottleneck for the accuracy of the reading taken. Ultrasonic method finds better results for detection of fat content in milk considering variations in temperature [1]. The distribution of milk fat globule can be observed in figure 2.1 at 15°C and in figure 2.2 at 40°C.

![Microscopic picture of fat content at 15°C](image)

Figure 2.1: Microscopic picture of fat content at 15°C [1]
As the variations in the temperature of milk sample under test increases, the accuracy of fat content detection is affected. A algorithm namely WPNOSC-NPLS is proposed in [2], to reduce the effect of temperature variations on the measurement of fat content. The algorithm constructs three dimensional (3D) spectra, that is spilt into different frequency components using wavelet packet transform. The calibration of system is done by N-way partial least square (NPLS) algorithm. Milk samples are tested at various temperatures, to observe effectiveness of algorithm. By applying WPNOSC-NPLS algorithm, the prediction ability can be improved considering variations in temperature.

The visible and near infrared spectrometry can also be applied to measure fresh milk parameters like fat, lactose and protein. An excitation light source, capable of producing continuous spectrum of wavelength from 400nm to 1100nm is used. LED and photodiodes can be used cost effectively for generation and light detection. [3] have proposed VIS-NIR spectrometry with Partial Least Square method to forecast total fat, total lactose and total protein contents in fresh milk.
The method can be applied for on-line estimation of the milk components, as it uses un-homogenized fresh raw milk without any diluting agent or pre-treatment on raw milk. Here the author have implemented VIS-NIR system for on-line estimation of fat and other components in milk, without considering variations in the temperature of milk sample on the estimated values. The figure 2.3 shows the detail procedure adopted to sample and analyze given milk sample.

Figure 2.3: Procedure adopted for sampling and analysis of sample milk [3]
The surface acoustic wave (SH-SAW) finds better application in analysis of liquid samples such as water, orange juice and milk. The device is fabricated using two lines: one is metalized and shielded and second is left electrically active. The study of temperature dependency, sensitivity and mass loading is carried out. System identifies separately the above mentioned liquids. All the experiments are conducted under controlled temperature for three of the liquids namely milk, orange juice and water. The analysis of principal components is done and its discrimination is shown in figure 2.4. After these tests, the milk containing 4% fat, the semi – skimmed milk containing 2% fat and the skimmed milk containing no fat where tested and its discrimination is shown in figure 2.5. Finally the milk samples were tested for continuously for 5 days and the measurements for same are depicted in figure 2.6. Initially DI-water is tested in 11 different steps by incrementing liquid loading of 10µl each time. The different fat content milk samples are tested with controlled temperature and dilution test is also carried by adding distilled de-ionised water in milk sample. The test shows linear dependency with temperature and fat content in milk samples [4].

![Figure 2.4: Discrimination of full milk, orange juice and water components [4]](image-url)
Figure 2.5: Discrimination of full milk, semi-skimmed milk and skimmed milk components [4]

Figure 2.6: Effect ageing on milk sample [4]
Milk fat content and the protein content can be represented by laser light scattering theory. The real time system implemented gives satisfactory results as per the requirements of dairy. Almost 50 samples are tested under controlled pressure, equipment temperature maintained at 40°C and compared with conventional methods based on Rose-Gottlieb and Kjeldahl determination of N method. The fat content is determined by curve fitting technique and protein content is determined by surface fitting technique. The figure 2.7 indicates changes occurred due to scattered – transmitted ratio for four different homogenization temperatures. The maximum suitable temperature can be kept upto 40°C, beyond which protein gets denatured. The method seems to be simple and directly applied for determination of fat and protein content in milk [6].

Figure 2.7: At different temperature changes occurred by scattered – transmitted ratio [6]
The near and mid range infrared spectroscopy technique is used to measure fat content in milk powder [11]. The fat content is determined based on infrared spectral transmission value using least-squares support vector machine (LS-SVM). System shows better prediction coefficient for LS-SVM model and root mean square error. There are three absorptions in Near-Infrared spectral curves. One arises from fat, other represents vibration of protein. The short-wave near-infrared spectroscopy has the capability to determine fat of milk powder. The 800nm - 1025nm NIR spectra is implemented and performance of least-square support vector machine (LS-SVM) and partial least squares are determined. The content determined founds better results at 900nm, 928nm, 990nm and 1018nm wavelengths [66].

Majority of dairy industries use infrared spectrometers that are too expensive. It is not possible for small scale dairy industry or a farmer to use this technique to analyze milk content. A cost effective technique is proposed in [12] that uses electromagnetic sensing. Planer electromagnetic sensors of mesh configuration and meander configuration as shown in figure 1.8 are operated with radio frequency excitation. Using the experimental setup the impedance (ohm) of water, juice, oil, yoghurt and milk is measured. The material under test acts as a dielectric materials that affects on the value of transfer impedance. Results shows the compositions of dairy products can be determined using electromagnetic sensor technique.

Ultrasound can also be applied for milk sterilization and pasteurization. The ultrasonic irradiation is made oscillate at frequency of 22 KHz that consumes 90W, 120W and 150W. Pasteurization takes place after the period of 11min, 6min, or 7min with respect to the power 90W, 120W and 150W. By increasing the power of ultrasound and reducing the volume of processed milk, the pasteurization and sterilization can be achieved in less duration [13].
The densitometer based on resonant frequency can be used to determine fat content in milk. Hydrochloric acid is used to decompose the given milk sample and the fat content is estimated with hexane. The principle based on resonant frequency U-tube oscillation that allows precise density analysis of milk sample. The fat content in milk sample changes with respect to density. This method can also be applied to determine fat content in cream and cheese [20].

The real-time monitoring of breeding of cow and diagnosis of problems related performance is presented in [67]. The measures of intervening time from calving, interval of milk production, peak of lactation occurs after calving, record of pedigree, etc. The information management system is designed with form of two-dimensional and three-dimensional data storage.
2. Literature survey – Fuzzy Logic Control:

The Fuzzy control is the most emerging, active and successful areas that have implemented various applications of fuzzy set theory since several decades. The research of Mamdani, motivated by Zadeh implemented control system applications using Fuzzy Logic Control (FLC). Fuzzy logic is based on the human thinking and natural language. It provides the effective means to correlate the human thinking with the real time process control, apart from conventional controllers that relate logically. The FLC converts expert knowledge into linguistic control form to get the control action of a process control type applications or other. The FLC consist of Fuzzification, Knowledge, Decision making, and Defuzzification blocks. These blocks are further connected to the process that has to be controller. The inputs from sensors or instrumentation circuit are connected to fuzzy system by converting crisp values into linguistic form. These fuzzified values are inputed to decision making logic that is known as kernel of an FLC. The decision making logic is capable to mimic human decision into fuzzy concepts. Defuzzification scales the output values provided by decision making block into corresponding universes of discourse.

The experts knowledge is implemented in form of set of linguistic rules. Thus expert knowledge can be represented as:

IF (a set of conditions are satisfied) THEN (a set of consequences can be inferred)

The primary part of IF-THEN rule is antecedent and later part is termed as consequent that are related to fuzzy linguistic terms, know as fuzzy conditional statements. Figure 2.9 represents the membership functions for speed having linguistic terms as slow, medium and fast. The membership functions can be tuned coarsely or finely as shown in figure 2.10. In some of the cases there may be several linguistic variables in antecedents and consequents. These systems can
be characterized in multi-input-multi-output (MIMO) or multi-input-single-output (MISO).

\[ R_1: \text{if } x \text{ is } A_1 \text{ and } y \text{ is } B_1 \text{ then } z \text{ is } C_1, \]

\[ R_2: \text{if } x \text{ is } A_2 \text{ and } y \text{ is } B_2 \text{ then } z \text{ is } C_2, \]

\[ \ldots \ldots \]

\[ R_n: \text{if } x \text{ is } A_n \text{ and } y \text{ is } B_n \text{ then } z \text{ is } C_n. \]

Numerical and functional are the two ways of defining membership function of primary fuzzy set to find universe of discourse. For deciding the optimum number of fuzzy control rules, there is no any standard method available. All it depends on how the experts knowledge is incorporated in fuzzy if-then rule base to achieve better performance [47].

Figure 2.9: Triangular membership function for speed with linguistic terms slow, medium and fast [47]
As it is seen in above paragraph, in FLC the knowledge of skilled operator is to be framed in fuzzy logic decision making. The mapping of human decision making into fuzzy if-then rule base plays an important role (figure 2.11). Different fuzzy implication functions are discussed by various researchers. The fuzzy implication functions can be categorized in three ways: fuzzy conjunction, fuzzy disjunction and fuzzy implication. In Triangular Co-Norms are associated with union, algebraic sum, bounded sum, drastic sum and disjoint sum. The Defuzzification methods employed are: The Max Criterion Method, The Mean of Maximum Method (MOM) and The Center of Area Method (COA) as shown in figure 2.12 [48]. Also the various applications are discussed in forth coming paragraphs.
The control problem can be defined for a given process or plant and knowledge about the plant operation. Control system is designed to achieve plant goals without violating its constraints. In a normal procedure the plants control system is designed using mathematical modeling that includes various plant
related control parameters. Designers find difficult to cast these parameters control the plant by means of control strategies such as PI or PID. This approach of problem solving includes numeric or logical information collected from the process. If the operation of a given plant and its constraints are known, then control problem can be solved using FLC framework [19]. The fuzzy systems implemented in control are based on “reasoning” and “universal function approximator”. The knowledge base from the plant operator can be implemented in fuzzy rule-base to the goals of the plant. Again the number of rules for a control problem depends on the number of variables. There is no straight forward strategy to decide number of rules, as they go on increasing with variables or membership functions. Normally implementers choose to have two membership functions. Based on the system the fuzzy rules can be tuned that performs satisfactorily.

The nonlinear systems that find continuity can be implemented in fuzzy linear model. Takagi-Sugeno (T-S) fuzzy model can be expressed in the form to implement non-linear system. The given problem is implemented in fuzzy logic by triangulation method [21].

In few of the cases the defined fuzzy rules may not perform satisfactorily. It can be considered that the designed rules need refinement. The [25] proposes a fuzzy rule refinement scheme based on maximizing fuzzy entropy on training set. Insufficient training data and limitations of rule extraction etc are the uncertain factors that affect fuzzy if-then rules extraction. The testing accuracy is increased by 6%, the rules average testing accuracy value is 0.68 before refinement and 0.74 after refinement. Two approaches are compared: the proposed approach entropy-maximum-based and previously available approach training error-reduction-based (GA). By maximizing the fuzzy entropy, the uncertainty information lost in classification process can be sufficiently utilized.

Fuzzy logic system is capable of handling numerical data and linguistic knowledge simultaneously. It maps nonlinear input data vector into scalar output. The objective knowledge can be formulated in traditional mathematical modeling
and subjective knowledge that is in linguistic form, is difficult to represent in traditional way as shown in figure 2.13. It is possible to have various ways of mapping input – output. The crisp numbers are mapped into fuzzy sets by fuzzifier. Using fuzzy sets or linguistic values fuzzy rules are activated, which are associated with them. Fuzzy inference engine maps fuzzy sets to fuzzy set. As per the applications requirement the output fuzzy set is mapped into crisp numbers known as defuzzifier. Feedforward neural networks and Fuzzy logic System can solve similar engineering problems [60].

![Diagram of linguistic terms for two different categories](image)

Figure 2.13: Representation of linguistic terms for two different categories [60]

Conventional fuzzy control consist two-term: the Fuzzy-Proportional-Derivative type control; Fuzzy-Proportional-Integral type control and fuzzy three-term control: Fuzzy-Proportional-Integral-Derivative type control. The system works on incremental control output from error, change in error. The simulation results of different order models are presented showing better performance related to new design methodologies as shown in figure 2.14 [62].
The different rules form Fuzzy Inference that plays an important role in the fuzzy logic based applications. The various fuzzy inference methods are tested on applications and found to be giving better performance. The equivalence study of these methods is carried out by knowing their antecedent part and consequent part of rules. The fuzzy function, weight, and compatibility function are introduced in fuzzy inference consequent part [35].

The stability and controllability of system is important fundamental problems studied in fuzzy control system. The final state cannot demand to be achieved exactly by classical approach. Hence, the final state is possible to achieve upto certain extent using some allowable controls. If the fuzzy control system reaches close enough to its final state $X_f$ from a initial state $X_0$ through a sequence of controls is said to be soft controllable. Algorithm based on Liapunov-like approach is proposed to find the set of controls. This method of soft
controllability can be applied to single or multi-dimensional fuzzy control systems [44].

The unknown parameters that model uncertainty used for fuzzy intervals membership functions. The classical interval can replaced with fuzzy in fuzzy sequencing problems. The general framework is proposed in [36] that deal with uncertainty parameters in sequencing problems. The likely values of interval uncertainty and parameters are collected from decision maker. The trapezoidal fuzzy interval can be modeled for fuzzy parameter.

The fuzzy system includes numbers, words and perceptions related to forms of data that has varying intensity of imprecision. The least imprecision is found for traditional approach of mathematical modeling technique. The industry problems can be categorized in type-1 fuzzy approach or type-2 fuzzy approach. It finds difficult to define a given industrial problem either in traditional approach type-1 or type-2 fuzzy approach. Once the theory behind fuzzy logic is understood, it can be applied to wide range of applications and the future work can be carried out in fuzzy logic, neural network and genetic algorithms. The existing or old techniques can be replaced with novel or new techniques that fulfil the requirement of industrial problem [59].

Temperature control is a key factor in various engineering, biological and other industry and non-industry applications. [27] describe one of the application that controls temperature of water using level sensor and temperature sensor. The whole control system is simulated in Fuzzy Tech Pre-compiler. System consist of water tank, sensor and signal conditioning with ADC-DAC, heater with switching device and the Fuzzy Logic Controller. Fuzzy controller is embedded with if-then rules and the various membership functions.

In the real life circumstances actual execution sequence depends on external event. The conditional temporal problem lead by a situation for which the solutions opt and in future if the situation changes, the solution built online must rely on past observations. Here [30] have proposed the algorithm that provides
temporal uncertainty and preferences. The algorithm is tested softly and needs to be proven for practical applications.

A fuzzy-logic controller is designed and implemented for solar-power air-conditioning system using two-input / two-output (TITO) variable structure i.e. Multi-Input / Multi-Output (MIMO) system. The system controls two motors. The two inputs to the fuzzy system are control voltages applied to motors and outputs are rotational speeds of two motors. A hybrid controller is designed to control TITO. The two single-input / single-output (SISO) fuzzy systems are firstly developed and later on both are coupled together. The fuzzy data is loaded into microcontroller in the form of matrix. This MIMO system is tested on the experimental setup and measured against step-input response. The results show improvement in the performance of mixed fuzzy control strategy. The hybrid system designed requires more memory space for fuzzification and defuzzication and additional computation too. Apart from this it is easy to design and implement Fuzzy Logic Controller that improves the overall performance of the system depicted in figure 2.15 [33].

The self-extracting rules fuzzy control (SERFC) method is simulated with multi-variable to nonlinear system. The system maintains constant temperature in chamber using air system and hot-water system. Based on each chamber temperature separate z-transfer function is derived considering supply air system and hot-water system. The 2-order type and 3-order type system models are compared and its model outputs and test results are presented shown in figure 2.16. From the control loops designed LP-2 and LP-5 founds to be performing satisfactorily giving smaller overshoot. Fuzzy rules extracted by using SERFC method are also capable of giving proper and satisfied control performance. Proposed system deal with the complex thermal processes, that is difficult to model. This process complexity is overcome by SERFC method [41].
Figure 2.15: The system response for SISO and TITO step input [33]
The temperature of methacrylate batch polymerization reactor, overhead composition of batch distillation column and evaporating and condensing of refrigeration system is controlled by designing fuzzy algorithms. If-then fuzzy rules are formed for a particular system using PID-fuzzy controller. The error and change-in-error are two input linguistic variables, which are AND together for PI-fuzzy rule set and PD-fuzzy rule set termed as PID-fuzzy control structure. This, so designed PID-fuzzy system is tested for different temperature based applications. In order to obtain appropriate membership functions process reaction curve procedure is carried out for input-output linguistic variables of refrigeration system and batch reactor process. The PID-fuzzy controller designed for respective applications where compared with the conventional PID temperature controller. The PID-fuzzy temperature controller keeps the polymerization reaction temperature closer to the set-point as that of conventional PID
temperature controller. In all PID-fuzzy provides better performance compared with conventional PID controllers [24].

Fuzzy Logic Control system is implemented and tested to control pressure and liquid levels in the crude oil separation gas-liquid ratio (GLR) [31]. Fuzzy logic controllers are proven to be performing better for complex, nonlinear, or uncertain type of applications. The training membership function between [-3 3], i.e. negative big to positive big are used to implement knowledge based fuzzy logic controller. In various crucial operating situations, different operators may take different decisions which will affect the performance of the system. Hence while implementing or automating a system expert knowledge must be extracted finely and accordingly FLC can be designed. The conventional control system are found unsuitable for such kind of applications, as that of FLC which provides a way to translate the operators experience into rule based knowledge. Also the FLC control system finds difficulty at extreme parameter values, adaptive controller provides the solution for such kind of control behavior.

Photosynthesis of plant is temperature dependent and its heat tolerance is measured by chlorophyll fluorescence measurement. Here the heat tolerance of plant is estimated using Fuzzy Bicluster Regression (FBCR). The heat tolerance data is uncertain or has fuzziness factor, due to which conventional method of estimating heat tolerance is unable to capture this uncertainty. Proposed FBCR has capability to overcome the drawback in traditional method and is suitable, gives better results when compared. Fuzzy heat tolerance of plants and fuzzy intersection set is derived by fuzzy bicluster regression analysis with genetic algorithms. Most of the problems faced by traditional method are resolved using this method. The analytical treatment and experimentation carried out is presented in [22].

Another interesting application and implementation of Fuzzy Logic is Fuzzy Logic Power System Stabilizer (FLPSS). The fuzzy and PID stabilizer parameters are optimized by genetic algorithm. Design of FLPSS is validated by applying various disturbances to the system. This designed fuzzy system is
simulated in MATLAB and compared conventional PID method. Simulation results show better performance as that of PID Power system Stabilizer (PIDPSS). Both the systems (FLPSS and PIDPSS) where implemented in Real-Time Windows Target toolbox MATLAB software. A laboratory model of 1 KVA is setup with transmission lines [14].

Fuzzy Logic Controller is implemented on FPGA using VHDL is presented in [18]. The fuzzy logic controller is designed considering two input and one output system. The two inputs to the system are error and change-in-error and a control output is generated accordingly. Triangular membership functions are used and at a given instant maximum 4 rules are active. Weighted average determines the defuzzified output sets. A 10 MHz clock speed FPGA with 8-bit input and 8-bit output fuzzy controller is firstly implemented as open loop. The system is simulated in MATLAB and implemented in laboratory. The results of both simulation and FPGA implementation found to be closer to each other.

A high level description implemented on FPGA using VHDL finds different applications in electronics. The natural language and the operators knowledge is converted into high level description language VHDL. Also it proves a better cost performing method. Triangular member functions are defined in VHDL through programming. Different architectures are modeled and analyzed using VHDL in [23].

Light tracking system based on two DC motors drive with the help of two sound cards attached to PC, implemented to operate webcamra. To track proposed light spot the angles of camera panel with two different Fuzzy Logic Controllers are designed. Both of the DC motors are controlled by pulse-width-modulation (PWM) technique. Depending on the width of pulse the DC motor is controlled and accordingly power consumption is reduced. The x-axis and y-axis coordinates are considered to make the movement of the camera panel [28].

Fuzzy Logic model is effectively proposed by Takagi and Sugeno to implement nonlinear type of systems. Linear type of input-output relationship is
used to represent respective rule. The modified Takagi and Sugeno model is tested and verified on a power plant simulation. To obtain static output and dynamic parameters every time the sample data is refreshed. As the proposed model results are based on simulation experiments, it needs further refining for on-line fuzzy identification [34].

Fluid level control system is implemented using fuzzy logic controller with the help of Supervisory Control and Data Acquisition (SCADA) and Programmable logic Controller (PLC). The membership function parameters are designed with MATLAB programming. The liquid level controller is simulated and compared with experimental model, similar results are obtained except some minor differences of actuator position [37].

A traffic light system is designed based on Fuzzy Logic Control that operates on traffic density. The red light waiting time is adjusted according to the density of traffic on the respect lane. The micro-controller based system take into account the number of vehicles on the lane, type of vehicles indicating its length such as bus, minibus, car etc. and gap between the vehicles. The multiple micro-controllers generates triggering signal to each other for the operation. The Fuzzy Logic Controller with two inputs and two outputs is designed to control red and green light waiting time. FLC controls the timing of two arteries primary and secondary. If the primary main artery is having 50s of green light, then secondary will have 50s of red light waiting time and so on. The performance of FLC system is compared with conventional system with respect to vehicle data. Almost 48% to 66% of superiority is observed as that of conventional control system [42].

Microprocessor based servomotor control is designed using Fuzzy Logic algorithm in [45]. The output of driver unit is controlled by fuzzy control system. The shaft of servo motor is rotated in accordance with setpoint. Rotations of the motor shaft are adjusted with respect to error between set point and current position of shaft and change-in-error. Out of various stages, six rules are described that controls the motor shaft rotations using training membership functions. The system is simulated and compared with PI and MRAC type of
conventional controllers and digital type of controllers, fuzzy controller is found to be better performing than other controllers as shown in figure 2.17. Also different issues related to fuzzy controller such as shape of membership function, minimum or maximum overlap of these membership functions is raised that affects the overall performance of the system.

Figure 2.17: The simulation result for PID controller, MRAC and Fuzzy Logic controller [45]
Fin position servo system (FPSS) of missile can be controlled by Fuzzy Logic Controller. Two point crossover and mutation operators are used for Genetic Algorithm with population size of 30. The system is simulated and several crossover and mutation probabilities are compared. The nonlinearity due to hydraulic system is overcome using proposed GA. It is fast and accurate in sense of tracking response [65].

The stability of fuzzy controller is measured fuzzy control designed with sliding modes. The phase plane of error and change-in-error is divided into nine operating regions to determine relation between fuzzy control and Variable System Structure (VSS). With differential geometric method the features of sliding mode theory is described for a single input nonlinear system. The designed fuzzy system is tested on motorcycle integrated system that is considered as nonlinear. The inverted pendulum hinged to rotating disk which represents cornering motion of motorcycle, using this a rider leans to maintain stability. Different cases are presented with various inverted pendulum angle and angular velocity. There is a consequence in stability control and handling control that contradict each other [63].

A cell state space algorithm is proposed to automatically fine tune the output function parameters of fuzzy logic. The antecedent means ‘if’ part deals with fuzzy logic control rule over which the rule operates and ‘then’ part the action to be taken by controller. In the different operating regions the system behaves differently and accordingly output actions are taken. It is found to be difficult for human expert to accurately specify consequent part of the control rule [54].

Still the industry is using PI, PD and PID controllers, as they are simple in structure, easy to design and have good performance at acceptable cost. These controllers may not give satisfactory performance for nonlinear control system problems. The solution is to have PI-FCs, PD-FCs and PID-FCs, implemented with some well defined conditions or with variable gains. Sliding mode fuzzy control improves the stability and robustness related to fuzzy control system. The
adaptation of membership function on universe of discourse is achieved by adaptive fuzzy control. Fuzzy Logic control demands model free design of control problem as that of conventional methods go through mathematically designed model. Various industrial applications that are reported contain both mathematics and model based approach [50].

Fuzzy Logic based applications are found to be increasing in the industry. Number of applications has increased in fuzzy set theory in production and operation management. In few of the applications a particular fuzzy technique is used. The implementation of different fuzzy control technique is mostly through programming languages like C/C++/Turbo C/Visual C and rest of prefer the advanced technique using MATLAB. Specific fuzzy logic based software package is not found to be developed for production and operation management applications [52].
3. Literature survey – Neuro–Fuzzy System:

Adaptive Neuro Fuzzy Inference System is the fuzzy based model that has ability to enhance ANN learning based on priori knowledge. ANFIS can construct a fuzzy inference system (FIS) whose membership function parameters are tuned using either a backpropagation algorithm alone with the help of input-output data[51]. Thus in this way the fuzzy system can optimize the membership function.

For the development of intelligent control system neural network technique is widely prepared. The neural network technique firstly learns the given model before it is actually used. As that of fuzzy logic controllers the neural network embedded fuzzy technique needs the prior knowledge regarding the dynamics of control system. The neural network is trained offline using multilayered backpropagation to control temperature of a water bath. The designed system is compared with traditional one. The experiments were conducted in three different steps with 100 samples, 30s sampling time and 50 min duration. Neural network controller was able to follow the reference as that of PI traditional controller. Once trained initially based on input-output properties the neural network controllers are not needed to re-tune [5].

The multilayered neural network can be applied when conventional approach of problem solving is not that effective. The human and machine takes the similar type of control actions. Human makes used of sensory information to take the decision. The man made controllers are based on the input-output data of system. Here an example of conversion from polar coordinates (r, θ) to Cartesian coordinates (x, y) is demonstrated. Two-layered architecture having two inputs and a fixed unity input, 10 hidden neurons and two output neurons is designed. The practical control application may provide adequate performance and allows the designer to train the network over operational range of plant [7].
The neural network technique is widely used for solving nonlinear type of control problems. The system dynamics are learned through multilayered neural network and then applied to actual dynamic system. The example of “truck backer upper” is presented of which the neural network controls steering of trailer truck while baking up to loading dock. A two layered neural network implemented to present truck and trailer emulator [8].

The hybrid learning system known as Adaptive Network Based Fuzzy Inference System (ANFIS) can be designed, that makes use of input – output pairs of data and fuzzy rules based on human knowledge. Fuzzy if-then rules are employed without precise quantitative analysis. The ANFIS consist of interconnected nodes through the directional links. This architecture uses feedforward network, each node is assigned particular parameters. The node performs specific operation on input signal and weighed output is generated. Five different layers are defined right from input node function to the overall output node. Proposed ANFIS structure can refine fuzzy if-then rules described using input-output behavior of the complex system [9].

P, PI and PID controllers are more popular in industrial applications due to their simplicity in modeling. Apart from classical control, the hybrid technique such as Neuro-Fuzzy can be implemented to control water temperature. Triangular membership functions with very small, small, medium, large and very large linguistic terms are used. The experimental setup includes PC with 12 bit ADC-DAC system and heater assembly. In comparison with conventional controllers the proposed system is found to be performing better in setting time, rise time and overshoot [10]. The system response are presented in figure 2.18 for 78°C and figure 2.19 for 55°C.
Dynamic Evolving Neural-Fuzzy Inference system (DENFIS) is another hybrid technique that implements adaptive online and offline learning. The
The proposed system makes use of \( m \) highly active fuzzy rules that are composed on Takagi-Sugeno fuzzy inference system. Both DENFIS online and offline models are validated on various practical applications and compared with existing techniques like RAN, ESOM for online learning and ANFIS and MLP for offline learning [16].

Flexible neuro-fuzzy inference system (FLEXFIS) based on input-output data is suitable for problem solving. The parameters of membership functions are learned for the Mamdani type system and logical type system. 11 different simulations are carried out at a known benchmark and designed in the same fashion. Here, Mamdani-type systems are found to be suitable for approximation type of problems and classification type of problem can be resolved using logical approach [17].

Mamdani-type neuro-fuzzy structure is suggested with rough fuzzy sets and also the rough neuro-fuzzy classifier is derived. Using traditional classification method control problem having limited knowledge can be solved. In practical cases the information available may be insufficient to define the problem. Two theorems: Rough Fuzzy Set in Real Number Universe and Rough Cartesian Product Fuzzy Set in Real Number Universe are discussed with example. Proposed architecture has the capability to work with insufficient input vector values [26].

The different adaptive fuzzy controller methods have been studied that are based on feedback linearization and tracking error based adaptive laws. Experimental results are compared with respect to these adaptive fuzzy control methods of its tracking performance. The linear adaptive controller, indirect adaptive fuzzy control with standard adaptive laws, indirect adaptive fuzzy control with the composite adaptive laws and indirect adaptive fuzzy control with the proposed composite adaptive laws are tested for the practically implemented electro-mechanical system with generator load [29].
The classical approach finds difficulty in resolving industrial problem such as the modeling and implementation of electric arc furnace. The availability of precise data or completeness of data generates need of intense treatment and filtering of data. Here fuzzy neural network can be employed to predict the final temperature of furnace. The neural network is used as classifier and triangular membership function is implemented. The energy can be saved and the plant process is optimized with the help of on-line estimation of tap temperature which is monitored by operator [32].

The vertical ground source heat pump (VGSHP) systems performance is measured by ANN and ANFIS. The R-22 is used as refrigerant having three U-tube ground heat exchanger placed at 30 m, 60 m and 90 m boreholes with 150 mm diameters. With the same input variables Pola-Ribiere Conjugate Gradient algorithms, ANN, Multi-layered Perception method, ANFIS, Scaled Conjugate Gradient, model were designed and compared for different membership functions [38].

To reduce training time zeroth order Takagi-Sugeno-Kang (TSK) based fuzzy neural network is implemented on graphic processor unit. ANFIS is successfully implemented in various applications of engineering. Single processor may consume large amount of processing time to process the large input data sets. The parallel processing approach can be applied to overcome this problem that uses graphic processor embedded with multiple processors. The CUDA is used to implement parallel algorithms on NVIDIA graphic processor unit. The block partitioning is done and the generated threads are feed in parallel. Experimental results indicate reduced training time as that of CPU implementation [39].

The conventional fuzzy control approach make use of ‘linguistic’ variables instead of numerical variables, these variables are related with each other by conditional statements. The linguistic variables such as tall, not tall, very tall, very very tall, etc. are made to relate by if-then fuzzy conditional statements. The role of fuzzy feedback in conjunction of fuzzy instructions; the implications of compositional rule of inference and the rule of preponderant alternative [40].
In the domestic, industrial and commercial field refrigeration system is generally used either for human comfort or the need of high end equipments or computer servers. The nonlinearity is observed in the working of refrigerating plant used in chemical and other industries. Here neuro-fuzzy models can be developed to control nonlinear behavior of refrigeration system. The bell shaped membership function is used for implementation of ANFIS controller that controls propylene glycol temperature with approximation of ±0.5 °C [43].

The vapor compression refrigeration system is controlled by adaptive neuro-fuzzy inference system (ANFIS). The experimental setup is built and the ANFIS is tested by changing evaporator load, dry bulb temperature and humidity of air. The ANFIS model is trained using the data collected for above parameters. The various operating conditions for 64 input-output pairs forward to design ANFIS structure. The cooling tower method with ANFIS approach provides better results [53].

Man made machines are fast and accurate as per the design, but then also many problems are still to be resolved at a satisfactory level. In most of the adaptive techniques, adaptive linear combiner is used whose output is linear with respect to the inputs. It may consist adaptive linear element as a basic building block for a neural network, these linear combiner are found to be limited in its capacity that can be overcome by nonlinear classifier. Usually multilayered neural networks that are adaptive in are feedforward and higher order networks use backpropagation method. The different methods and algorithms are discussed and the distinction is made with respect to error-correction rules and steepest-descent rules [46].

In the applications such as heating system of building, the conventional neuro-fuzzy system may not found much effective. The reason behind this is structure of neuro – fuzzy system which is feed forward type. Hence a hybrid technique can be employed to overcome such kind of problems by making use of feedback loop also. This hybrid designed neuro – fuzzy system is applied to control average air temperature in the building. The performance of inferential
model is found to be improved with incorporation of feed back loop with neuro-fuzzy system [49].

The design of air conditioning system based on fuzzy inference system, artificial neural networks and adaptive neuro-fuzzy inference is carried out. The performance of these different soft computing approaches is analytically and soft computing is predicted. It is found that the performance of artificial neural network is better as that of adaptive neuro-fuzzy inference system [55].

Thermal control of building is done using artificial neural network, fuzzy logic control and ANFIS based control. The performance of all these system is measured in a two story residential building with the help of computer simulation having International Building Physics Toolbox (IBPT) and MATLAB. The test results are analyzed based on indoor air temperature conditions, thermal comfort and amount of heat supply and removal. The performance of ANN and ANFIS are found to be better [56].

Fuzzy classification problem can be solved by means of adaptive networks. Backpropagation algorithm is used to calibrate parameterized t-norms that are combine conjunctive conditions. The gradient decent algorithm updates the parameters of adaptive network. The neuro-fuzzy approach is better as that of neural network classifier [57].

In an industrial 440 MW power plant steam turbine fault detection and diagnosis is presented using adaptive neuro-fuzzy inference system classifier. Five layered ANFIS model is simulated and tested for the performance of hybrid and back propagation of 12 different sensor faults. Experimental observations indicate that fault detection and diagnosis is insensitive to reasonable changes in fault time-series patterns [58].

The radial based function network and the neural network of the type backpropagation is used in adaptive neural network. The adaptive network make use of weighted links to interconnect the nodes. These interconnected nodes may have different weights or node function. The mapping between input-output space
is done in feedforward adaptive network which is known as training data. Off-line learning is batch learning and on-line learning is pattern learning where parameters are updated after every data that is presented. The ANFIS network can be drawn as that of Sugeno fuzzy model using *if-then* rules. Consider $x$ and $y$ are the two inputs and $z$ as the output, the two fuzzy *if-then* rules can be:

$$\begin{align*}
If \ x \ is \ A_1 \ and \ y \ is \ B_1 \ then \ f_1 &= p_1 x + q_1 y + r_1 \\
If \ x \ is \ A_2 \ and \ y \ is \ B_2 \ then \ f_2 &= p_2 x + q_2 y + r_2
\end{align*}$$

Gives the reasoning mechanism for Sugeno type model and the corresponding equivalent ANFIS model can be illustrated with five layer architecture. Also the hybrid models can be though off for nonlinear systems parameters. A typical modeling approach comprise of structure determination and parameter identification [61].