# A SCADA Expert System of Fuzzy Knowledge-based System for Fault Tracing of Marine Applications

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## ABSTRACT

SCADA systems run global mission critical infrastructures and industrial systems. The purpose of the development of a SCADA expert system relies in the necessity to preserve the human knowledge acquired in several maintenance tasks. The security and vulnerabilities of the knowledge-based system is important because compromise or destruction of the system would impact multiple areas of society far removed from the original comprise. As mechanical conditions, maintenance processes of marine diesel engine should be monitored periodically, for diagnosis and prognosis purposes. A rich functionality of the SCADA expert system and its extensive developments facilities enhances reliability, efficiency, economics, and robustness.

## General Terms

SCADA Expert system, Fuzzy Knowledge-based system

## Keywords

SCADA, Knowledge-based system, marine diesel engine.

## 1. INTRODUCTION

To develop a SCADA (Supervisory Control and Data Acquisition) system that fulfill the requirement of being an expert and runs in real time according with the normative [1]. It involves automation of signals and several activities from instrumentation [2]. The expert system stored knowledge of human experts to solve a given problem. The knowledge is modelled so that it can be stashed in a database structure. The problem is supplied to the expert system as a dataset in the form of answers to questions as shown in Fig.1.

SCADA becomes popular in the 1960's for a variety of reasons. It enables the achievement of monitoring and controlling the plant operation remotely using communication technology [3].Many automation companies are using the SCADA to provide access to real-time data display, alarming, treating, and reporting from remote sites. It gives the flexibility to choose equipment and systems based on performance rather than compatibility with installed base [4]. Expert system shells are the software containing an interface, an inference engine, and the formatted skeleton of a knowledge base. Expert systems are computer applications that provide problem-solving help for specific problems [5].

The main activities in building systems namely, knowledge acquisition, knowledge representation, reasoning/inferencing, knowledge validation/verification are elaborated upon. A knowledge engineer would use this shell to develop the knowledge base and customize it to meet the needs of its client base of users. It would be customized to take a user's input and interpret that information to the data repository and, by comparison, locate matching information that might help guide the user to a solution as shown in Fig.2.

Expert system shells must provide capabilities to bolster the knowledge engineer's job in the development of a knowledge base that may operate as a real time expert system. In such an expert system, the base may be in constant data change by deletions or additions of data because industrial system, networks, hardware, and software systems change overtime.

There are three kinds of knowledge based on content and purpose including declarative, procedural, and inferred knowledge. Knowledge- based `of a human expert

As shown in Fig.3; briefly, the module design of the SCADA expert system; the expert system must meet SCADA function [6] including human machine interface (HMI) interface and remote terminal units (RTU) of data acquisition, both fed to the rule base organized with alarm which generated as a result of inference is performed.

The output in the form of advice or warning is either sent to computer (PC) screens or can be linked to alarm or control systems. The structure program of expert system for modules and its influence on decision making of the fuzzy inference system [7]. This is a definitive parameter when transferring knowledge from expert of maintenance about the system.

This paper is organized as follows: First, Motivation of using Fuzzy knowledge base system (FKBS) in section 2. Inference engine of the expert system in section 3. Flowchart for the basic configuration of the fuzzy logic system in section 4. GUI tools of FIS Data Structure Management in section 5. The Fuzzy Logic Approach including typical lists of qualifier, outputs, rules, and screenshots of the proposed system are shown in section 6. SCADA expert architecture are drawn in section 7. Integrating Data Mining, Expert Systems, and intelligent agents are displayed in section 8. Finally, the conclusions are deduced in section 9.

## 2. MOTIVATION OF USING FUZZY KNOWLEDGE BASE SYSTEM (FKBS)

Fuzzy knowledge base system (FKBS) Modern diesel engines are operated by highly skilled operators through computerized control systems. The main units of a typical diesel engine are shown in Fig.4.

### 2.1 Moving parts

A marine diesel engine's moving parts comprise as following; the crankshaft, the pistons, fuel valves, air start valve, exhaust valve, exhaust gas valve, inlet valve, fuel injectors, turbo blowers, connecting rod, crank pin, camshaft, push rod and rocker arms, crosshead guide, governor, and fuel pump.

### 2.2 Fixed parts

The fixed parts of the diesel engine include the bedplate, the cylinder head, the thrust block, the propeller shaft, and stern tube.

In all types of ships, the main power andmotion are produced by a diesel engine having a very complicated power generation. As a result, we need a great experience and measuring points at the engine itself or any important environmental data outside the engine e.g. wind speed, tide level, current, and ambient temperature. This information comes via different measuring points means something to the operator or to the expertise.

Also, this information is used as a database for the suggested knowledge base system which is automatically updated via on-line connection from the field to the information system [8]. The planning capabilities of knowledge base systems allow ready use of condition information to produce revised maintenance and fault tracing charts of marine diesel engine.

The accessibility of the knowledge base allowing easy updating when parameters changed due to the inherent changes of diesel engine elements or operating conditions [9].

## 3. INFERENCE ENGINE OF THE EXPERT SYSTEM

Fuzzy logic system is used for data processing. The aim of a fuzzy system is to create a system based on behavior and human advice from a fuzzy logic based on experience as shown in Fig.4. A fuzzy inference system has three parts [10] and [11]:

### 3.1 Fuzzification

Fuzzification is the method of converting a crisp input quantity into fuzzy quantity. It is the process of decomposing a system input and/or output into one or more fuzzy sets. The process of fuzzification allows the system inputs and outputs to be expressed in linguistic terms to allow rules to be applied in a simple manner to express a complex system.
Membership functions (MF) of the sets can be described as:

**3.1.1 Trapezoidal Membership Function**

**3.1.2 Gaussian Membership Function**

### 3.2 Rule Base

To build a fuzzy inference system, there is necessary to generate a rule base from the knowledge base. Most fuzzy knowledge base systems are developed via specialized software tools called shells, which come equipped with an inference mechanism (backward chaining, forward chaining, or both) [12].

Rule base has two parts: the antecedent and the consequent. The antecedent is composed by the logical (AND/OR) combination of the input variables and the latter is the consequence of that interaction. The logical combination of the inputs and its membership value (through operator max, min, product, prober, or custom) representing the degree of membership of the outputs to the sets established in the rule.

When multiple rules are in the agenda, the inference engine uses a conflict resolution strategy to select which rule should have its actions executed first. The rule with the highest priority will fire first and then the inference engine selects another rule and executes its action until no applicable rules remain.

### 3.3 Defuzzification

Defuzzification is the process of producing a quantifiable result in crisp logic, given fuzzy sets and corresponding membership degrees. It is the process that maps a fuzzy set to a crisp set. Defuzzification process allows the user to define a value in the range of the variable. In the case of the SCADA expert system development for fault detection of the marine diesel engine, a fuzzy inference system was generated for each Fault tracking mode of the system as shown in Fig.5.

## 4. FLOWCHART FOR THE BASIC CONFIGURATION OF THE FUZZY LOGIC SYSTEM

This item is the heart of the fuzzy knowledge-based of the expert system. Simply, the whole mechanism process of three stages for the fuzzy inference system can be demonstrated as shown in Fig.6.

The user interface is the system's component that determines the way for the user and the computer to communicate with each other. Graphical user interfaces (GUI) which use images, graphics, icons, temperatures, and color present most of the system's options on the screen increase the friendliness of the system.

## 5. GUI TOOLS OF FIS DATA STRUCTURE MANAGEMENT

The fuzzy Logic Toolbox for use with MATLAB is a tool for solving problems with fuzzy logic. Fuzzy logic knowledge-based system (FKBS) is a fascinating area of research because it does a good job of trading off between significance and precision__ something that humans have been managing for a very long time as shown in Fig.7.
It is a system using human knowledge captured in a computer to solve problems that ordinarily require human expertise. FKBS can be used by either experts or non-experts to improve their problem-solving capabilities [13].

In this section, Surgeon, or Takagi-Surgeon-Kang (introduced in 1985 [Sug85]); a method of fuzzy inference is completely sufficient for the needs of a given problems. The dependence of each rule on the input variables acts as an interpolating supervisor of multiple applied controllers.

This GUI tool allows editing the feature of the fuzzy inference system, such as the number of input and output variables, the defuzzification method used, and so on. The diagram FIS Editor displayed at the top of the window shows five inputs, sixteen outputs, and a central fuzzy rule processor. This interface allows convenient access to all other editors with an emphasis on maximum flexibility for interaction with the fuzzy system as shown in Fig.8.

## 6. THE FUZZY LOGIC APPROACH

It would be nice if we could capture the essentials of the problem, leaving aside all the factors that could be easily applied. Fuzzy Knowledge-based system (FKBS) could function better than any single expert in making judgment in a specific, usually narrow area of expertise [14]. There are three major problem detection methods: observation of the problem cause, measurements of equipment and analysis of corrective control actions.

**6.1 Inputs:** are arranged in questions with all possible answers for each question [15].
A typical qualifier list is indicated as following:

- **Engine start**: Membership functions for that input are poor, not start, well.
- **Exhaust gas color**: Membership functions for that input are blue, white, opaque.
- **Engine state**: Membership functions for that input are reach ignition speed, not reach ignition speed, reach full power, not reach full power.
- **Engine speed**: Membership functions for that input

are steady, not steady.

- **Differential pressure**: Membership functions for that input are high, not high.

**6.2. Outputs:** are representing the possible causes of engine faults as experimental results.Typical output lists of the designed system are shown as following:

- **Magnetic valve**: Membership functions for that output is defective.
- **Air pressure**: Membership functions for that output is low.
- **Combustion engine**: Membership functions for that output is oil.
- **Daily oil tank**: Membership functions for that output are empty, full.
- **Cylinder head**: Membership functions for that output is leakage.
- **Governor**: Membership functions for that output are admit fuel, fail.
- **Fuel filter**: Membership functions for that output is clogged, blocked.
- **Vibration damper**: Membership functions for that output is defective.
- **Injection pump**: Membership functions for that output is strictly.
- **Linkage**: Membership functions for that output is defective.
- **Injection pressure**: Membership functions for that output low, high.
- **Nozzle**: Membership functions for that output is defective.
- **Combustion air feed**: Membership functions for that output is insufficient.
- **Differential pressure gauge**: Membership functions for that output is defective.
- **Oil**: Membership functions for that output is hot, cold, too cold.
- **Fuel**: Membership functions for that output is water.

**6.3. Rules**: A rule is composed of an if portion and then portion, IF portion is a series of patterns specifying the facts which cause the rule to be applicable. THEN portion is the set of actions to be executed when the rule is applicable. The inference engine selected a rule and then the actions of the selected rule are executed[15].

Knowledge representation as rules has the following advantages used in this developed system:

- ♦ Modularity, where each rule defines an independent piece of information.
- ♦ Increment ability: new rules can be added without affecting existing rules.
- ♦ Associating a degree of uncertainty; this information permits within the (IF-Then) statements.

The following fifteen typical rules based on fault tracing diesel engine chart are listed as shown in Fig.9 (certainty factor range from zero to one); screenshots have been taken from the Rule Editor of FUZZY LOGIC using MATLAB:

- If the engine start is poor, then magnetic valve to the air is defective (confidence=0.6).
- If the engine starts well, then low starting air pressure in the bottle (confidence=0.5).
- If the exhaust gas is blue, then oil in the combustion engine (confidence =1.0).
- If the exhaust gas is white, then water in the fuel (confidence =0.7).
- If the exhaust gas is not white, then leakage at the cylinder head (confidence =0.3).
- If the engine reaches ignition speed but does not start, then the governor does not admit fuel (confidence =0.5).
- If the engine does not reach ignition speed, then the daily oil tank is empty (confidence=0.5).
- If the engine not reaching full power, then the governor fails (confidence =0.6).
- If the engine reaches full power, then clogged fuel oil filter (confidence=0.4).
- If the engine speed not steady, then the vibration damper is defective (confidence =0.5).
- If the engine speed is steady, then injection pump plunger is strictly (confidence =0.3) AND linkage between governor and injection pump is defective (confidence =0.2).
- If the exhaust gas is opaque, then low injection pressure (confidence=0.4).
- If the exhaust gas is not opaque, then defective nozzle (confidence=0.3) AND combustion air feed are insufficient (confidence=0.6).
- If the differential pressure is high, then the fuel filter is blocked (confidence =0.4).
- If the differential pressure is not high, then the differential pressure gauge is defective (confidence=0.6) AND the oil is too cold (confidence=0.6).

The Rule Viewer displays a roadmap of the whole fuzzy inference process. Each rule is a row of plots, and each column is a variable. The Rule Viewer that opens during the simulation can be used to access the Membership Function Editor, the Rule Editor, or any of the other GUIs. The left five columns of plots show the membership functions referenced by the antecedent, or if-part of each rule. From the fourth column to the last one shows the membership functions referenced by the consequent or the then-part of each rule.

Typical screenshots of the designed fault tracing system have been taken; including analysis of the system dynamics; the parameters of the diagnostic scheme; and the sensor-control signals. Screenshots contain graphical representation of both trapezoidal and gaussian membership function for the system rule base at different inputs can be chosen in Fig.11 & Fig.14, respectively. The input variables at different values of parameters can be edited either trapezoidal or gaussian as shown in Fig.10 & Fig.13. The corresponding view of surface for the experimental results at both trapezoidal and gaussian membership function will be shown in Fig.12 & Fig.15, respectively.

## 7. SCADA EXPERT SYSTEM ARCHITECTURE

An expert system would be helpful in developing a SCADA system making several repetitive, tedious tasks, like configuring alarms, which take a lot of time and are prone to errors. This means that a knowledge database is used to store the information needed to generate the SCADA system without the need of hard coding data in the expert system.

There is a very important step of need the user to provide the system with facts about the platform for SCADA system implementation shown in Fig.16. Also, the user needs to define the alarms, and the command sequences [16].

The major components of expert system are Graphical User Interface (GUI), knowledge database, and inference mechanism. Using the GUI, the user describes the platform with predefined parts through a drag & drop interface like programming IED's (Integrated Development Environment). Once the platform is described, the inference mechanism generates the SCADA system based on the knowledge database.

The desired output of the expert system is used to implement the SCADA system including.

- **Hardware structure**, a full list of sensors, input modules, input and output interfaces, remote terminal unit, etc.
- **Connection diagrams**, a table that describes all the connection between the hardware elements depending on the attributes of start and end points.
- **Tag list**, a full list of tags used by the SCADA system software.
- **Software**, a collection of files will run on the field devices.

The expert system can't compile the code and transfer it to the RTU, so this operation needs to be done manually. The code snippets need to be written in ST (Structured Text). The software has a modular structure and an input buffer module, that handles the data acquisition and scaling. The buffering of the input data checks alarms. Human Machine Interface (HMI) [17] configuration file; contains data about the graphical representation of the platform, a list of alarms and a list of displaying the inputs and outputs. The research efforts related to integration of the object-oriented database and knowledge base technologies [18].

## 8. INTEGRATING DATA MINING, EXPERT SYSTEMS, AND INTELLIGENT AGENTS

Intelligent agents, data mining models, and expert systems are similar in that they each use intelligent techniques to solve difficult problems. Intelligent agents are goal directed, whereas data mining models are used to test and create new hypotheses about data. Expert systems designed for high-level problem solving in specialized domains, while intelligent agents contain basic knowledge necessary for performing everyday tasks [19].

At the center of the proposed model lies a data mining agent as shown in Fig.17. The agent is responsible for coordinating various data mining sessions. The user is responsible for presenting the agent with the data to be mined as well as the goals to be achieved.

When a set of data is presented, the agent sends the data to a rule-based domain analyzer for initial analysis. The domain analyzer returns a summary report indicating the location of missing and noisy data. After the domain analysis, the data mining agent is responsible for cleaning the data and selecting a set of candidate input attributes. After a set of attributes have been selected, the agent invokes a rule-based model selector. The rule-based model and parameter selectors are shown in the top portion of the model.

If the results satisfy the specialized goals, a summary report is written. If the results are not acceptable, the agent decides on one or more of the following actions:

- Invoke the parameter selector.
- Choose a new data mining model.
- Modify the selection of input attributes.
- Conclude that the domain is not amenable for data mining.

## 9. CONCLUSIONS

In this paper, a proposed expert system using fuzzy knowledge - based system (FKBS) is designed and implemented for fault tracing of marine diesel engine. The goal of this fuzzy logic approach for the ship engine is to increase the matters of data identification of the actual faults, validation, accuracy of experimental results, updating all the certainty factors, time-tagging, consistency across databases, etc. The development of data management of the SCADA expert system covers all aspects of gathering, analyzing, saving time, and preparing data to users. SCADA expert system links the various parts designed with individual software tools into one easy to follow historical data, easy to implement real time measurements and easy to modify structure. As data mining model, expert systems, and intelligent agent differ in their intent, the techniques are complementary and can be used together to build useful models for solving difficult problems.

## 10. FIGURES/CAPTIONS

**Table 1 The fifteen typical rules based on fault tracing diesel engine chart are listed**

| Rule 1 | Rule 2 | Rule 3 | Rule 4 | Rule 5 | Rule 6 | Rule 7 | Rule 8 | Rule 9 | Rule 10 | Rule 11 | Rule 12 | Rule 13 | Rule 14 | Rule 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Engine start Poor 0.6 | Engine start Well 0.5 | Exhaust gas Blue 1.0 | Exhaust gas White 0.7 | Exhaust gas Not White 0.3 | Engine reaches ignition speed Not start 0.5 | Engine not reach ignition speed Not start 0.5 | Engine notreac h Full power 0.6 | Engine reaches Full power 0.4 | Engine speed Not steady 0.5 | Engine speed Steady 0.2 | Exhaust gas Opaque 0.4 | Exhaust gas Not Opaque 0.3 | Differential pressure High 0.4 | Differential pressure Not High 0.6 |
| Magnetic valve defective | Air pressure Low | Combust-ion engine Oil | Fuel Water | Cylinder Head Leakage | Governer Not admitfue l | Oil Tank Empty | Governer Fail | Oil Filter Glogged fuel | Vibration Damper defective | Injection pump strictly linkage defective | Injection Pressure Low | Defective Nozzle& combustion air feed Insufficient | Fuel Filter Blocked | Pressure Guage defective Oil Too cold |

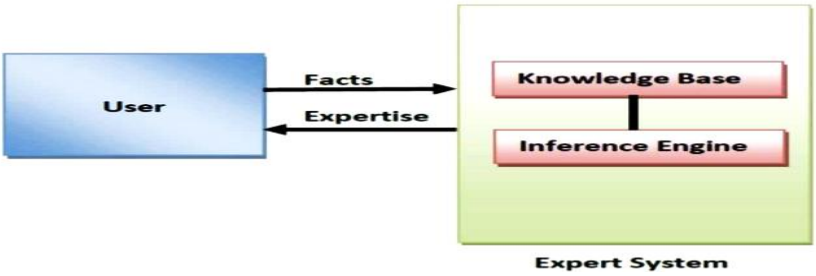


**Fig.1 Basic concept of expert system**

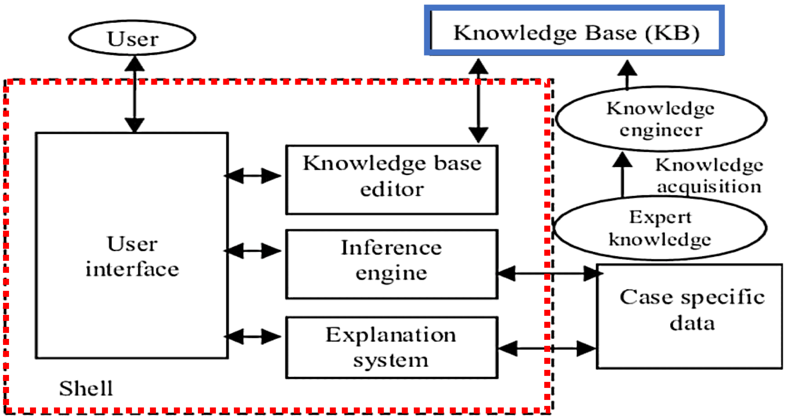


**Fig.2 Expert system Structure**

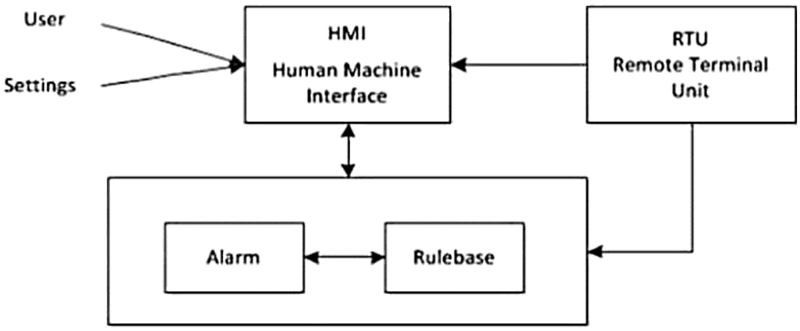


**Fig.3 Module design of a SCADA expert system**

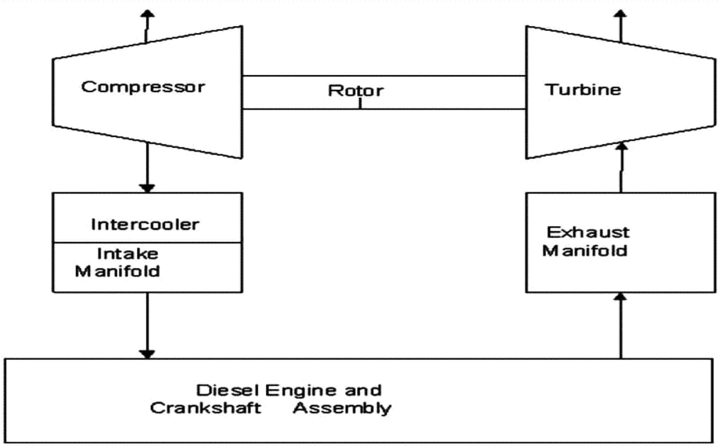


**Fig.4 Schematic diagram of a turbocharged diesel engine**

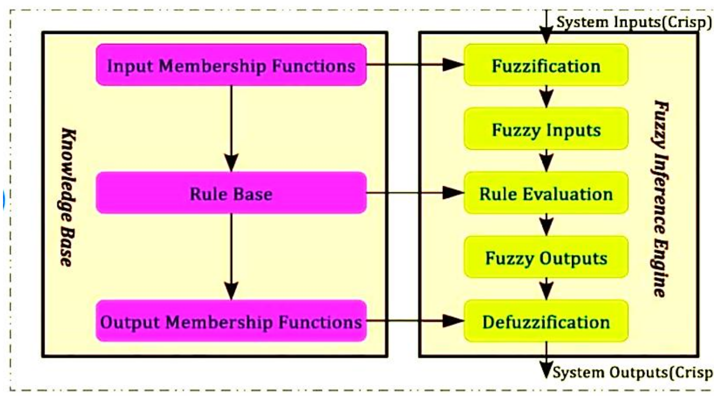


**Fig.5 Structure of Fuzzy logic expert system**

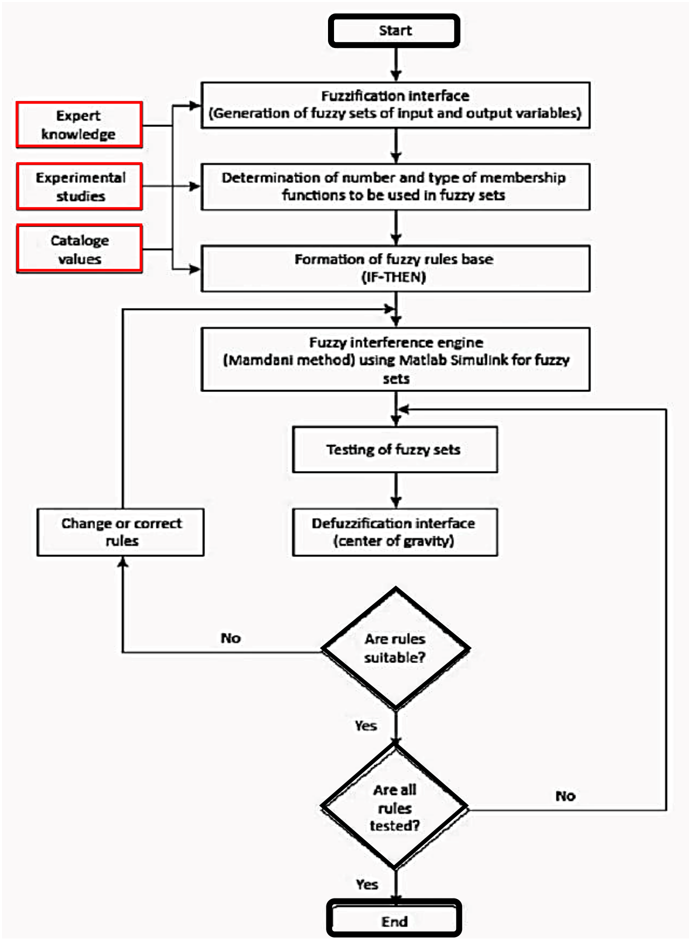


**Fig.6 A flowchart of the basic configuration of Fuzzy logic system**

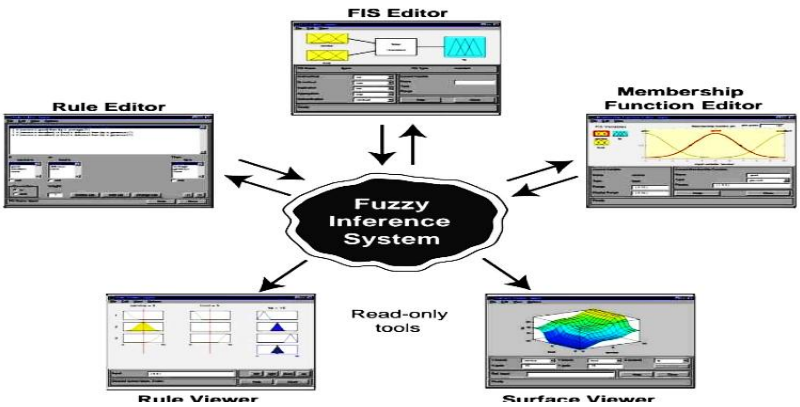


**Fig.7 Building Systems with the Fuzzy Logic Toolbox**

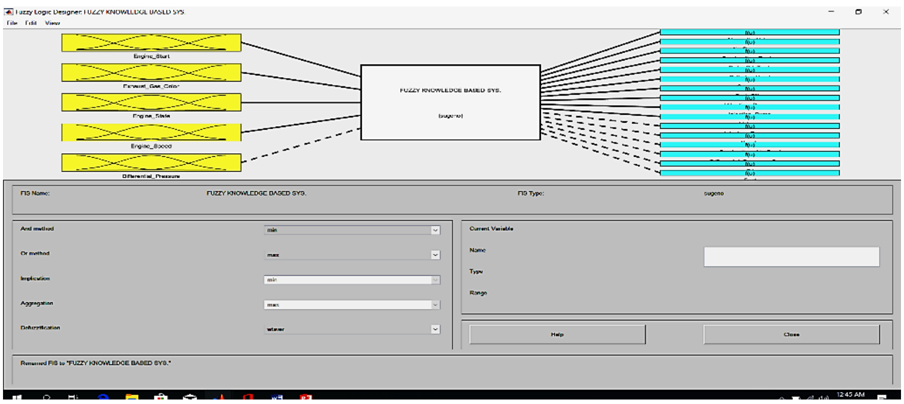


**Fig.8 The FIS Editor**

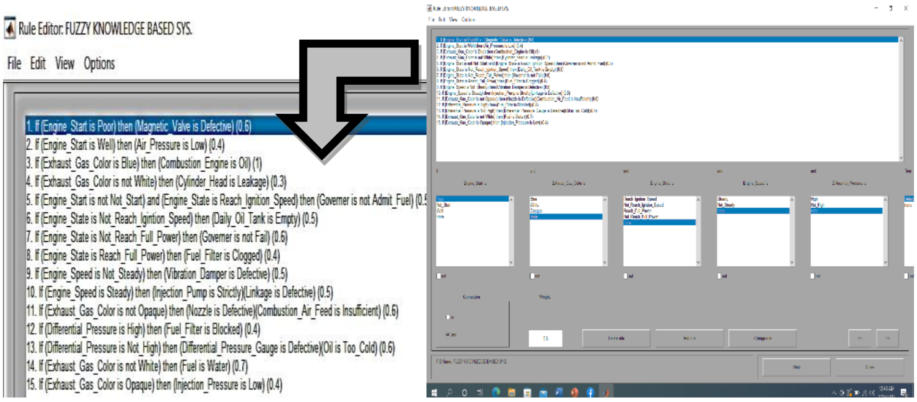


**Fig.9 System rule base user should build rules from input and output lists.**

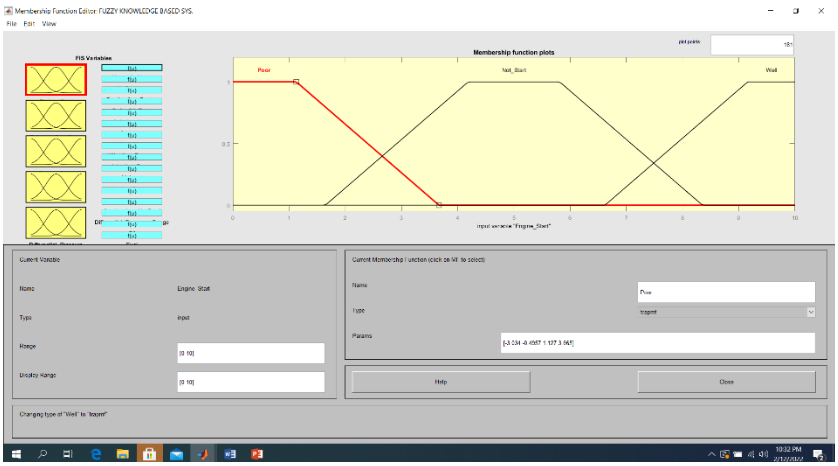


**Fig.10 Trapezoidal Membership Function Editor**

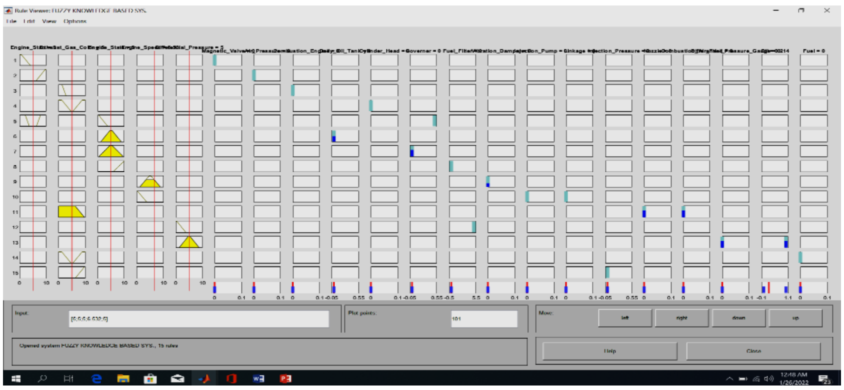

**Fig.11 Graphical representation for the system rule base at Trapezoidal membership function**

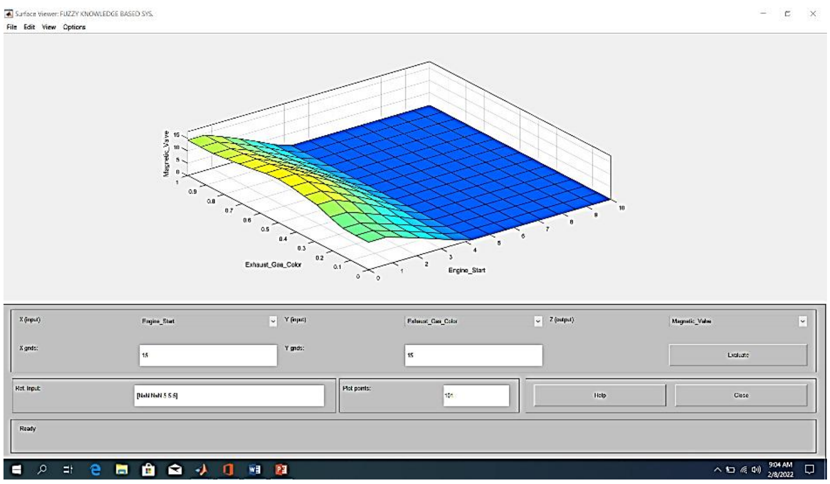


**Fig.12 Surface view of the constructed rule base at Trapezoidal membership function**

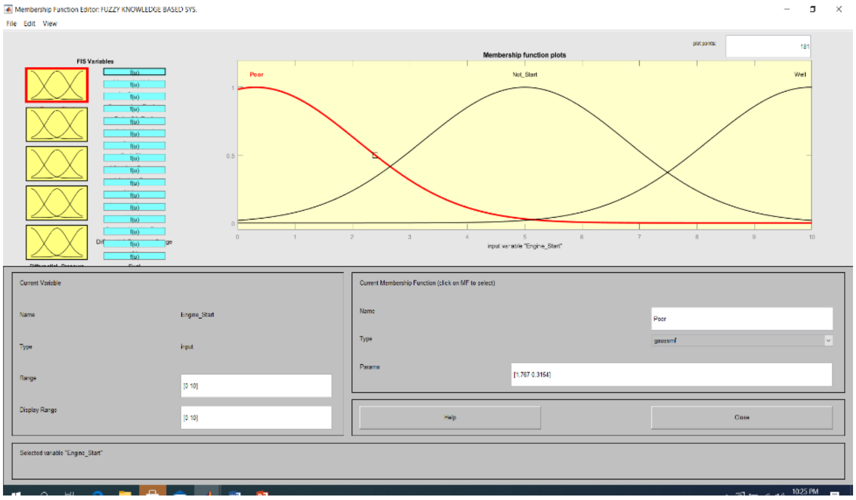

**Fig.13 Gaussian Membership Function Editor**

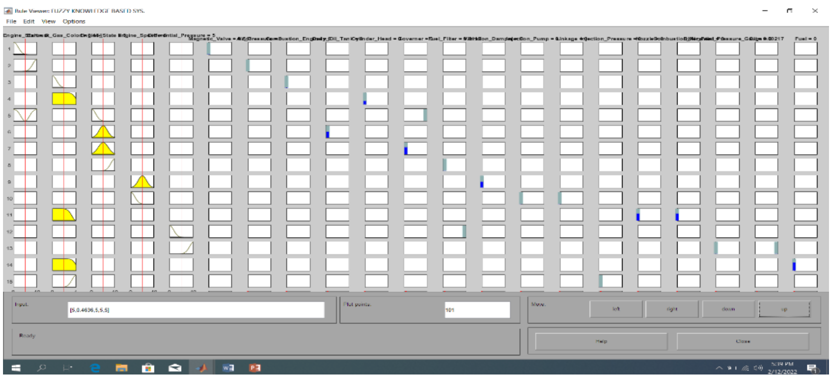

**Fig.14 Graphical representation for the system rule base at Gaussian membership function**

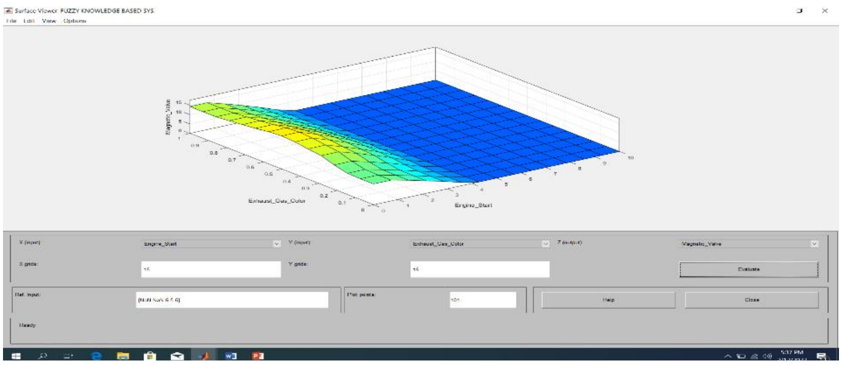

**Fig.15 Surface view of the constructed rule base at Gaussian membership function**

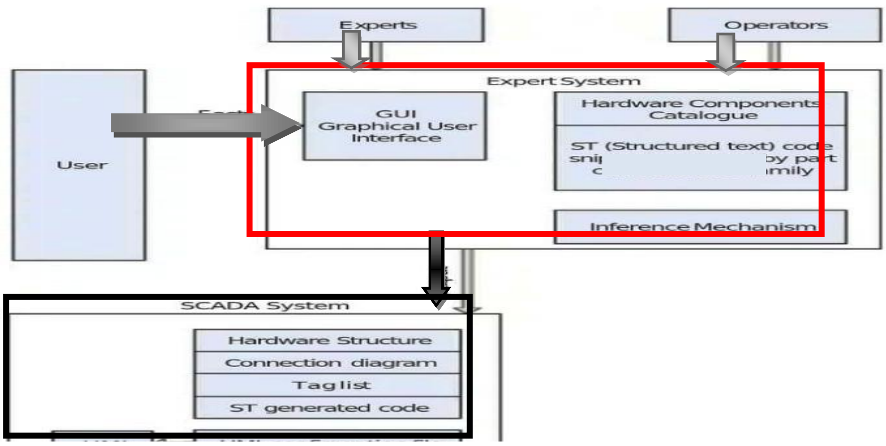


**Fig.16 SCADA expert system architecture**

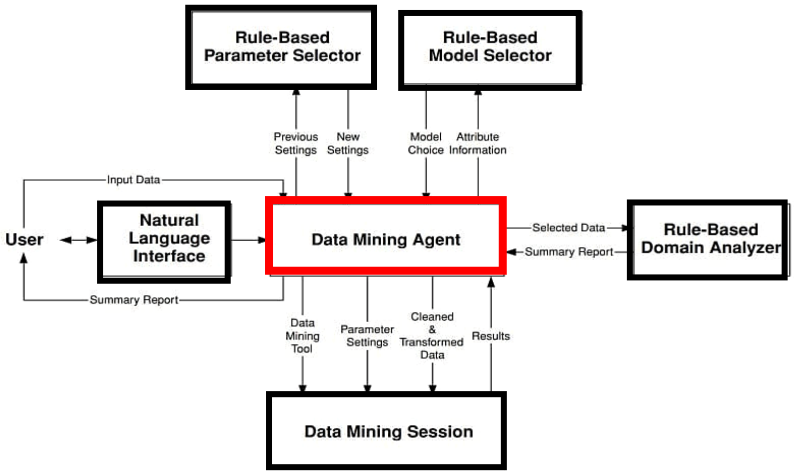


**Fig.17 An agent-based model for data mining**

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