# Fuzzy Knowledge Base System for Fault Tracing of Marine Diesel Engine

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**Abstract**

*Marine diesel engine provides the prime mover for the majority of ship propulsion systems and as such plays a fundamental role in ship operational and economy. Ship owners and operators focuses to the development of improved method of analysis, operation, fault condition diagnosis, performance monitoring, performance optimization, and recently emission analysis and control. Information technology can be used to raise the technological level of diesel engine automation and control to enable a new generation of engines with high level of safety and friendly use for the operators. Fuzzy knowledge base systems are practically suitable for these problems and will inevitably become an essential element in marine technology.*

*The main objective of this paper is designing a prototype fuzzy knowledge base system (FKBS) to improve the capabilities of fault tracing for a ship diesel engine. Such system can be used by non-experts to improve their problem solving skills. Also it can be used as a training tool for new staff. For implementing the Knowledge base system, a special software package has been proposed. This software package has been designed for building the prototype knowledge base system shell. The developed system has a friendly user interface and does not require any special programming skills to encourage all operators to use it.*

**Keywords**: Diesel engine, Fuzzy knowledge base systems, Fault tracing systems.

## 1. Introduction

Fuzzy Knowledge base systems are basically a cluster of software routines especially organized in a computer that tends to emulate the human expertise in a certain domain [1], [2]. Fuzzy knowledge base system is an expert system that uses fuzzy logic instead of Boolean logic. In other words, a fuzzy expert system is a collection of membership functions and rules that are used to reason about data. Unlike conventional expert systems, which are mainly symbolic reasoning engines, fuzzy expert systems are oriented toward numerical processing. The end user provides input by selecting one or more answers from a list or by entering data. The program will ask questions until it has reached a conclusion. Knowledge base systems can be developed with Knowledge base system Shells [3], [4]. Knowledge base systems software can be developed for any problem that involves a selection from among a definable group of outputs where the decision is based on logical steps. Also Knowledge base systems can help automate anything from complex regulations to aiding customers in selecting from among a group of products, or diagnosing equipment problems [5], [6].

In all types of ships, the main power and motion are produced by a diesel engine. This type of engine is very complicated power generation system, which need a great experience and measuring points at the engine itself or any important relevant environmental data outside the engine (e.g. ambient temperature, wind speed, tide level and current). The information, which normally comes via different measuring points, means some thing to the operator or to the expertise. This information is used to be as database for the suggested Knowledge base system. This database is automatically updated via on-line connection from the field to the information systems [6].

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. Even trends generated from sensor data can be used to automatically revise the planned 'time to maintenance or fault tracing' interval. Another advantage of such uses is the accessibility of the knowledge base, allowing easy updating when parameters changed due to the inherent changes of diesel engine elements or operating conditions [7].

This paper is organized as follows: First, motivation of using fuzzy knowledge base system is given in section 2. A brief review about fuzzy knowledge base systems basics is introduced in section 3. Procedures of developing a prototype fuzzy knowledge base system are introduced in section 4. Typical lists of qualifier, outputs, rules and screens of the developed system are shown in section 5. Finally the conclusions are drawn in section 6.

## 2. Motivation of Using Fuzzy Knowledge base systems

Fuzzy knowledge base system (FKBS) is a system that uses human knowledge captured in a computer to solve problems that ordinarily require human expertise. Such systems can be used by non-experts to improve their problem solving capabilities. KBS can also be used by experts as knowledgeable assistants. Such systems could function better than any single human expert in making judgment in a specific, usually narrow area of expertise [3].

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. 1. The engine automation systems are the center of a control system organized in a hierarchical structure utilizing remote terminal units, communication links, and various levels of computer processing systems. The main function of this computerized controllers are to ensure the secure and economic operations of the overall ship as well as to facilitate all tasks carried out to be used in the normal state where such function are, security analysis and optimal operating conditions [6].

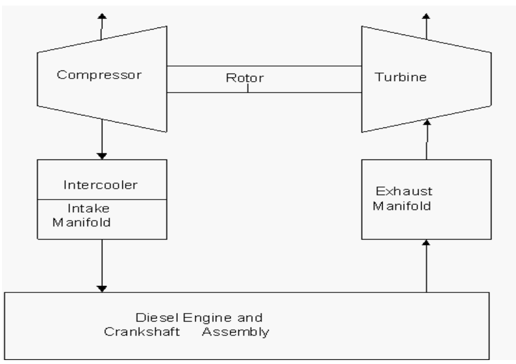


*Fig. 1 Schematic diagram of a turbocharged diesel engine*

Copying with emergency events is refereed to as a diagnosis and decision process. In marine applications, these events include wind speed, tide level, current speed and ambient temperature. Dealing with such events is ill structured and their solution rests heavily on the experience and skill of the human operators to react correctly. The key to human ability in such situations lies in the experience with similar events and the use of heuristics to map existing complex situations on to learned past events to solve problems. Since artificial intelligence allows the realization of heuristic techniques in a computer, the way is now open for many new applications of Knowledge base system in ship and diesel engine automation [6].

## 3. Fuzzy Knowledge base systems Fundamentals

The knowledge base systems consist of many basic components [2]. The first component is an input/output module. Its main functions are to provide a mechanism for communications between the user and the knowledge base system. The user supplies problem descriptions, and advice and explanations of decisions reached by the Knowledge base system outputs. The output in the form of advice or warning is either sent to computer screens or can be linked to alarm or control systems.

The knowledge base contains all the available knowledge about a particular subject. The database contains all the facts known, learned and acquired by education and experience over a prolonged period of time or deduced about this particular problem. Interface strategies are then applied in order to derive a solution to this problem. It is one of the basic characteristics of an Knowledge base system that allowing alterations and improvements to the knowledge without changes to the inference mechanism, and allowing common inference techniques to be applied to a Varity of problems. Inference strategies are then applied in order to derive a solution to this problem. [1], [3].

### 3.1 Knowledge base systems Architectures

Fuzzy-expert system is an expert system that uses a collection of fuzzy sets and rules. The rule in the fuzzy-expert system usually takes the form:

**If A is low and B is high; then C = medium.**

Where A and B are input variables, C is the output variable, and low, high and medium are membership functions defined for A; B and C; respectively. The antecedent (the rule's premise) describes the degree that the rule applies, while the conclusion (the rule's consequent) assigns a membership function to the output variable. The set of rules in a fuzzy-expert system is known as the rule base or knowledge base.

Many fuzzy knowledge base systems are not complex or difficult to build. In a very simple case, consider a tree diagram on paper describing how to solve a problem. By making a selection at each branch point, the tree diagram can help someone make a decision. In a sense, it is a very simple knowledge base system. More elaborate systems may include confidence factors allowing several possible solutions to be selected with different degrees of confidence [4]. Typical basic architectures can be shown in Fig. 2.

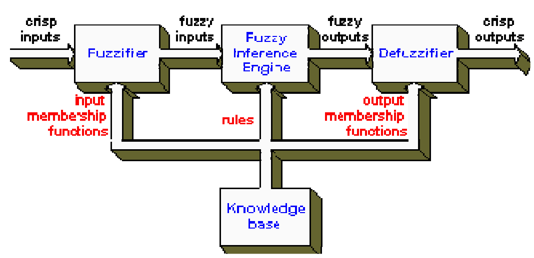


*Fig. 2 Typical architecture of Fuzzy Knowledge base system*

### 3.2 Rule Based System Software Tools

Most fuzzy knowledge base systems are developed via specialized software tools called shells. These shells come equipped with an inference mechanism (backward chaining, forward chaining or both), and require knowledge to be entered according to a specified format. They typically come with a number of other features, such as tools for writing hypertext, for constructing friendly user interfaces, for manipulating objects, and for interfacing with external programs and databases [3].

A variety of knowledge representation schemes have been developed over the years. They share two common characteristics. First, they can be programmed with existing computer languages and stored in memory. Second, they are designed so that the facts and other knowledge contained within them can be used in reasoning. That is, the knowledge base contains data structure that can be manipulated by an inference system that uses search and pattern-matching techniques on the knowledge base to answer questions, draw conclusions, or otherwise perform an intelligent function [3].

The major knowledge representation schemes are rule based systems and frames. Rule based system have been used in the developed system in this paper. A rule is composed of an *if* portion and a *then* portion. The *if* portion of a rule is a series of patterns which specify the facts (or data) which cause the rule to be applicable. The *then* portion of a rule is the set of actions to be executed when the rule is applicable. The inference engine selects a rule and then the actions of the selected rule are executed. [3].

## 4. Diesel Engine Fault Tracing Systems Development

In this section a prototype fuzzy knowledge base system is built for the diesel engine, which is the main item in the ships.

### 4.1 The Development Life Cycle of FKBS

Fuzzy knowledge base system is basically computer software, so its development follows a software development process. The goal of such a process is to maximize the probability of developing viable, sustainable software within cost limitations and on schedule. The main functions of a model of this process are to determine the order of steps (or tasks) involved in the software development and to establish the transition criteria for progressing from one stage to another [3].

### 4.2 Building FKBS

The system is made up of a rule-based knowledge base system module plus a complete database tool for data recording and retrieval. Its knowledge base is made of eight rules as a prototype module with a typical fault-tracing chart of marine diesel engine. The developed system building steps can be summarized in two steps as follows:

1- The first step in building an Knowledge base system is to fill both inputs and outputs lists [8], where the inputs list contain all the expected problems of the engine while the choice list include all the possible causes of the expected problems which are listed in the qualifier list.

2 - The second step, fit a rules which consists of IF THEN ELSE. In the first part of the rule (IF part) is chosen from the qualifier list, while the second part is chosen from the outputs list. If there are many causes in the second part (THEN part) we can use ELSE condition with AND or OR relation.

## 5. Typical List Qualifies, Outputs and Rule of the Developed Knowledge base system

In this section, a typical list of inputs, outputs and rules are shown. Where eight rules are built based on a typical marine diesel engine fault-tracing chart. Also this system include certainty factor. It is important to remember that confidence is not the same as probability. Certainty factor is the degree of the expert that a certain conclusion will occur if a certain premise is true [3].

### 5.1 Inputs

In this section a list of qualifies from the designed system is shown. Each qualifier represents a possible apparent symptom that can easily noticed by the operators. In this system inputs are arranged in questions with all possible answers for each question. A typical qualifier list is shown as follows:

**- 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

### 5.2 Outputs

Outputs are representing the possible causes of engine faults. Typical outputs lists of the designed system are shown as follows:

**- Magnetic valve**

Membership function for that output is: - Defective.

**- Air pressure**

Membership function for that output is: - low.

**- Combustion engine**

Membership function for that output is: - Oil.

**- Daily oil tank**

Membership functions for that output are: -Empty, full

**- Cylinder head**

Membership function for that output is: - leakage.

**- Governor**

Membership functions for that output are: - Admit fuel, fail

**- Fuel filter**

Membership function for that output is: - Clogged

**- Vibration damper**

Membership function for that output is: - Defective

**-Injection pump**

Membership function for that output is: - Strictly

**- Linkage**

Membership function for that output is: - Defective

**- Injection pressure**

Membership functions for that output are: - Low, high

**- Nozzle**

Membership function for that output is: - Defective

**- Combustion air feed**

Membership function for that output is: - Insufficient

**- Fuel filter**

Membership function for that output is: - Blocked

**- Differential pressure gauge**

Membership function for that output is: - Defective

**- Oil**

Membership functions for that output are: - Hot, Cold, too cold

**- Fuel**

Membership functions for that output is: - water

### 5.3 Rules

Rules are built where inputs and outputs are used to complete the structure of each rule. Typical rules based on fault tracing diesel engine chart are listed as follows (certainty factors range 0 -1):

- **If** the engine poorly or not start at all, **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 in 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 fail (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 sticky (confidence= 0.3) **AND** linkage between governor and injunction 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 is insufficient (confidence= 0.3).
- **If** the differential pressure is high, **Then** the fuel filter is blocked (confidence= 0.4).
- **If** the differential pressure in not high, **Then** the differential pressure gauge is defective (confidence= 0.3) **AND** the oil is too cold (confidence= 0.3).

### 5.4 Typical Screens of the Knowledge base system

Typical screens of the designed fault tracing system are shown in this subsection. A screen contains a sample of typical rule is shown in Fig. 3. Graphical representation of trapezoidal membership function for the system rule base at different inputs can be chosen in Fig. 4. The corresponding view of surface for the constructed rule base the output will be shown in Fig. 5. Finally Fig.6 and Fig.7 shows the same result at Gaussian membership function .
and Fig.(5) typical running sample of the developed system are shown.

## 6. Conclusion

In this paper, the benefits of fuzzy knowledge base systems in marine applications have now been successfully demonstrated. The development of fuzzy knowledge base for the ship engine which shown in this paper can be used actually to save time and effort for the operators and maintenance engineers. Also this fussy knowledge base can be adopted to be on-line software to increase the accuracy of results through updating all the certainty factors, depending the actual fault occurs and its actual solutions. The developed shell is a prototype, which can be extended for real engine if extra rules are added depending on the special properties of each type of engine (more than 200 rules in many engine types). The fault-tracing chart that is actually drawn from troubleshooting manual of marine diesel engine type called MAK Germany. This type of engine is used extensively in marine application.

## 8. References

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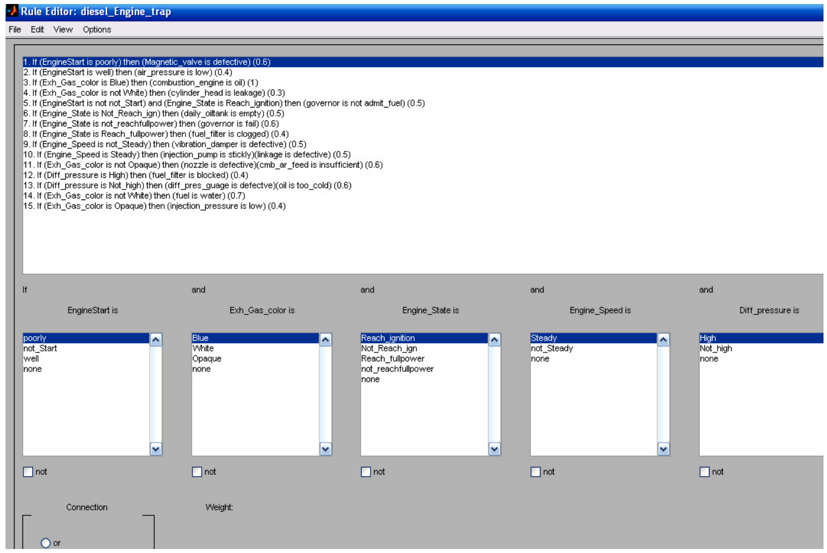


*Fig. 3 System rule base* user *should built rules from inputs and outputs lists*

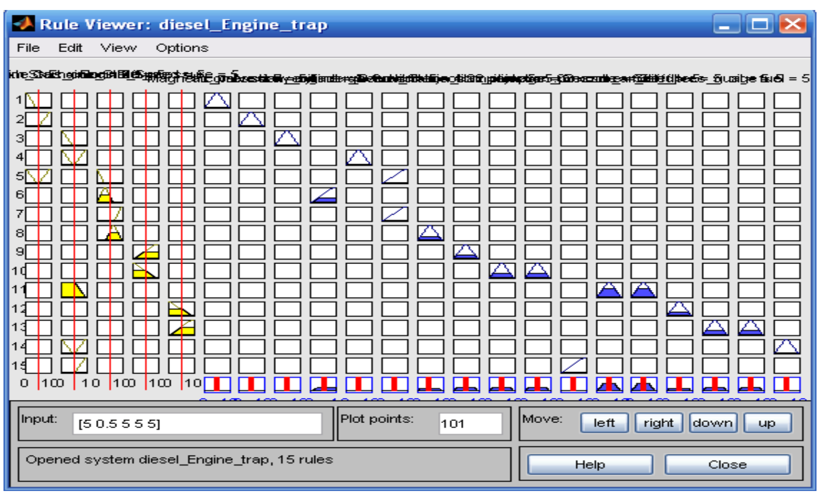


*Fig. 4* Graphical representation for the System rule base at Trapezoidal membership function

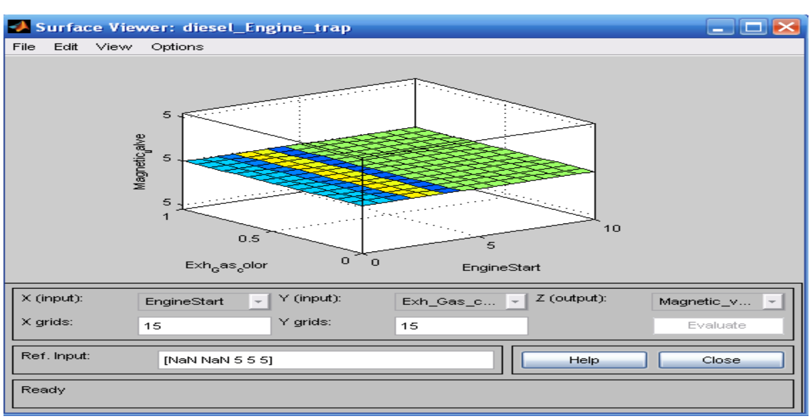

Fig.5 Surface view of the constructed rule base at Trapezoidal membership function

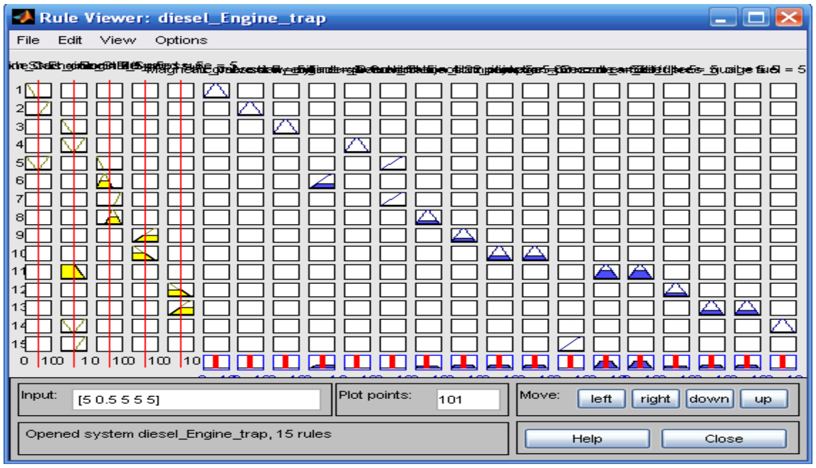


*Fig. 6 Graphical* representation for the System rule base at Gaussian membership function

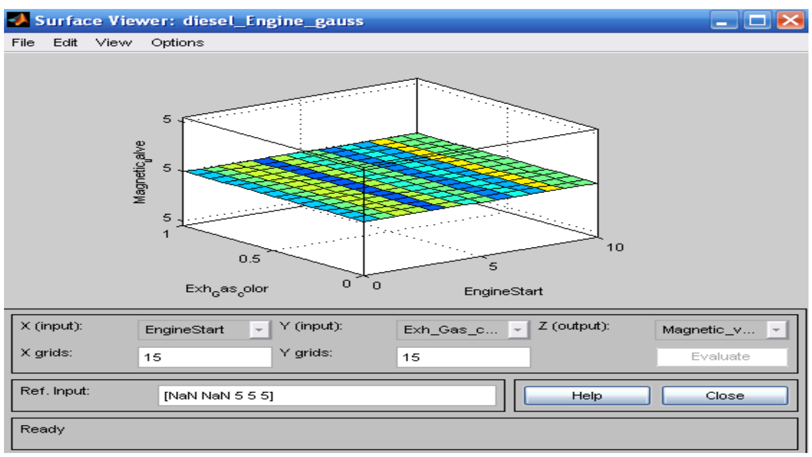


Fig.5 Surface view of the constructed rule base at Gaussian membership function