Implementing an Expert Diagnostic Assistance System for Car Failure and Malfunction

Salama A. Mostafa[1], Mohd Sharifuddin Ahmad[1], Mazin Abed Mohammed[1] and Omar Ibrahim Obaid[1]

[1] College of Graduate Studies, Universiti Tenaga Nasional, Putrajaya Campus
Jalan IKRAM-UNITEN, Kajang, 43000, Selangor Darul Ehsan, Malaysia

Abstract

Applications in fault diagnosis are continuously being implemented to serve different sectors. Car failure detection is a sequence of diagnostic processes that necessitates the deployment of expertise. The Expert System (ES) is one of the leading Artificial Intelligence (AI) techniques that have been adopted to handle such task. This paper presents the imperatives for an ES in developing car failure detection model and the requirements of constructing successful Knowledge-Based Systems (KBS) for such model. In addition, it exhibits the adaptation of the ES in the development of Car Failure and Malfunction Diagnosis Assistance System (CFMDAS). However, CFMDAS development faces many challenges such as collecting the required data for building the knowledge base and performing the inferencing. Furthermore, diagnosis of car faults requires high technical skills and experienced mechanics who are typically scarce and expensive to get. Thus, systems such as CFMDAS can be highly useful in assisting mechanics for failure detection and training purposes. Moreover, capturing and retaining valuable knowledge on such domain yield more accurate and less time consuming models.

Keywords: *Expert system (ES), Artificial Intelligence (AI), car fault, Knowledge-Based System (KBS), Inference engine.*

1. Introduction

Nowadays, the car technology is very crucial and significant to any car manufacturing companies as car specifications are changing rapidly stimulated by environmental and economic factors. This issue presents a challenge to both car mechanics and drivers in handling car failures and malfunctions. With the advent of new technologies like the hybrid engine, there are many changes that need to be learned. In fact, in a normal situation, car fault identification is still a challenging task, especially for the inexperienced mechanics and drivers. Consequently, the success of finding the fault is extremely dependent on the expertise of the individual. However, the dependence on the experts can be minimized if the expertise is captured, documented, and retained in some computer applications [1].

Researchers, institutions, and firms focus a great deal of attention in theoretical and practical diagnosis on technical systems failure [2]. Different types of AI techniques have been successfully applied in the diagnosis domain such as those presented in [3], [4] and [5]. The required AI techniques for such domain have to be capable of emulating the human brain's diagnostic processes [6]. The Expert System (ES) is one of the well-known reasoning techniques that is utilized in diagnosis applications domain. In ES, human knowledge about a particular expertise to accomplish a particular task is represented as facts and rules in its knowledge base [7]. It seeks and uses the information provided by a user. Reasoning process is then performed over the represented knowledge using heuristic approaches to formulate a solution [6].

The definition of an ES as proposed by [8] is: "an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution" [9]. The ES is a knowledge-based system that consists of two main modules: the knowledge base and the inference engine. It usually has a knowledge acquisition module and an explanation module as extra components. A typical expert system is as shown in Figure 1.

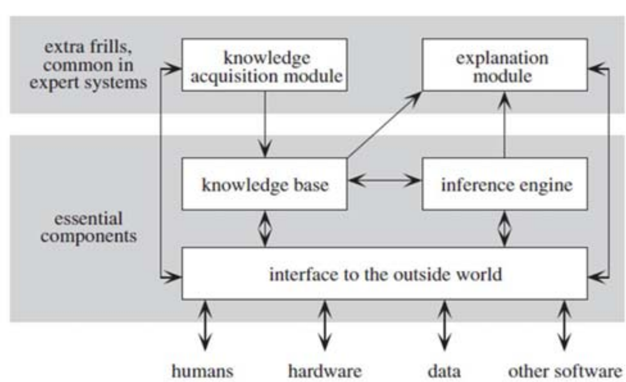

Fig. 1 Expert system main components [7].

Systems that utilize the knowledge base approach are more straightforward than the conventional approach. Knowledge is represented explicitly in the knowledge base so that it can be altered with relative ease. This representation often takes the form of rules. The inference engine utilizes the knowledge base contents to solve a particular problem according to the user responses through an interface (e.g. enter the symptoms of the car fault). The inference module exploits the knowledge to apply that knowledge to the given problem [7].

2. Research Objectives

The main objective of the research is to develop Car Failure and Malfunction Diagnosis Assistance System (CFMDAS). The aim of the proposed CFMDAS is to provide quick and precise expert guidance to car fault diagnosis. Additionally, for training purposes, it helps in reducing the knowledge gap between different individuals in car fault diagnosis. The specific objectives of the research are as follows:

- To investigate the related works on car fault and malfunction diagnosis and Expert System (ES) domains.
- To design appropriate representation architecture to the proposed Car Failure and Malfunction Diagnosis Assistance System (CFMDAS).
- To develop an ES that supports the implementation of the proposed system's functionality.
- To test and validate the system's performance.

3. Literature Review

One of the earlier published references on Expert System (ES) is done by [10] whereas the first diagnostic ES for technical fault diagnosis was developed at MIT in the early 1970's as stated by Scherer and White in 1989 [9]. Some researches that utilize the expert system for the purpose of diagnosing the failure of different machines are reviewed in the following paragraphs.

Kadarsah [1] proposed and designed a decision model for car fault diagnosis in which an ES is utilized to help inexperienced mechanics and drivers. The model consists of inference engine, knowledge base, database, user interaction and adaptive mechanism. The Inference engine uses backward chaining as a result of a small number of outputs with many possible inputs. In addition, the adaptive mechanism is utilized in the user interaction section in order to receive feedback about system diagnosis result. The feedback results are stored in a database. The adaptive system then processes the stored data and extracts additional rules with the goal of improving the knowledge base.

Car failure detection KBS is proposed by [11]. In this system, car faults are divided into three states: Start-up state, Run-stable state and Movement-state. Shell Rule-based expert system (CLIPS) with forward chaining inference engine is used in the implementation. CLIPS store's the knowledge in rules form, which has logic-based representation as well as the production rules. The system interacts with the user through an interface and gives the diagnosis result with illustration. The rule-based expert system contains 150 rules for car failure causes. However, improvement in the domain knowledge and applying adaptive technique for knowledge creation are required in such system.

In the work of Peter Nabende and Tom Wanyama [12], Heavy Duty Diesel Engines (HDDEs) diagnosis is proposed. HDDEs maintenance requires high technical skills and extensive experienced mechanics who are scarce. As a result, employing an expert system in such domain can be highly useful. The HDDE faults diagnosis ES is able to successfully detect malfunctions in the engines and give recommendation of corrective actions. System development leads to collection of valuable information related to HDDE fault diagnosis and training. However, updating the knowledge base affects the reasoning process performance especially in the continuous run.

A research has been done by [13] to assist in the designing of an ES for car failure diagnosis and repair. Many factors are considered in this research such as the required time, the place and human expertise level. In addition, the ES development is accompanied by reviewing the technologies used in designing such system to conclude the best means to be followed. However, the proposed prototype is not promoted to be used as a complete application due to time and resources limitations. Thus, adopting new rules to be performed is an example of further enhancements that the system need.

A survey was done by [2] for developing motocultivator fault diagnosis model. This model is based on the hybridization of Expert System (ES) and Decision Support System (DSS) in which ES outcome represents the input to the DSS. The supplier selection for faulty component replacement is made by DSS based on ES outcome. In practice, the designed hybrid system was applied in a small motocultivator importer and distributor company for servicing purposes. It has proved to be a very useful tool for equipment servicing needs with low development cost. It increases the efficiency of labour and workers' satisfaction.

4. CFMDAS Prototype Modelling

Fault diagnosis is the task of investigating the symptoms that identify the system components that are not functioning as intended [14]. A wide range of diagnostic applications in different domains exploits the rule-based expert system's approach [11]. It is believed to be very convenient in situations where expertise and experience availability rate is high and the system's understandability rate is either low or costly to obtain [6].

4.1 CFMDAS Architecture

The CFMDAS consists of three main parts starting firstly, with the knowledge acquisition part which captures the knowledge from expertise sources and retains it in the knowledge base storage. It contains the following components; human expert, knowledge engineer, external sources of data and system users, as shown in Figure 2. All of these are participants in constructing the system's expertise. Secondly, the Graphical User Interface (GUI) contains all the required interfaces in performing system functionality such as application program interface. The third part is the system modules which are responsible for reasoning and finding the solutions. The modules are Reasoning Specification module, the Inference Engine, the Knowledge Base and the User Adviser module.

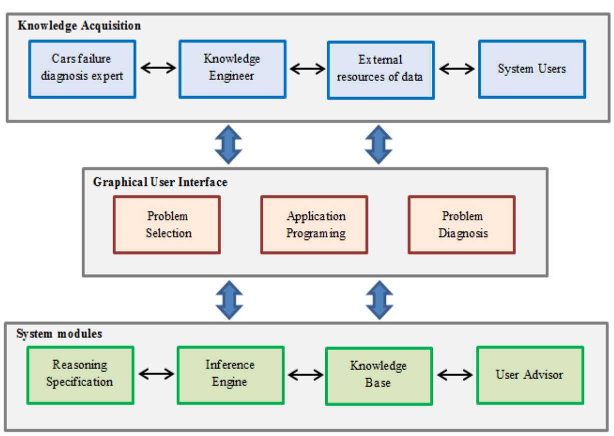

Fig. 2 CFMDAS architecture.

The Reasoning Specification module assists the inference engine in translating the logical results into meaningful text to be understandable by the users (i.e. the recommendations), while the User Adviser assists the user on how to handle the given problem. In case the user is a driver, it can suggest to the user the nearest car service centers in the region. The applicable maps and information that the system has belong to specific regions of Malaysia such as Kuala Lumpur and Selangor.

4.2 The Inference Engine Specifications

The inference engine traces the applicable facts that represent the corresponding symptoms (i.e. the observed variables or behaviour) and apply them to the tagged rules. In the proposed Car Failure and Malfunction Diagnosis Assistance System (CFMDAS), production-rules is the chosen form for knowledge representation. Additionally, the inference engine is the forward-chaining type (data driven mode) as shown in Figure 3.

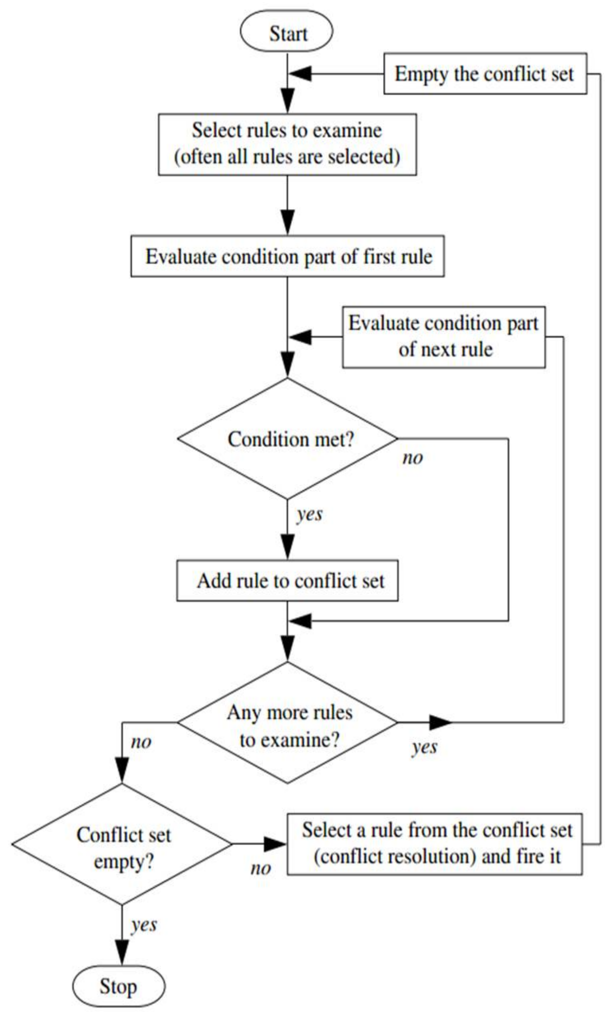

Fig. 3 Forward-chaining algorithm [7].

Forward-chaining inference engine has the advantages of producing solutions for the unformulated problems. In this type of engine, the satisfactory facts that meet the rules conditions are promoted to be triggered [7]. All the applicable rules resulting from the previous process make up the conflict set of rules to be implemented according to specific order that enables solution generation.

4.3 CFMDAS Decision Tree

Car failure diagnosis is an investigation process which requires search operation of the symptoms and the indicators that can lead to the problem's solution. Due to the fact that the car consists of many internal systems such as ignition system, fuel injection system, cooling system, braking system, lubrication system, air intake and exhaust systems which all are interconnected, faults are difficult to trace and find. As a result, a decision tree is considered as a useful approach in such situation. Rule-based approach is a good candidate to the problems that can be represented in decision tree form.

In the following example, a basic rule is presented as it is needed in the system analytical reasoning process:

if ? motion starter gives sound is Yes and
? motion starter sound is normal Yes and
? fuel tank empty is No
then ? fuel pump damaged is Yes.

According to [6], "a rule describes the action that should be taken if a symptom is observed. The empirical association between premises and conclusions in the knowledge base is their main characteristic." In the previous rule example, the system looks for then examines the keywords like give sound, sound normal and tank empty which are the conditions variables to find the satisfied rule or rules. The following figure shows one of the main branches of the decision tree of the proposed system.

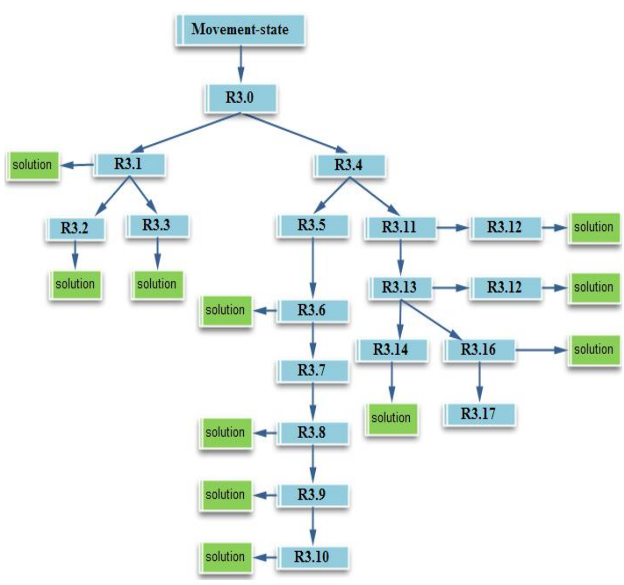

Fig. 4 Decision tree branch example.

Since a single rule might lead to a branch of rules, selection of the applicable one can be easily made by adopting a structured tree. However, such approach does not require a process model, but an intensive decomposition made to each diagnostic case to construct rules that can cover all the possible faults [6]. Nonetheless, there are some limitations needed to be considered in applying rule-based expert system such as system learning capability and the reliability of the acquired knowledge.

4.4 CFMDAS Main Processes

The CFMDAS is an online system with multi-tasking capabilities that is directive for car fault detection. It provides information sources and knowledge interaction and evaluation regarding the technical process to be tackled. Such tasks are failure tracing, failure recognition, and customer advising that requires it to adopt various types of modules (see Figure 5) [15].

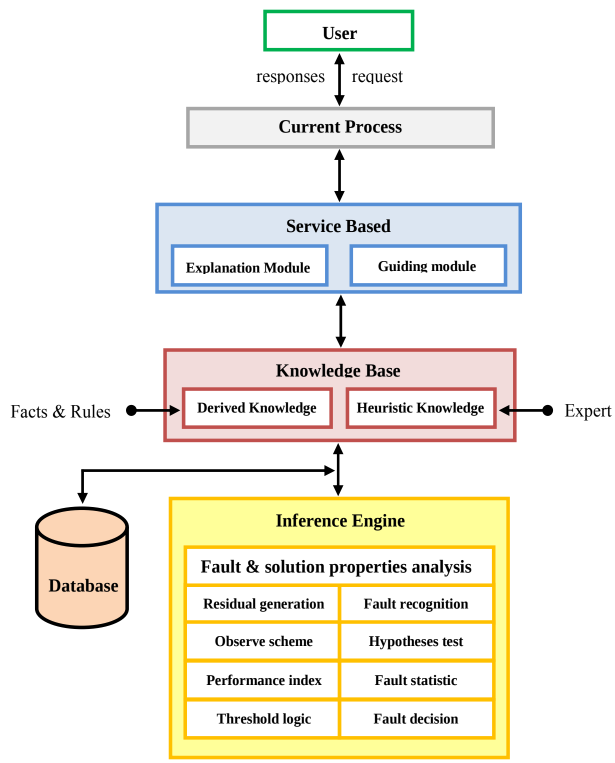

Fig. 5 CFMDAS processes [16].

Each module's goal is achieved by applying a number of processes. Figure 5 shows the system components in a process level. One of the main characteristics of the CFMDAS is the addition of the database to be in parallel with the system's knowledge base. An interaction is held between the knowledge base and the database including information transfer about the processes under execution.

The database works as a temporary storage due to its continuous change in state [17]. The knowledge base of the system encompasses both the derived and the heuristic knowledge about the required car failure diagnostic process [16]. The inference engine is built to do the reasoning based on several algorithmic procedures that enable it to reach the required conclusion.

5. CFMDAS Implementation and Results

To implement the CFMDAS model, Win-Prolog [18] logical programing language is used as a general purpose tool for system concept development and prototyping. Win-Prolog is more adept to computation logic than to mechanics where the drudgery of tasks such as stack pointers, memory allocation, and etc. are left to the computational engine.

Win-Prolog is well-suited for expressing complex thoughts. It reduces the drudgery of handling compact expressions and allows the developer to focus on the problem representation and solution. In addition, Win-Prolog incorporates logical inferencing mechanism and this powerful property can be exploited to develop distinctive inference engine. Moreover, Win-Prolog provides Prodata database interface toolkit which offers many facilities [18]. We consider three main states for car failure diagnosis [15], in each of these states the expert system can determine and give a step by step explanation of what the problem is to the user. The system also has two features; help and advice.

In our work, we try to deal with a non-expert user and benefit from simple and clever ideas to diagnose and solve the problem. If the user did not succeed in solving the problem, the application gives the user advice on what he/she should do and a help window, which contains names of different cities in Malaysia. For each city, the system provides the address of car service shops and their phone number for car tow and repair. The Graphical User Interface (GUI) performs as a communication tool that connects the user with the system. It displays the questions in English to be answered by the user and shows the corresponding results.

5.1 System Functionality

The system can be utilized by mechanical engineers or technicians with little knowledge or experience including local and foreign drivers who are new to the Malaysian environment and who are yet to familiarise themselves to where they can get help when they have problems with their cars. The proposed CFMDAS provides the following functions:

- The system poses a set of questions to the user to be answered and system decomposition is made based on user responses.
- The events and the collected data for each diagnostic process are retained in the system database to be analysed and exploited in enhancing the knowledge base and constructing new rules for future use.
- Explanation section is provided to help and guide the user in the diagnostic and on how to implement the repair tasks.
- Final diagnostic result is evaluated by the user for system inferencing improvement.
- The system has the feature for car service location guide that provides information about the nearest car service locations in the region and contact details.

5.2 The Prototype

The proposed online diagnostic expert system utilizes a combination of qualitative and quantitative procedures for car fault and malfunction detection. The mixture of both provides reliability to the technical process and facilitates knowledge interaction and analysis.

An executable prototype of the proposed Car Failure and Malfunction Diagnosis Assistance System (CFMDAS) has been successfully implemented and validated. The results show that basic diagnostic procedures are very satisfactory and the online processing ability is acceptable and gives the required information such as the positioning system services. CFMDAS implementation and samples of the user interface along with the results are described in the following paragraphs.

CFMDAS starts by displaying its main window, which contains the three car fault states of the system as shown in Figure 6. The user is expected to choose a case that is particular to the problem he/she is facing.

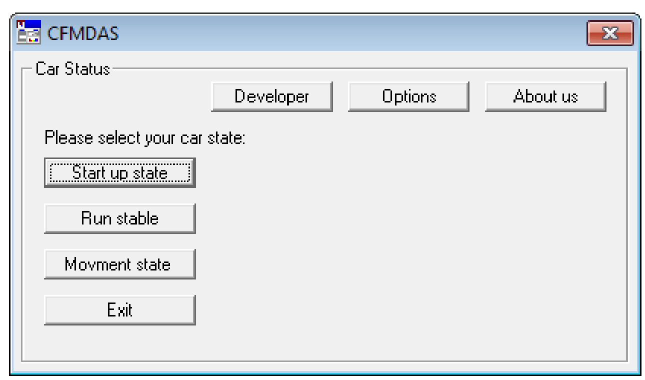

Fig. 6 CFMDAS main menu.

The following figure is an example of a dialogue that may occur in the start-up state. It depicts one of the early problems that may be encountered when the engine starts.

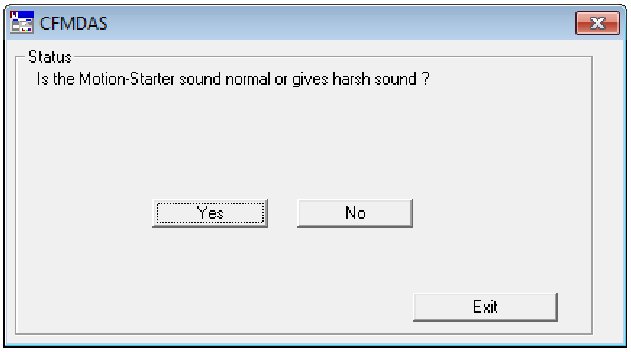

Fig. 7 Start-up state dialogue example.

The system asks the user if he/she hears the sound of the motion starter. If yes then it asks about the sound of the starter in the next step. If the user clicks the No button it means that at the start of the engine there is no sound. At the click of the No button, another dialogue appears and the scenario changes based on the user's responses.

The application contains many characteristics such as enabling the user to replay the application if the user did not succeed in solving the problem while modifying the dialogue scenarios accordingly. In addition, the help button helps users or drivers to find car service centers in their city. If a user clicks any help button in the application, then the help window in Figure 8 pops up for them to choose the nearest location where they can find services.

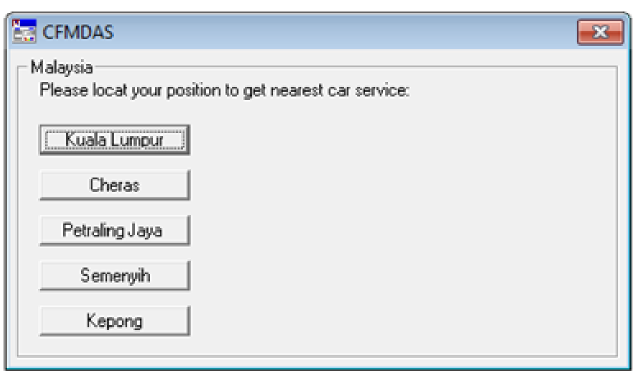

Fig. 8 Location window.

If a user in Cheras clicks Cheras button, the corresponding window in Figure 9 pops up containing all the necessary information of the car service center.

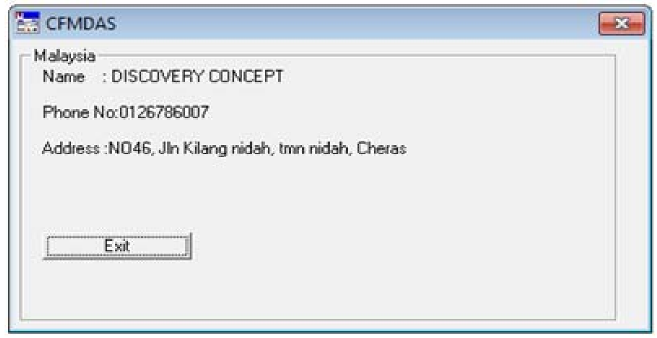

Fig. 9 Car service information window.

5.3 Analysis

The parallelism of the knowledge base and the database improves system performance [16]. Database utilization involves recording of the processes that are taking place in the system knowledge base. The advantage behind this procedure is to overcome the repetition of incorrect decisions during the reasoning by changing the sequence of the applicable rules in the conflict set. The online processing is another advantage of this parallelism. It reduces the reasoning time by selecting the best sequence of the triggered rules during execution. However, in such system where a diagnostic result is based on system reliability and it is user reliability dependent, inaccurately provided data to the system is more likely to cause inappropriate diagnostic result.

6. Conclusion and Future Work

In this paper, a Knowledge-Based System (KBS) for car failure and malfunction diagnosis is presented. The proposed CFMDAS is utilized to assist inexperienced mechanics or drivers who face sudden failure in the car and provide decision support system. In addition, CFMDAS is considered as an interactive training tool that can provide expert guidance in car fault detection. Using this system, loss of customers and income due to lack or inadequacy of knowledge can be mitigated.

System implementation results indicate that the system has significance in places where work productivity is improved by decreasing fault diagnosis time and increasing users understanding. More so, it can be considered as a successful alternative to the highly skilled mechanics. Further improvement to the system domain knowledge specifications is required to enhance domain knowledge representation. Furthermore, adopting another AI technique to work in system rules revision to add more effectiveness to the diagnosis process will be considered.

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