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Car failure fuzzy fault diagnostic system based on fault tree analysis

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ABSTRACT : In this paper, we use fuzzy set logic to account for imprecision and uncertainty in information and data while employing fault tree analysis.

INTRODUCTION

A method is presented for process fault diagnosis using information from fault tree analysis and uncertainty/ imprecision of data related to faulty component in Car Engine. Fault tree analysis, which has been used as a method of which provides a procedure for identifying failures within a process. A fuzzy fault diagnostic system is constructed which uses the fuzzy fault tree analysis to represent a knowledge of the causal relationships between various component of Car Engine and process operation in the whole system

Fault tree analysis is useful for system reliability and fault identification related risk involved in the system , since which illustrates the failure logic of a system, and shows combinations and sequences of failure which can lead to a failure condition under consideration .The fault diagnosis decision support system is developed which uses fault tree analysis for representation and acquisition of knowledge from the process operation For many systems, estimation of qualitative/quantitative information from fault tree analysis is difficult due to uncertainty and imprecision of information about process malfunction.

In this paper, we use fuzzy set logic to account for imprecision and uncertainty in information and data while employing fault tree analysis. Qualitative information of fault tree analysis, i.e. minimal cut sets from a fault tree, is transformed into the knowledge base in the form of production rules. Quantitative information which obtained by fuzzy tree analysis is used to determine the Surety factors and stored in the knowledge base. The fuzzy fault diagnostic system can identify component failures and process disturbances which can lead to system malfunctions by matching the process uncertainty data from system with the pattern of IF statements stored in the computers. From the uncertainty detected data and knowledge, the system also evaluates Surety factors of component failures and process disturbances for sequence checking in diagnosis.

FAULT TREE FOR OPERATION PROCESS IN CAR ENGINE

A process of activities carried out in Car Engine along with their corresponding component is shown in Fig.1.

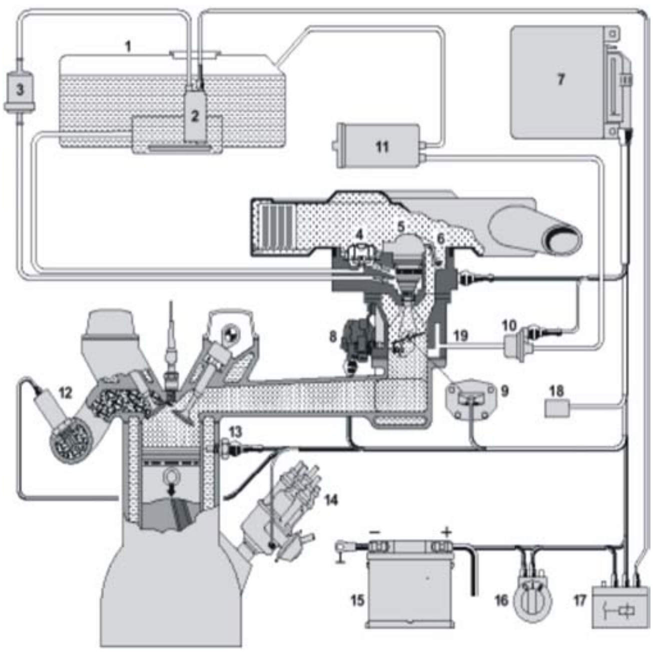

Fig.1. (1. Fuel tank, 2. Electric fuel pump, 3. Fuel filter, 4. Fuel-pressure regulator, 5. Solenoid-operated fuel injector, 6. Air-temperature sensor, 7. ECU, 8. Throttle-valve actuator, 9. Throttle-valve potentiometer, 10. Canister-purge valve, 11. Carbon canister, 12. Lambda oxygen sensor, 13. Engine-temperature sensor, 14. Ignition distributor, 15. Battery, 16. Ignition-start switch, 17. Relay, 18. Diagnosis connection, 19. Central injection unit.)

The main function of engine is to provide necessary momentum to the Car. Car Engine consists of few important component which may leads to disturbance in activities of engine. The number in circle in the diagrams show nodes which are connecting points of components. The following notation is used to describe deviation in process variables at different nodes.

Process variables in the fault tree can be divided into two groups. G1 type and G2 type. The G1 type such as too high, high, normal, low and too low is used to describe disturbance in the process. Too high, too low denote large deviations in the high, low direction respectively which, and high, low denote deviations which can be corrected. The G2 type such as more, less is used to describe deviations,. More, less denote no signal to cancel the effect of deviations in the process variables, and normal denotes a standard state.

KNOWLEDGE REPRESENTATION AND ACQUISITION

Fault tree analysis is used for the representation and acquisition of knowledge from the process operation in car engine. The fault propagation in process is modulated by causal relationship from the qualitative information, i.e. a fault tree and it's minimal cut sets. The method can determine the minimum number of sensors and the monitoring points to detect basic events in six sensors in circles is illustrated in Table 1, such as fuel sensor (S1), Ignition Sensor (S2), IAT Sensor (S3), Air Fuel Ratio System (S4), Crank shaft sensor (S5) and finally Power supply Sensor (S6). These sensors are having standard reading for normal operation as per following table.

Table 1 : Sensor reading under normal status.

S.No.	Name of Component/ System/Subsystems	Process Variable	Sensor Reading
1	Fuel delivery system	PW	**S1 = 6.4**
2	Iginition system	IGT	**S2 = 9**
3	IAT System	AT	**S3 = 40**
4	AFR System	AR	**S4 = 10:1**
5	Crank shaft	ROT	**S5 = 26**
6	Power supply	VL	**S6 = 24**

Abbreviations :

AT : Air temperature Sensor

AR : Air fuel Ratio

ROT : Rotation of Crank shaft

VL : Voltage

PW : Pulse width/sec

IGT : Ignition /sec

Table 2 : Minimal cutsets of fault tree classification.

Minimal cut set	Classification
Cut set (2,(4,9)	Intake Air Temperature system Failure
Cut set (2(5,11)	Air Fuel Ratio System Failure
Cut set (3(6,12))	Crank Shaft Failure
Cut set (3(7,14))	Power System Failure
Cut set (2(4,8))	Over all system disturbance leading to system failure
Cut set (2(5,10))	
Cut set (3(6,14)	
Cut set (3(7,15))	
Cut set (1,2))	Fuel delivery system failure
Cut set (1,3)	Ignition system failure

Based on the minimal cut sets for the process operation in Car engine. The qualitative information can be transformed into production rules. For example cutest (2,4,9) shows there is a problem in Intake Air Temperature system of car engine and could cause temperature high and Similarly disturbance can be predicted using minimal cutest (2,5,11) where Fuel delivery system is getting improper amount of fuel ratio which may be lean in qty cause trouble to combustion process in car engine Further this can be transformed into a well defined production rules as show below :

GENERATION OF PRODUCTION RULES

RULE 01 (IF S1 IS NORMAL & S2 IS NORMAL THEN CAR ENGINE WILL FUNCTION PROPERLY)

RULE 02 (IF S1 IS ABNORMAL & S2 IS NORMAL THEN WHOLE SYSTEM IS UNSTABLE LEADING TO DISTURBANCE IN WHOLE SYSTEM)

RULE 03 (IF S1 IS HIGH & S2 IS NORMAL & S4 IS NORMAL & S5 IS NORMAL, S6 IS NORMAL & S3 IS ABNORMAL THEN TEMPERATURE IS ABNORMAL LEADING TO DISTURBANCE IN WHOLE SYSTEM)

RULE 04 (IF S1 IS HIGH & S2 IS NORMAL & S4 IS NORMAL & S5 IS NORMAL & S6 IS NORMAL & S3 IS HIGH {HAVING HIGH TEMPERATURE > 40 THEN COMBUSTION IS DISRPUTED}

RULE 05 (IF S1 IS HIGH & & S2 IS NORMAL & S4 IS NORMAL & S5 IS NORMAL & S6 IS NORMAL & S3 IS VERY HIGH {HAVING HIGHER TEMPERATURE < 70 THEN COMBUSTION IS DISRPUTED }

RULE 06 (IF S1 IS LOW & S2 IS NORMAL & S5 IS NORMAL & S6 IS NORMAL & S3 IS NORMAL & S4 IS ABNORMAL {THEN FUEL RATIO REACHING INTO FDS IS EITHER RICH OR LEAN LEADING TO BLOCKADE COMBUSTION PROCESS}

RULE 07 (IF S1 IS LOW & S2 IS NORMAL & S5 IS NORMAL & S6 IS NORMAL & S3 IS NORMAL & S6 IS NORMAL & S4 IS HIGH { THEN FUEL RATIO REACHING INTO FDS IS LEAN LEADING TO BLOCKADE COMBUSTION PROCESS}

RULE 08 (IF S1 IS LOW & S2 IS NORMAL & S5 IS NORMAL & S6 IS NORMAL & S6 IS NORMAL & S4 IS LOW {THEN FUEL RATIO REACHING INTO FDS IS HIGH LEADING TO BLOCKADE COMBUSTION PROCESS}

RULE 09 (IF S1 IS NORMAL & S2 IS ABNORMAL THEN SYSTEM IS UNSTABLE LEADING TO SYSTEM FAILURE)

RULE 10 (IF S1 IS NORMAL & S2 IS ABNORMAL & S3 IS NORMAL & S4 IS NORMAL & S6 IS NORMAL & S5 IS ABNORMAL THEN CRANKSHAFT POSITION SYSTEM IS IN ABNORMAL STATUS (LEADING TO DISTURBED STATE OF THE SYSTEM)

RULE 11 (IF S1 IS NORMAL & S2 IS HIGH & S3 IS NORMAL & S4 IS NORMAL & S6 IS NORMAL & S5 IS HIGH {THEN CRANKSHAFT SHIFT IN POSITIVE DIRECTION BUT LESS THEN 26 DEGREE THEN IGNITION SYSTEM WILL GET EFFECTED {LEADING TO SYSTEM FAILURE}

RULE 12 (IF S1 IS NORMAL & S2 IS HIGH & S3 IS NORMAL & S4 IS NORMAL & S6 IS NORMAL & S5 IS VERY LOW {CRANKSHAFT SHIFT IN NEGATIVE DIRECTION THEN IGNITION SYSTEM WILL GET EFFECTED LEADING TO SYSTEM FAILURE}

RULE 13 (IF S1 IS NORMAL & S2 IS LOW & S3 IS NORMAL & S4 IS NORMAL & S5 IS NORMAL & S6 IS ABNORMAL {IMPROPER VOLTAGE IS RECEIVED BY POWER SUPPLY UNIT DUE TO EITHER FAULTY SUPPLY WIRE OR IMPROPER POWER GENERATION BY POWER UNIT LEADING TO SYSTEM FAILURE)

RULE 14 (IF S1 IS NORMAL & S2 IS LOW & S3 IS NORMAL & S4 IS NORMAL & S5 IS NORMAL & S6 IS VERY LOW {IMPROPER VOLTAGE IS 08 VOLT RECEIVED BY POWER SUPPLY UNIT DUE TO FAULTY FUSED SUPPLY WIRE LEADING TO SYSTEM FAILURE)

RULE 15 (IF S1 IS NORMAL & S2 IS ABNORMAL & S3 IS NORMAL & S4 IS NORMAL & S5 IS NORMAL & S6 IS VERY HIGH {IMPROPER VOLTAGE 48 VOLT IS RECEIVED BY POWER SUPPLY UNIT DUE TO IMPROPER POWER GENERATION BY POWER UNIT LEADING TO SYSTEM FAILURE}

METHOD USED FOR RULE FORMULATIONS

RULE 07 (IF S1 IS LOW & S2 IS NORMAL & S5 IS NORMAL & S6 IS NORMAL & S3 IS NORMAL & S6 IS NORMAL & S4 IS HIGH { THEN FUEL RATIO REACHING INTO FDS IS LEAN LEADING TO BLOCKADE COMBUSTION PROCESS}

Here If Pulse Width is Low and S2 is normal, S3 is normal, S5 is normal, S6 is normal and the sensor reading in S4 is high *i.e.*, Air Fuel Ratio is 12:1 which means Fuel is Rich in content causing combustion process disrupted

FUZZINESS IN RULES

An imprecision of component failure can be described by using the failure rate of the component, Surety function **S** will be used to describe the fuzziness' of logical sum for THEN statement.

We use Surety factors of production rule, in writing SF_rule, to deal with the uncertainty of the information in the knowledge base. A **SF_rule** means a surety factor in THEN statement of a rule under it's IF statement occurred exactly, and defined by Eqn. (*i*).

Table 3 : Failure rates and estimation of unavialability factors.

Component/System	Event numbers	Basic event	Repair Time (r)	Failure Rate of Component /System(λ)	Unavailability Factor (Q_i)
Intake Air Temperature	9	2	0.06	0.40	0.224
Air Fuel Ratio system	11	2	0.02	0.23	0.246
Crank Shaft Rotation	12	3	0.03	0.32	0.396
Faulty Fuse wire	14	3	0.05	0.22	0.058
Fuel Delivery System	2	1	0.08	0.18	0.119
Ignition System	3	1	0.07	0.10	0.220

Here r-denotes repair period of a component/System during T = 1yr; l = denotes failure rate of component/system

$$Q_i = \lambda\left(\frac{T}{2}+r\right) \quad ...(i)$$

$\mu_{c_i}(x)$ = Denotes membership function for corresponding component.

Surety Factor

$$S_i = Q_i * \mu_{c_i}(x) \quad ...(ii)$$

SF_Rule(x) = Max {(S_1, S_2, S_3, ..., S_m)} of Abnormal behaving Component/System available in ANTECEDENT of Rule identified}

FUZZYNESS IN PROCESS VARIABLES

We can consider a process variable in fault tree as a fuzzy set. Uncertainty about process variables, which detected from sensor readings, is dealt through membership functions, and transformed to surety factors of sensor readings. The relation for these fuzzy sets with process variables appear as in for Example (IF S1 IS HIGH & S2 IS NORMAL & S4 IS NORMAL & S5 IS NORMAL & S6 IS NORMAL & S3 IS HIGH {HAVING HIGHER TEMPERATURE > 40 THEN COMBUSTION IS DISRPUTED)

We can calculate surety factors of process variables by the membership functions and sensor readings From the fuzziness of process variable, Surety factors about IF statements in knowledge base will be determined.

FAULT DIAGNOSIS

The fuzzy expert system attempts to identify the component failures and process disturbances which can lead to system malfunction by searching through the IF statements of rules, corresponding to process data obtain from the sensors installed, such as sensor readings in Table 4. The pattern recognition in inference engine is completed by means of which a production rule will fire through certainty factor in IF statement having n members with SF_pv(1), SF_pv(2), ……. SF_pv(n), the certainty factor

Table 4 : Sensor readings at six monitoring points.

S.No.	Sensor Reading	Surety Factor (SF)					
		G1 Type			G2 Type		
		High	Normal	Low	Very High	Normal	Very Low
1	S1 = 6.4	0.80	1.00	0.60			
2	S2 = 9		1.00		0.60		0.40
3	S3 = 40		1.00	0.37	0.57		
4	S4 = 10:1	0.83	1.00	0.58			
5	S5 = 26	0.86	1.00				0.46
6	S6 = 24		1.00		0.50		0.33

in the IF statement can be presented in the form.

SF_if = SF_pv(1)∧ SF_pv(2), ……. ∧S_pv(n) ...(*iii*)

Here pv- Process Variable

For example, using the values of.

(IF S1 IS HIGH & S2 IS NORMAL & S4 IS NORMAL & S5 IS NORMAL & S6 IS NORMAL & S3 IS HIGH {HAVING HIGH TEMPERATURE > 40 THEN COMBUSTION IS DISRPUTED)

In turns, the expert system identify the positive causes in THEN statements which are composed of component failures and disturbances, and reasoning results are shown in Table 5.

Table 5 : Reasoning results for the example.

Rule No.	Positive Cases	SF_ If	SF_ Rule	SF_Then	Sequence No.
04	FUEL DELIVERY SYSTEM FAILURE	0.825	0.098	0.0805	1
05	FUEL DELIVERY SYSTEM FAILURE	0.825	0.127	0.1047	2
15	IGNITION SYSTEM FAILURE	0.444	0.191	0.8480	4
16	IGNITION SYSTEM FAILURE	0.500	0.290	0.1450	3

Finally, sequence checking in diagnosis for complex positive causes is carry out in the expert system through evaluating Surety factors of THEN statement for fired rules by a multiplication.

SF_then = SF_if * SF_rule ....(*iv*)

A checking sequence for our example on detection of faulty components Using Equ. (iv) yields diagnosis using fault tree analysis and Surety factors, the system can successfully diagnose any single or multiple faults in the Automotives.

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