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Application of Artificial Intelligence in Fault Diagnosis of Automotive Systems

Aru, O.E., *Adimora, K.C. and Mba, C.P.

Department of Computer Engineering, College of Engineering and Engineering Technology, Michael Okpara University of Agriculture, Umudike, PMB 7267, Umuahia, Abia State, Nigeria.
*adimora.kyrian@mouau.edu.ng; aru.eze@mouau.edu.ng

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ABSTRACT

The automobile fault diagnosis system is specifically built for identifying, characterizing, and analyzing faults whenever there is a breakdown or a failure in a system for a precise solution. Most times the attributed fault from the trial and error method is false and an attempt to resolve such a fault always leads to a worse situation with great loss of resources. However, in this paper, the application of artificial intelligence for fault diagnosis of the automotive system was employed to overcome these problems. This research paper also aims at minimizing downtime through the provision of an intelligent fault diagnosis system that is capable of giving precise fault information on the system and provide solutions on how it will be repaired at a zero time. The new system is flexible in application and was designed with the help of artificial intelligence based on machine learning principles. Algorithm for critical fault determination was developed and probability set equations were formulated also at the implementation of the new system. The research result was analyzed and tested in MATLAB software and the results revealed that the new system favorably eliminates the problems indicated by the trial and error method.

1. INTRODUCTION

In recent times, a lot of vehicle accidents on the road have been recorded. From the statistical point of view, over 50 percent of a vehicle accident on the road besides drivers' recklessness is caused by unidentified mechanical vehicle faults. Bekibele *et al.* (2007) carried out research on risk factors for road traffic accidents. According to the research result, the cause of road traffic accidents includes mechanical fault (50 %), and bad road (12.5 %). This is because most automobile engineers adopt a trial and error approach in their daily automobile system maintenance. According to their viewpoint, a situation where a vehicle with brake fault is mistaken for shock or alignment fault even after the repair poses vulnerability to road accidents and thus, is a big threat to life. Since the system breakdown or failure is inevitable, there is a need for precise and effective analysis of faults that resulted in the breakdown in order to avert accidents and save lives. Before now, many scholars have done some relevant researches concerning fault diagnosis and they are viewed as follows.

Zeki *et al.* (2020) carried out a comprehensive review work of the recent advancements of machine learning (ML) techniques that are widely applied to predictive maintenance for smart manufacturing. The research study was merely a review work without a system developed to handle the predictive maintenance highlighted unlike the new system. Nedeye (2019) conducted a review work that summaries the diagnosis, research of systems using artificial intelligence approaches to examine the application particularly in the field of diagnosis of complex systems. The work was also a mere review and never built a new system. Sathish *et al.* (2018) conducted research on an electric power system that focused on accurate fault location on the electric power line to minimize the time needed to repair the damage, restore power, and reduce costs through internet of things (IoT) applications. The research study is limited to faults in electric power system distribution and transmission and may not be applicable to the maintenance of the automobile system. Bhavana *et al.* (2020) executed *a* research study for monitoring home appliances through the internet and thereby detect faults without much human interaction. The fault detection system implemented in the study only takes care of home appliances and may not be applicable to automobile system maintenance. Sepasgozar *et al.* (2020) conducted a comprehensive article review of the state-of-the-art applications of the internet of things technology applied in homes. The paper study is a review work only and never developed a new system to solve highlighted the problem. Raza *et al.* (2020) conducted a comprehensive review of fault-diagnosing methods in the power transmission system that serves as a guide for the researcher to understand different methods and techniques in the field. The paper is only a review work and never implements a workable system besides the review of the existing work conducted. The work of Mulvey *et al.* (2019) focuses on the literature survey application of machine learning to fault management in cellular networks from an operational perspective. It is just a research survey on a cellular network and never built a new system. Arcos *et al.* (2020) conducted a research study that is focused on the insight for the design of household appliances that will make fault diagnosis easy through possible symptoms that depict faults on household appliances. The research paper focused only on faults with household appliances and never made it generic for automobile maintenance purposes. Singh et al. (2019) conducted a paper study on fault diagnosis that is focused on advancing building fault diagnosis to reduce the complexity often experienced in diagnosing faults on buildings. The work is limited to building fault diagnosis and may not be applicable to the automobile engineering system. According to Lunze (2017), a research study was conducted in the best way to derive analytical redundancy relations in the fault diagnosable system. The study is focused on diagnosable systems for analytical redundancy and may not be applicable to finding faults in the automobile system.

None of the relevant reviewed works stated in this study paper, was able to develop a system that is capable of giving precise information on automobile system faults and this is the research gap the paper study is contributing to the body of knowledge through its solution.

2. MATERIALS AND METHODS

2.1. Materials

The materials used in the design and implementation of the new system are:

- Computer system on which the fault diagnosis software is run
- The data cable that connects the automobile system
- Fault diagnosis software application
- Hardware, software automobile interface system
- Digital oscilloscope for comparing manufacturer's graphical results
- Internet facility

2.2. The New System Framework Description

The artificial intelligence fault diagnosis automobile system that is machine learning-based is the adopted methodology for the design of the new system. Figure 1 is the conceptual framework of the fault diagnosis automobile system of this research study.

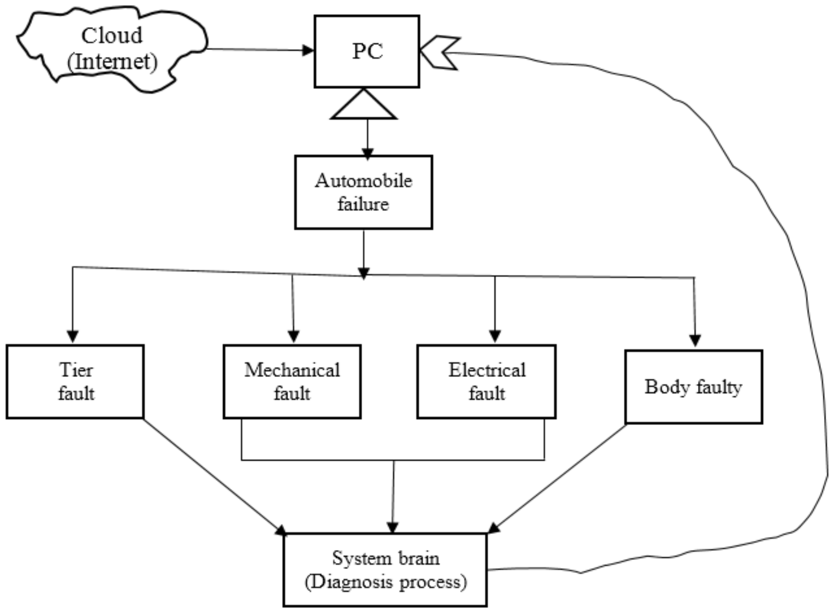

Figure 1: Conceptual framework of the new system

The cloud section of the framework is the internet facility the PC uses in exploring the manufacturer's design graphs online based on the input model of the diagnosable automobile system and compare with the current state status of the system using the new system. The same result shows no fault while deviation on the comparison results show that faults exist and the parts of the automobile system involved are specified by their respective names for immediate repair. Wherever there is a deviation on the trough or crest of the oscilloscope generated graph the test is saying the degree of the fault is high while deviation near the base shows a minimal fault occurrence. These processes are carried out within the new system in microseconds and once the fault is detected the next process is to isolate the identified fault with a red x sign denoting danger.

2.3. Significance of Automobile Fault Diagnosis

In this research, the automotive fault diagnosis system was designed to provide the following:

- high system uptime
- low exhaust emissions
- high system safety
- efficient repair

Considering a vehicle as a typical automobile system to drive home the fault diagnosis idea in this research study. High vehicle uptime together with efficient repair, is defined in terms of the minimized time at the workshop that maximizes the possible revenue for a vehicle operator. Requirements on low exhaust emissions are mainly driven by legislations and the new system takes care of the situation through faults detection process. The properties high vehicle uptime, low exhaust emissions, high safety, as well as efficient repair, are all examples of the more general dependability attributes availability, reliability, safety, integrity and maintainability provided by the automotive fault diagnosis system as presented in Figure 2. To ensure achievement of the required properties, fault diagnosis is performed by means of the three activities:

- legislative on-board diagnosis
- off-board diagnosis
- on-board fault accommodation

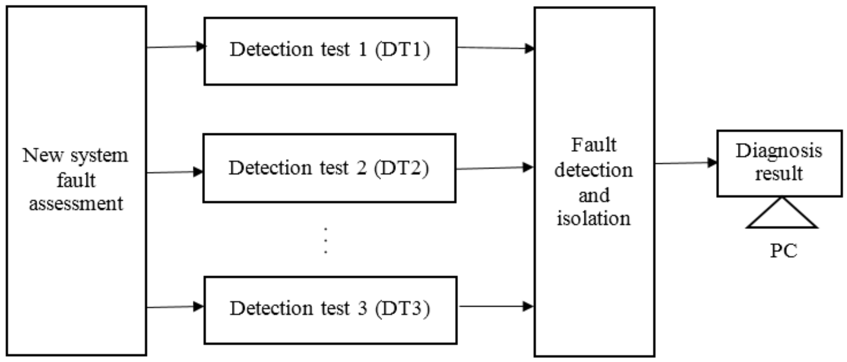

Figure 2: Diagram of automobile fault diagnosis system

In this research study, the Bayesian fault isolation principle was employed in the design of the new system and the detailed concept of fault isolation method which is referred to as structured residuals or structured hypothesis tests was considered. The sets of detection test results ($DT_1, DT_2, DT_3, DT_4, DT_5$) of Figure 2 and the corresponding isolated faults ($f_{i1}, f_{i2}, f_{i3}, f_{i4}, f_{i5}$) have confirmed the efficacy of the new system in fault diagnosis of automotive systems. Table 2 shows which detection tests that are sensitive to which faults. The unit value of 1 represent sensitivity whereas zero value represents non-sensitivity of the fault detected. DT_1 denotes legislative on-board diagnosis, DT_2 denotes off-board diagnosis, and so on. In general, any fault detection by the new system at its isolation unit which contains the detection tests $\{DT_1, DT_2 \ldots, DT_n\}$, where the outcome of the test DT_n is a detection result D_R with a corresponding sub-diagnosis result DT_i must be considered critical and resolved immediately otherwise the detected fault will degenerate. Under a single fault assumption, the diagnosis result (D_R) can be obtained as stated in Equation 1.

$$D_R = \bigcap_{i=1}^{n} DT_i \quad (1)$$

For multiple faults, the Kleer diagnosis theory is applied and is used in analyzing "Davis Circuit" depicted in Figure 3 (Kleer and Brown, 1986).

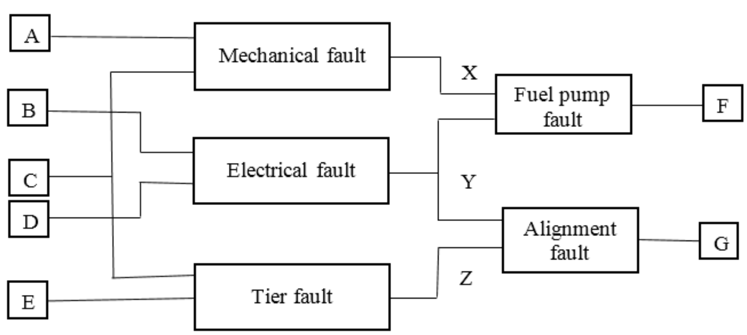

Figure 3: Davis circuit

In Figure 3, the letters A –Z denote faults at different level and can be diagnosed using Davis circuit. The letter C specifically denotes critical fault. The circuit also tests if a system diagnosable or not. A system is diagnosable if for any set of possible measurements (any complete set of observations) that have a unique diagnosis, there is a fault to be detected. Therefore, if it can observe A, B, C, D, E, F, G, then the system is not diagnosable. Else if it can observe A, B, C, D, E, F, G, X, Y, Z, then the system is diagnosable (meaning that fault is present).

$$AB(M_1) \Rightarrow Out\ (A_1, 0)$$

Let C and D be a conjunction of literals C covers D if any literal of C is a literal of D. This simply denotes the following mathematical expression for fault diagnosis using Davis Circuit in solving problem on automobile system. The Table 1 defines the digital values corresponding to every fault on automotive system.

$$C = Ft(C_1) \wedge \llcorner\ Ft(C_2) covers \tag{2}$$

$$D = Ft(C_1) \wedge \vdash Ft(C_1) \wedge Ft(C_3) \tag{3}$$

$$C = Ft(C_1) \wedge \perp Ft(C_2) does\ not\ cover \tag{4}$$

$$D = Ft(C_1) \wedge Ft(C_2) \wedge Ft(C_3) \tag{5}$$

Equations 2 to 5 depict the input units through which the new system diagnosis a system.

The values in Table 1 are the numbers defined in the new system for fetch specific fault with accuracy since the new system fault analysis result is represented in numbers and graphs.

Table 1: Davis circuit fault analysis with numbers

Davis labels	Degree of fault	System parts	System defined parameters
A	High = 1.0	Engine top	[0 - 0.25]
B	Medium = 0.5	Fuel pump	[0.5 – 1]
C	Low = 0 or less 0.5	Fan belt	[0.01 -0.5]
D		Piston and valve	[1.0-1.5]
E		Carburetor	[0.0-0.3]
F		Fan belt	[-1 – 0.5]
G		Gear box	[1 -3.5]
X		Electrical fuse	[0 -0.5]
Y		Body dent	[1.5 – 3.0]
Z		A/C	[1.0 – 2.0]

2.4. Fault Diagnoses Representations

The new system represents all the possible faults for automotive applications as follows;

- Fault:
  $n\ components\ \Rightarrow 2^n\ states$
- Intuition:
  $Ft(C_1) \wedge \perp Ft(C_2) \wedge Ft(C_3)$
  $Ft(C_1) \wedge \perp Ft(C_2) \wedge Ft(C_3)$

$$Partial\ diagnosis = Ft\ (C_1) \wedge \perp Ft\ (C_2) \tag{7}$$

These expressions take care of the new system intuitive reasoning process during fault diagnosis. Where a partial diagnosis is a Ft-clause Φ such that any state e covered by Φ is a diagnosis. The partial diagnoses were divided into state diagnosis and purely partial diagnosis.

- State diagnosis
  $Ft\ (C_1) \wedge Ft(C_2) \wedge Ft(C_3) \Rightarrow \{f_{i2}, f_{i4}\} \cap \{\{f_{i5}, f_{i3}\} \cup \{f_{i1}, f_{i2}\}\}$
  $Ft(C_1) \wedge Ft(C_2) \wedge \perp Ft(C_2)\ \forall\ n\{\{f_{i5}, f_{i3}\} \cup \{f_{i1}, f_{i2}\}\} \cup \{f_{i4}, f_{i2,} f_{i3,}\}$
  $Ft(C_1) \wedge \perp Ft(C_2) \wedge Ft(C_3) \Rightarrow \{f_{i2}, f_{i1}\} \cap \{f_{i2}, f_{i2}\} \cap \{f_{i2}, f_{i3}\} \cap \{f_{i2}, f_{i4}\}$
  $Ft(C_1) \wedge \perp Ft(C_2) \wedge \perp Ft(C_3) \rightleftarrows \{f_{i2}, f_{i1}\} \cap \{f_{i2}, f_{i2}\} \cap \{f_{i2}, f_{i3}\} \cap \{f_{i2}, f_{i4}\}$
  $\vdash Ft(C_1) \wedge Ft(C_2) \wedge Ft(C_3) \Rightarrow \{\{f_{i2}, f_{i1}\}\ U\{f_{i2}, f_{i2}\}\} \cap \{f_{i2}, f_{i3}\} \cap \{f_{i2}, f_{i4}\}$

These expressions are what determine the actual state of the detected fault through the elements of the sets intersections.

- Partial diagnoses that are not states:
  $Ft(C_1) \wedge Ft(C_2)$
  $Ft(C_1) \wedge Ft(C_2) \wedge Ft(C_3)$
  $Ft(C_1) \wedge Ft(C_2)$
  $Ft(C_1) \wedge \perp Ft(C_2)$
  $Ft(C_1) \wedge \perp Ft(2) \wedge Ft(C_3)$

These expressions allow the system to conduct partial test on a system when there is need.

Algorithm 1: Determination of critical fault (C_f).

Given: Incidence Matrix (F_D) of the over-determined structure graph of $\oint$ and $\sum$

1. Ignore the diffenetial constraints and insert the first derivative

   of the output to get F_d, and $n = 0, 1, \ldots, n^i$

2. Loop: Set $i := i + 1$

   Determine C_f from F_D by introducing additional derivatives of the

   sate diagnosis and the output.

   If C_f does not satisfy or represent an over − determineed oscilloscope

   graph from the manufacturer repeat Step 2.

3. Determine F^p and reduce it to F^p (with $q = \imath$)
4. Determine the expression in Equation 8 for Ft(i)

   Diagnosis Result: C_f of the form Equation 9

The algorithm is what analyzes the weight of every fault detected using the incidence matrix stated in Equations 8 and 9.

Consider these vectors that depict the categories of fault.

$$\begin{pmatrix} F(\ddot{t}) \\ F(\dot{t}) \\ F(t) \end{pmatrix} = \begin{pmatrix} -I & A & B \\ C & -I & A \\ C & B & A \\ -I & D & C \end{pmatrix}^{-1} * \begin{pmatrix} 0 \\ 0 \\ F(t) \\ \dot{F}(t) \end{pmatrix} \quad (8)$$

By ignoring some factors and the differential constraints $F(\ddot{t})$ *and* $F(\dot{t})$ as highlighted in step 1 of the algorithm, the following is obtained.

$$F(t) = y(\ddot{t}) - C_f x(\dot{t}) \Rightarrow that\ F^p\ is\ reduced\ to$$

$$F(t) = \dot{y}(t) - (C_f, 0, 1) * \begin{pmatrix} -I & A & B \\ C & -I & A \\ C & B & A \\ -I & D & C \end{pmatrix}^{-1} * \begin{pmatrix} 0 \\ 0 \\ F(t) \\ \dot{F}(t) \end{pmatrix} \quad (9)$$

Which is the required analytical expression for $Ft(i)$. The $Ft(i)$ is the critical fault detected using the algorithm stated above that employs the incidence matrix.

Algorithm 1 was applied to vehicle automotive system to enable the verification of the efficiency of the new system on a real life system. The application of the new system shows that the algorithm can be used for systems with input u (t). The vehicle under consideration has a velocity controller shown in the structure of the vehicle model presented in Figure 4 which adapts the velocity v (t) towards the reference velocity u (t).

$$Cv : \begin{cases} F_{\emptyset}(t) = v(t) - u(t) \\ a(t) = -C_1 F_{\emptyset}(t) - C_p(v(t) - u(t)) \end{cases} \quad (10)$$

The control input used by the controller is accelerating force a (t), which is the input to the model that yields the velocity v (t).

$$F_D: \dot{V}(t) = -\frac{C_p}{M} v(t) + \frac{1}{m} a(t) * \frac{\sin(\emptyset - n)}{C_f} \quad (11)$$

Where Cv depicts void (meaning fault is not critical), $F_D: \dot{V}(t)$ is detected fault at a particular state and time, M is the mass rated in kg, $C_1 F_{\emptyset}(t)$ is the system controller parameter at a known degree, $C_p(v(t))$ is the system controller parameter at particular state and time, $F_{\emptyset}(t)$ is the fault at a known degree and time with no defined state, $v(t)$ is the vertical state, $u(t)$ is the horizontal state, C_f is the critical fault, sin $(\emptyset - n)$ is the range of system test captured in the design scope.

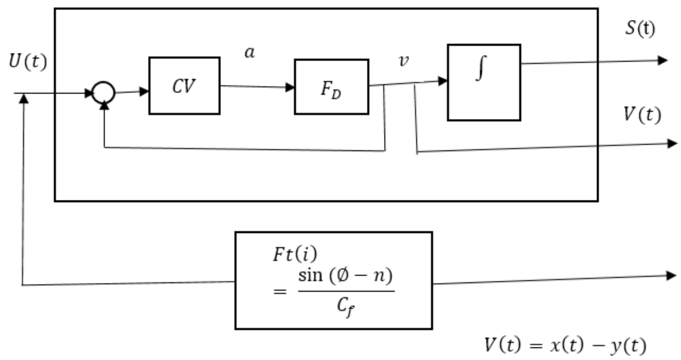

Figure 4: Structure of vehicle

The general fault detection and isolation mathematical model is given as:

$$U(t) = \frac{(C_V (4\pi)^3)}{(F_D V^2 \; a^2)} * \frac{\sin(\emptyset - n)}{C_f} \quad (12)$$

In this study, the concept of stochastic dominance i.e. situation where strategy F_P (fault present) is said to dominate strategy F_N (fault not present) if, for all possible outcome t, the probability that the outcome exceeds t is greater for strategy F_P than for strategyF_N was employed. To express this condition, mathematically, the distribution function is defined for strategy F_P as $F_P(t) = probability\ (outcome < t)$ and similarly, $F_N(t)$. The strategy F_P dominates strategy F_N if $F_P(t) < F_N(t)$. This implies that the $F_P(t) < F_N(t)$. Also, the second order of stochastic dominance is exhibited by F_P if:

$$\int_u^n F_P(t)dt > \int_u^n F_N(t)dt \ for\ all\ values\ of\ n$$

3. RESULTS AND DISCUSSION

The fault signature matrix detection tests of Table 2 showed that test DT_1 is sensitive to faults $f_{i3}\ and\ f_{i5}$ respectively because they have the value of 1. Also DT_2 is sensitive to faults $f_{i1}, f_{i2}, and\ f_{i4}$ because they have the value of 1 and it keep on iterating in this order with respect to sensitivity and non-sensitivity based on the value of 1 or 0. Therefore, the outcome from the detection tests are thus $DT_1 = 0, DT_2 = 1, DT_3 = 0, DT_4 = 0, DT_5 = 0$, which is combined with the fault signature matrix results in the sub-diagnosis results $DT_1 = \{f_{i2}, f_{i3}, f_{i5}\}$,

Table 2: The fault signature matrix

Tests	f_{i1}	f_{i2}	f_{i3}	f_{i4}	f_{i5}
DT_1	0	1	1	0	1
DT_2	1	1	0	1	0
DT_3	1	0	0	1	0
DT_4	1	1	0	0	1
DT_5	0	1	1	0	1

$$DT_2 = \{f_{i1}, f_{12}, f_{i4}\},\ DT_3 = \{f_{i1}, f_{i4}\},\ DT_4 = \{f_{i1}, f_{i2}, f_{i5}\},\ DT_5 = \{f_{i1}, f_{i3}, f_{i4}\}. \tag{13}$$

The latter is due to a common convention, saying that nothing can be deduced regarding the status of the system if a test has not alarmed. The diagnosis result (D_R) becomes:

$$D_R = DT_1 \cap DT_2 \cap DT_3 \cap DT_4 \cap DT_5 \tag{14a}$$

$$D_R = \{f_{i5}\} = \{f_{i2}, f_{i3}, f_{i5}\} \cap \{f_{i1}, f_{14}, f_{i5}\} \cap \{f_{i3}, f_{i4}, f_{i5}\} \cap \{f_{i1}, f_{i2}, f_{i5}\} \cap \{, f_{i3}, f_{i4}, f_{i4}\} \tag{14b}$$

It can be concluded that fault f_{i5} is present because it is the only element that is common to all the sets implemented in the new system design for diagnosing faults in automotive system.

Figures 5 and 6 depict the vehicle fault analysis and were used to compare the manufacturers' vehicle condition at production time and its current status after some years of use by the owner. The graphs on the left side has data on it whereas the graph on the right side is blank which shows no fault after diagnosis test.

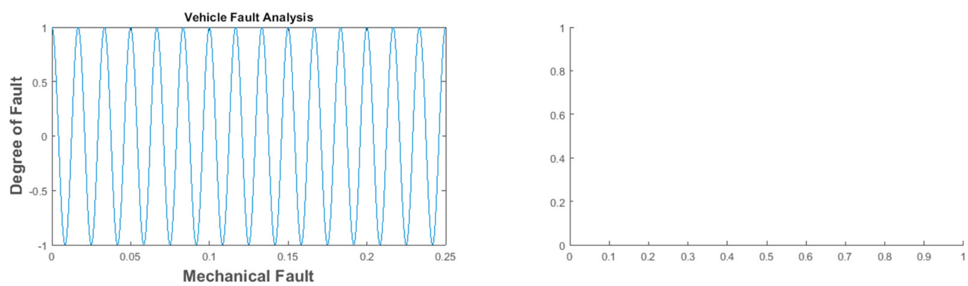

Figure 5: Vehicle fault analysis

The left-hand side of the graph in Figure 5 showed some degree of mechanical faults with the value ranges from 0 to 0.25. This range of values is defined in Table 1 under materials and methods section of this research study and indicated engine top as the existing fault. Therefore, the precise fault of the vehicle is probably from the engine top and nothing else. The right-hand side with a plane graph depicts no fault on the other parts of the vehicle except the detected engine top fault. The new system for scanning through the entire system generates digital numbers automatically that corresponds to the defined faults in Table 1. In Figure 6, the red color indicates fault occurrence while the blue color indicates minimal or no fault at all. Also, all the red colors are pointing towards the zero lines which implies a healthy condition of the vehicle in all aspects. Also, the blue color begins from the zero points on the x-axis spread to the y and z axes. This shows a very good condition of the tested vehicle. Figure 7 depicts the manufacturers' result comparison of an automotive system at a production stage and now is currently in use. The graphs with plots on the left side denote that some many things are not functioning well on the part of the engine diagnosed which is regarded as fault. In Figure 8, the plotted line begins from 0.5 and after two and half years, the vehicle began to depreciate with some minor problems known as electrical and mechanical faults. These faults keep on increasing to the level of serious damage because the faults were not identified. However, the application of the new system to the vehicle has revealed the hidden problem of the vehicle and has provided a solution. Thereby, validating the efficacy of the new system over the current system.

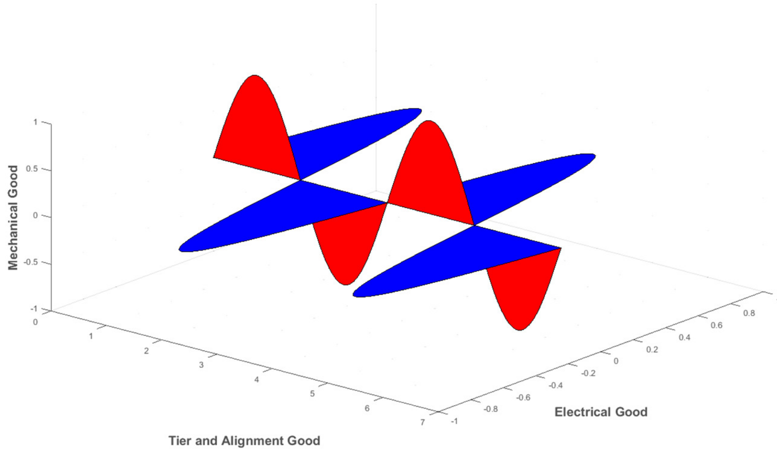

Figure 6: Vehicle health status analysis

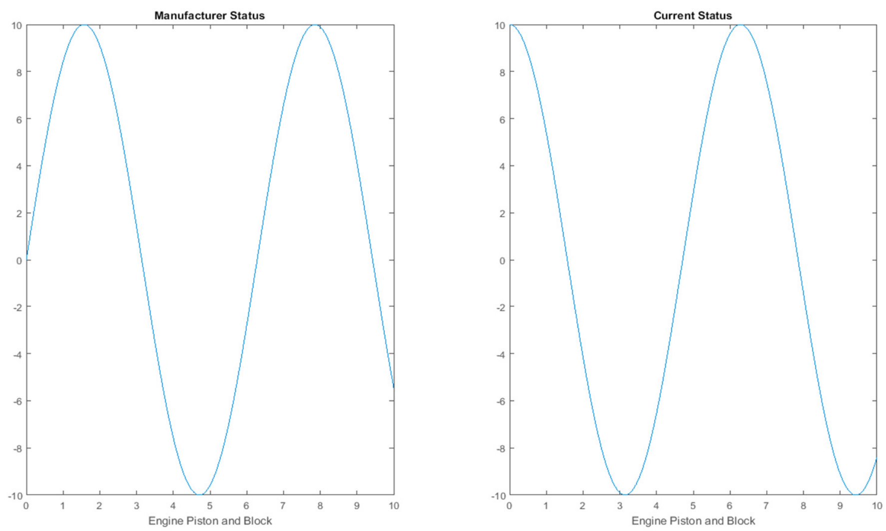

Figure 7: Vehicle manufacturer and current status comparison

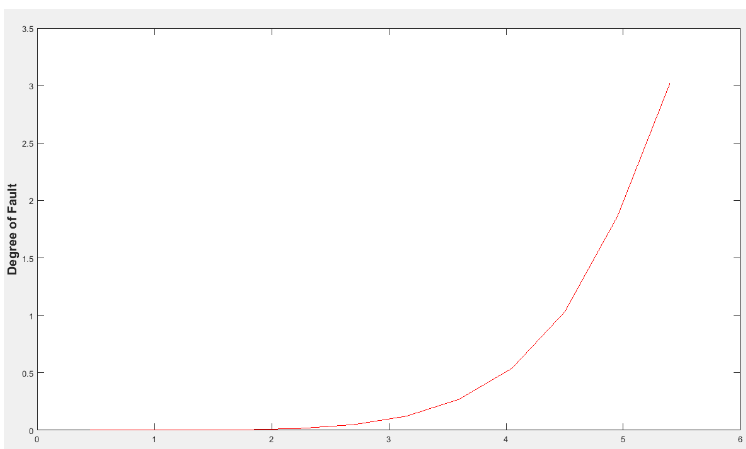

Figure 8: The outcome of Figure 3 (E/M fault)

4. CONCLUSION

In the paper study, the automobile fault diagnosis system was designed to help automobile engineers easily detect faults on a breakdown system with much accuracy at the fastest speed. The new system detects faults using defined information in its database achieved by the principle of artificial intelligence and then proffer a solution on how it will be repaired without any further damage. It reveals the status of every fault of a system by pointing directly to the affected location through its name and numeric identity on the database. The research results showed that the new system is friendly in use and most accurate in identifying faults, repairing faults compared to other existing methods.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Arcos, B. P., Bakker, C., Flipsen, B. and Balkenende, R. (2020). Practices of fault diagnosis in household appliances: Insights for design. *Journal of Cleaner Production*, *265*, p. 121812.

Bekibele, C. O., Fawole, O. I., Bamgboye, A.E., Adekunle, L.V., Ajav, R., and Baiyeroju, A.M. (2007). Risk factor for road traffic accidents among drivers of public institutions in Ibadan, Nigeria. *Africa Journal of Health Science*, 10(14), pp. 137 – 142.

Bhavana, K., Nekkanti, V. and Jayapandian, N. (2019). Internet of Things Enabled Device Fault Prediction System Using Machine Learning. In: *International Conference on Inventive Computation Technologies* (pp. 920-927). Springer, Cham.

De Kleer, J. and Brown, J. S. (1986). Theories of causal ordering. *Artificial intelligence*, *29*(1), pp. 33-61.

Lunze, J. (2017). A method to get analytical redundancy relations for fault diagnosis. *IFAC-PapersOnLine*, *50*(1), pp. 1006-1012.

Singh, M., Kien, N. T., Najeh, H., Ploix, S. and Caucheteux, A. (2019). Advancing building fault diagnosis using the concept of contextual and heterogeneous test. *Energies*, *12*(13), p. 2510.

Mulvey, D., Foh, H.C., Imran, A.M. and Tafazolli R. (2019). Cell fault management using machine learning techniques. *IEEE Access*, 7(4), pp. 124514 -124539.

Nedeye, G.L., Jean-Marie, F., and Oliver, A. (2019). Review of Machine Learning Approaches in Fault Diagnosis applied to IoT system. In: *International Conference on control Automation and Diagnosis ICCAD'19, July 2019 Grenoble, France, hal-02344344*.

Raza, A., Benrabah, A., Alquthami, T. and Akmal, M. (2020). A review of fault diagnosing methods in power transmission systems. *Applied Sciences,* 3(2*),* pp. 1-27.

Sathish, S., Renugadevi, B., Rajalakshmi, V. and Ramya, S.P. (2018). Automatic device fault diagnosis using artificial intelligence in IoT. *National Technology and Management, NCSDTM – OCT 2018*, pp. 1-6.

Sepasgozar, S., Karimi, R., Farahzadi, L., Moezzi, F., Shirowzhan, S., Ebrahimzadeh, S.M., Hui, F. and Aye, L. (2020). A systematic content review of artificial intelligence and the internet of things applications in smart homes. *Applied Sciences,* 7(4), pp. 1- 45.

Zeki, M.C., Abubakar, A.N., Qusim, Z., Orhan, K.M.A. and Babak, S. (2020). Machine Learning in Predictive Maintenance towards Sustainable Smart Manufacturing in Industry 4.0. *Sustainability,* 6(3*),* pp. 2-42.