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Expert System for Detecting and Diagnosing Car Engine Brake Failure Fault using Dynamic Control System (DCS)

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Abstract

Dynamic Control Systems (DCS) can be applied in detecting and diagnosing car engine brake failure faults which has continuously being implemented to serve different branches such as Mechanical Engineering and many others. Car engine Brake Failure is a sequence of diagnostic processes that brings about the deployment of expertise. It is very important to note that Expert System (ES) is one of the leading Artificial Intelligence techniques that have been adopted to handle such task. This paper presents the imperatives for an Expert System in developing Dynamic Control Systems for detecting and diagnosing car engine Brake Failure faults through input and output requirements of constructing successful Knowledge-Based Systems. Furthermore, diagnosis of car engine Brake Failure faults requires high technical skills and experienced mechanics which are typically scarce and expensive to get. Thus, DCS provides input and output equations in form of Matrix/Vector State Space Representation (MSSR) which is useful in assisting mechanical technicians for car brake failure detection and diagnosis via mathematical Differential Equations in form of DCS.

Keywords: Car engine brake failure faults; Dynamic Control Systems (DCS); Differential equations; Expert system; Matrix/Vector State Space Representation (MSSR); Generating function; Input and output equations; State equation

Introduction

A Dynamic control system (DCS) is a system of devices or set of devices, that manages commands, directs or regulates the behaviour of other device(s) or system(s) to achieve desired results through the use differential equations or mathematical models. In other words the definition of control system can be rewritten as a control system is a system, which controls other system [1].

Day by day, the demand of automation is increasing accordingly. Automation highly requires control of devices. In recent years, control systems plays main role in the development and advancement of modern technology and civilization. Practically every aspects of our day-to-day life are affected less or more by some control system. A bathroom toilet tank, a refrigerator, an air conditioner, a geezer, an automatic iron, an automobile all are control system. These systems are also used in industrial process for more output. We find control system in quality control of products, weapons system, transportation systems, power system, space technology, robotics and many more. The principles of control theory are applicable to engineering and non-engineering field both.

Method of Solution

Dynamics control system (DCS)

In applied mathematics and engineering the central theory deals with the behaviour of dynamical system over time. The dynamic behaviour of a system may therefore be understood by studying their mathematical description. For instance, the flight path of an airplane subject to certain engine thrust, rudder elevation angles and particular wind condition or the current flowing in an electrical circuit consisting of interconnections of resistors, inductors, capacitors, transistors, diodes, voltage or current source etc. can be predicted using mathematical description of the pertinent behaviour. Mathematical equations in the form of Differential or difference equations are used to describe the behaviour of the process usually referred to governing equations whose solutions give the required response of the particular system under consideration [2-8].

A system is a group of component part put together to accomplish a certain task. It is also said to be an arrangement or collection of things connected or related in such a manner as to form an entire whole. Simply, a system is an arrangement of physical component connected or related in such a manner as to form and or act an entire unit. Whereas the concept of Control is analogous as either to direct, regulate or to command. Thus a Control System is an arrangement of physical components connected or related in such a manner as to command, direct and regulate itself or another system. It is therefore important to note that a control system is made up of three components namely; input, process and output.

Control theory: Is an interdisciplinary branch of engineering and mathematics that deals with the behavior of dynamical systems with inputs, and how their behavior is modified by feedback. The usual objective of control theory is to control a system, often called the plant, so its output follows a desired control signal, called the reference, which may be a fixed or changing value. To do this a controller is designed, which monitors the output and compares it with the reference. The difference between actual and desired output, called the error signal, is applied as feedback to the input of the system, to bring the actual output closer to the reference. Some topics studied in control theory are stability (whether the output will converge to the reference value or oscillate about it), controllability and observability.

Extensive use is usually made of a diagrammatic style known as

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the block diagram. The transfer function, also known as the system function or network function, is a mathematical representation of the relation between the input and output based on the differential equations describing the system [9-16].

Although a major application of control theory is in control systems engineering, which deals with the design of process control systems for industry, other applications range far beyond this. As the general theory of feedback systems, control theory is useful wherever feedback occurs. A few examples are in physiology, electronics, climate modeling, machine design, ecosystems, navigation, neural networks, predator-prey interaction, gene expression, and production theory.

Mathematical classification of systems

In this paper we shall not dwell on a comprehensive classification of systems as this may not give the much desired understanding of the concept. Hence an enumeration of the more common classes of systems most often encountered in field of engineering and science is of high consideration. Any particular set of equation describing a given system generally depends on the effect to be captured. Some of these systems may include Lumped Parameter or Finite-Dimensional Systems; Distributed Parameters or infinite-Dimensional Systems; Continuous-Time and discrete-Time Systems; Deterministic and Stochastic Systems and appropriate combination of any of the fore mentioned is known as hybrid systems. It must however be noted that the appropriate mathematical setting for Finite-Dimensional System are Finite-Dimensional Vector Spaces and for infinite-Dimensional system are defined Infinite Dimensional Linear Spaces. Continuous-Time Finite-Dimensional Systems are described by Ordinary Differential Equations or some kinds of integral Equations while Discrete-Time Finite Dimensional Systems are governed by Ordinary Difference equations or Discrete- Time Counterparts to those Integral equations. The governing differential equations to Infinite-Dimensional Systems include partial Differential equations Volterra intergro-Differential Equations, Functional Equations etc. [17-22].

Finite-dimensional system

This is mainly concerned with continuous-time and Discrete-time finite dimensional system.

The continuous-time finite dimensional dynamic system for our consideration will be those described by the following set of governing differential equations:

$$\dot{x}_i = f_i\left(t, x_1, x_2, \ldots x_n, u_1, u_2, \ldots u_m\right), i = 1,2,3,\ldots n$$
$$\dot{y}_i = g_i\left(t, x_1, x_2, \ldots x_n, u_1, u_2, \ldots u_m\right), i = 1,2,3,\ldots p$$

where u_i,i = 1(1)m denote the inputs or the stimuli; y_ii = 1(1)p denote outputs or responses; x_i,i = 1(1)n represent state variables; t denotes time $\dot{x}_i$ denote time derivatives of state variables; f_i,i = 1,2,3,…n, real value functions of 1 + m + n real variables; g_i,i = 1,2,3,….p, real value function of 1 + m + n real variables.

A complete description of the system will usually require a set of initial conditions;

$x_i(t_0) = x_i(0)$, i = 1,2,3,…..,n where t_0 is initial time.

In most cases of practical application, there often arises the need to impose constraints on the quantities f_i, g_i and u_i.

Definition of basic terms

Open loop control system: An opened-loop controlled system is that in which the control action is independent of the output of the system Manual control system is also an open loop control system. Figure 1 shows the block diagram of open loop control system in which process output is totally independent of controller action.

Closed-loop control system: Control system in which the output has an effect on the input quantity in such a manner that the input quantity will adjust itself based on the output generated. As such the system of car engine overheating brake failure is categorized under the closed loop control system due to the fact that respective inputs depend upon the respective outputs of the system.

Feedback loop of control system: A feedback is a common and powerful tool when designing a control system. Feedback loop is the tool which takes the system output into consideration and enables the system to adjust its performance to meet a desired result of system.

In any control system, output is affected due to change in environmental condition or any kind of disturbance. So one signal is taken from output and is fed back to the input. This signal is compared with reference input and then error signal is generated. This error signal is applied to controller and output is corrected. Such a system is called feedback system. Figure 2 shows the block diagram of feedback system.

When feedback signal is positive then system called positive feedback system. For positive feedback system, the error signal is the addition of reference input signal and feedback signal. When feedback signal is negative then system is called negative feedback system. For negative feedback system, the error signal is given by difference of reference input signal and feedback signal [23-26]. Some of the characteristics of feedback include

1) Increases accuracy oscillation

2) Tendency towards instability

3) Reduces the sensitivity of ratio output to variation in system parameters

4) Reduces effect of nonlinearity

5) Reduces the effect of external disturbance or noise

6) Increases bandwidth.

For a given set of differential equations describing a certain dynamical system (system that changes with time) there is need to

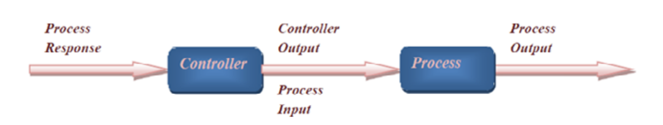

Figure 1: Closed-loop control system.

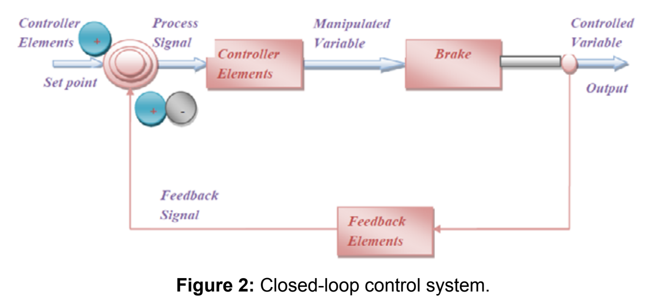

Figure 2: Closed-loop control system.

know the set of state variables and there number in the system. That is;

i) How many state variables are involved?

ii) What are these state variables?

For (i) above; the number of state variables is equal to the total number of initial conditions required to completely solve the differential equations of overheating for a car engine. For instance, if a dynamic system is described by a single second order differential equation then two initial conditions is required to completely solve the differential equation. Thus there are two state variables for this system. For (ii); these variables for which initial conditions are required for the solution of the governing differential equation defined above are chosen as the required state variables.

An example of such a control system is a car's cruise control, which is a device designed to maintain vehicle speed at a constant desired or reference speed provided by the driver. The controller is the cruise control, the plant is the car, and the system is the car and the cruise control. The system output is the car's speed, and the control itself is the engine's throttle position which determines how much power the engine delivers.

A primitive way to implement cruise control is simply to lock the throttle position when the driver engages cruise control. However, if the cruise control is engaged on a stretch of flat road, then the car will travel slower going uphill and faster when going downhill. This type of controller is called an open-loop controller because there is no feedback; no measurement of the system output (the car's speed) is used to alter the control (the throttle position.) As a result, the controller cannot compensate for changes acting on the car, like a change in the slope of the road [27].

In a closed-loop control system, data from a sensor monitoring the car's speed (the system output) enters a controller which continuously subtracts the quantity representing the speed from the reference quantity representing the desired speed. The difference, called the error, determines the throttle position (the control). The result is to match the car's speed to the reference speed (maintain the desired system output). Now, when the car goes uphill, the difference between the input (the sensed speed) and the reference continuously determines the throttle position. As the sensed speed drops below the reference, the difference increases, the throttle opens, and engine power increases, speeding up the vehicle. In this way, the controller dynamically counteracts changes to the car's speed. The central idea of these control systems is the feedback loop, the controller affects the system output, which in turn is measured and fed back to the controller. This example is also similar to detecting car brake failure by the concept of control system as will be discussed in details by some governing DE.

General formulation

Once the state variables are appropriately selected the next step is to construct the state variable equations. These state equations are system of first order differential equations in the state variables on the left hand side and algebraic system (function) of the state variables as system input and possibly time on the right hand side. In general for a multi-input multi-output system with m state variables we have

$x_1,x_2,x_3,\ldots x_m$,p inputs $u_1,u_2,u_3,\ldots u_p$, and r outputs

$y_1,y_2,y_3,\ldots y_r$, the state variable equations are given in this form:

$$\left.\begin{aligned}\dot{x}_1 &= f_1\left(x_1,x_2,\ldots x_m,u_1,u_2,\ldots u_p,t\right)\\ \dot{x}_2 &= f_2\left(x_1,x_2,\ldots x_m,u_1,u_2,\ldots u_p,t\right)\\ \dot{x}_3 &= f_3\left(x_1,x_2,\ldots x_m,u_1,u_2,\ldots u_p,t\right)\\ &\vdots\\ \dot{x}_m &= f_m\left(x_1,x_2,\ldots x_m,u_1,u_2,\ldots u_p,t\right)\end{aligned}\right\} \tag{1}$$

Where f_j are in general nonlinear functions of the arguments

Similarly, the system output variables may also be expressed as follows:

$$\left.\begin{aligned}\dot{y}_i &= g_1\left(x_1,x_2,\ldots x_m,u_1,u_2,\ldots u_p,t\right)\\ \dot{y}_2 &= g_2\left(x_1,x_2,\ldots x_m,u_1,u_2,\ldots u_p,t\right)\\ \dot{y}_3 &= g_3\left(x_1,x_2,\ldots x_m,u_1,u_2,\ldots u_p,t\right)\end{aligned}\right\} \tag{2}$$

Where $g_k^{'}$ s, are in general nonlinear functions.

In the event that non-linear elements are present in the system the functions $f_j(j = 1(1)m)$ and $g_k(k = 1(1)m)$ also turn out to be non-linear and quite complex in nature thereby making the analysis or solution complicated.

Matrix vector formalism

This involves the representation of equations 1,2 more conveniently using matrix-vector form by the following definitions:

$$\left.\begin{aligned}&X=\begin{bmatrix}x_1\\x_2\\\vdots\\x_m\end{bmatrix} \textit{is state vector},\quad F=\begin{bmatrix}f_1\\f_2\\\vdots\\f_m\end{bmatrix} \textit{as the function},\quad Y=\begin{bmatrix}y_1\\y_2\\\vdots\\y_m\end{bmatrix} \textit{output vector;}\\ &G=\begin{bmatrix}g_1\\g_2\\\vdots\\g_m\end{bmatrix} a\lg ebraic\ Function\ and\ U=\begin{bmatrix}u_1\\u_2\\\vdots\\u_m\end{bmatrix} \textit{input vector}\end{aligned}\right\} \tag{3}$$

Thus; the state variable equations are represented by

$$\dot{X} = F\left(x,u,t\right) \tag{4}$$

And the system output as

$$\dot{Y} = G\left(x,u,t\right) \tag{5}$$

As expected the complexity associated with the general formulation reduces considerably for the case of a linear system. In the event that all the elements in the model of a dynamical system are linear the algebraic functions (f_j and g_k) appearing in equations (1) and (2) will take the following special forms:

$$\left.\begin{aligned}\dot{x}_1 &= a_{11}x_1 + a_{12}x_2 + \cdots + a_{13}x_3 + b_{11}u_1 \cdots + b_{1r}u_r\\ \dot{x}_2 &= a_{21}x_1 + a_{22}x_2 + \cdots + a_{23}x_3 + b_{21}u_1 \cdots + b_{2r}u_r\\ \dot{x}_3 &= a_{31}x_1 + a_{32}x_2 + \cdots + a_{33}x_3 + b_{31}u_1 \cdots + b_{3r}u_r\\ &\vdots\\ \dot{x}_{\backslash m-1} &= a_{m-1,1}x_1 + a_{m-2,2}x_2 + \cdots + a_{m-3,m}x_m + b_{m-1,1}u_1 \cdots + b_{m-1,p}u_p\\ \dot{x}_{\backslash m} &= a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mm}x_m + b_{m1}u_1 \cdots + b_{mp}u_p\end{aligned}\right\} \tag{6}$$

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$$\left.\begin{aligned}
y_1 &= c_{11}x_1 + c_{12}x_2 + \cdots + c_{1m}\, x_m + d_{11}u_1 + d_{12}u_2 + \cdots + d_{1p}u_p \\
y_2 &= c_{21}x_1 + c_{22}x_2 + \cdots + c_{2m}\, x_m + d_{21}u_1 + d_{22}u_2 + \cdots + d_{2p}u_p \\
y_1 &= c_{31}x_1 + c_{32}x_2 + \cdots + c_{3m}\, x_m + d_{31}u_1 + d_{32}u_2 + \cdots + d_{3p}u_p \\
&\vdots \\
y_{r-1} &= c_{r-1,1}x_1 + c_{r-2,2}x_2 + \cdots + c_{r-1,m}x_m + d_{r-1,1}u_1 \cdots + d_{r-1,2}u_2 + \cdots d_{r-1,p}u_p \\
y_r &= c_{r1}x_1 + c_{r2}x_2 + \cdots + c_{3m}x_m + d_{r1}u_1 \cdots + d_{r2}u_2 + \cdots d_{rp}u_p
\end{aligned}\right\} \quad (7)$$

By defining the following quantities to enable us represent the formulations above in matrix-vector form:

$$\left.\begin{aligned}
A &= \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix}_{m\times m} = \textit{State matrix}, \\
B &= \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1p} \\ b_{21} & b_{22} & \cdots & b_{2p} \\ \vdots & \vdots & & \vdots \\ b_{m1} & b_{m2} & \cdots & b_{mp} \end{bmatrix}_{m\times p} = \textit{Input matrix}
\end{aligned}\right\} \quad (8)$$

$$\left. C = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1m} \\ c_{21} & c_{22} & \cdots & c_{2m} \\ \vdots & \vdots & & \vdots \\ c_{r1} & c_{r2} & \cdots & c_{rm} \end{bmatrix}_{r\times m} = \textit{Output Matrix},\ D = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1m} \\ d_{21} & d_{22} & \cdots & d_{2m} \\ \vdots & \vdots & & \vdots \\ d_{r1} & d_{r2} & \cdots & d_{rp} \end{bmatrix}_{r\times p} \right\} \quad (9)$$

Therefore, the final form of the system in the matrix-vector form is given as:

$$\dot{X} = AX + BU \quad \text{State equation} \quad (10)$$

$$\dot{Y} = CX + DU \quad \text{Out equation} \quad (11)$$

The above system of equation is known as the state-space representation or state-space form of the system model. This very convenient form of representing a system model is particularly useful in the analysis and control of a dynamic system (Figure 3).

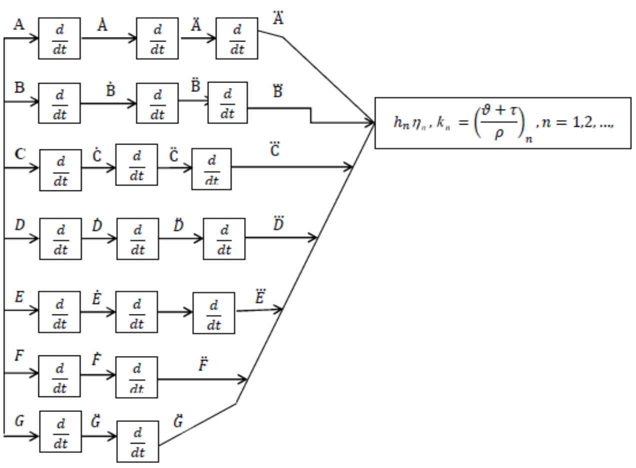

Figure 3: Expert/Dynamic system representation using block diagram.

Where ϑ and τ represent responses of sequences of decisions to be responded as either (Yes/No) respectively while ρ represents the total chances of decisive events that requires an absolute response at a time, h_n is the input generating function and k_n is the equiprobable response generating function [28-30].

Governing Differential Equations for Diagnosing Brake Problems

Suppose there is said to be a resulting fault in stopping the car then the DE gives the formulation for detecting the several decisions to be taken to the highest order of resolution given as:

$$\frac{1}{\eta_1}\left[\dddot{A} + \ddot{A} + \dot{A} + A\right] = h_1 \quad (12)$$

Certainly if it has decided to say clearly there is no such brake fault exist then there exist a free stable state system given by the DDE below:

$$\frac{1}{\eta_2}\left[\ddddot{B} + \dddot{B} + \ddot{B} + \dot{B} + B\right] = h_2 \quad (13)$$

Also; if there is said to be optimistic dragging from the wheel the DE is thus deduced for such a given conditioned and defined system as:

$$\frac{1}{\eta_3}\left[\dddot{C} + \ddot{C} + \dot{C} + C\right] = h_3 \quad (14)$$

I the situation is however realistically known to say that there exist some elements of noises; therefore the DDE is also generated for such a conditioned system as:

$$\frac{1}{\eta_4}\left[\ddddot{D} + \dddot{D} + \ddot{D} + \dot{D} + D\right] = h_4 \quad (15)$$

Conversely if there exist no such situation of condition as that given in the governing DE in equation (15) the DE below provides an alternative formulation via Figure 1. For the absence of noise in the system described as:

$$\frac{1}{\eta_5}\left[\dddot{E} + \ddot{E} + \dot{E} + E\right] = h_5 \quad (16)$$

Similarly, if there exist no brake warning light rattles then we have the DDE:

$$\frac{1}{\eta_6}\left[\ddot{F} + \dot{F} + F\right] = h_6 \quad (17)$$

From equation (13) and (16) we thus have the State Variable Equations (SVE) as:

$$\left.\begin{aligned}
\dot{f}_1 &= f_3 \\
\dot{f}_2 &= f_4 \\
\dot{f}_3 &= f_5 \\
\dot{f}_4 &= -f_2 - f_4 + \eta_5 h_5 \\
\dot{f}_5 &= f_6 \\
\dot{f}_6 &= -f_1 - f_3 - f_5 - f_6 + \eta_2 h_2
\end{aligned}\right\} \quad (18)$$

Expressing equation (18) in a matrix vector form gives the Matrix State Space Representation (MSSR) of the State Variable Equation (SVE) and hence the State Equation (SE) is deduced thereafter.

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$$\begin{pmatrix} \dot{f}_1 \\ \dot{f}_2 \\ \dot{f}_3 \\ \dot{f}_4 \\ \dot{f}_5 \\ \dot{f}_6 \end{pmatrix} = \begin{pmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ -1 & 0 & -1 & 0 & -1 & -1 \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ 0 \\ \eta_5 \\ 0 \\ \eta_2 \end{pmatrix} h(t) \Bigg\} \tag{19}$$

Hence the State Equation (SE) for the diagnosis is given by equation (20):

$$\dot{F} = AF + Bh \tag{20}$$

Similarly if by using equation (14) and (15) to formulate another SVE as well as MSSR for the given system for the described system to be decisively diagnosed. Thus; equation (21) below gives SVE for the described system as:

$$\left.\begin{aligned} & D_1 = D, D_2 = C, D_3 = \dot{D}, D_4 = \dot{C}, D_5 = \ddot{D}, D_6 = \ddot{C} \\ & D_5 = \ddot{D} \quad and \quad D_6 = \ddot{C}, D_7 = \ddot{D}, \dot{D}_7 = \dddot{D} \\ & \dot{D}_1 = D_3 \\ & \dot{D}_2 = D_4 \\ & \dot{D}_3 = D_5 \\ & \dot{D}_4 = D_6 \\ & \dot{D}_5 = D_7 \\ & \dot{D}_6 = -D_2 - D_4 - D_6 + \eta_3 h_3 \\ & \dot{D}_7 = -D_1 - D_3 - D_5 - D_7 + \eta_4 h_4 \end{aligned}\right\} \tag{21}$$

If equation (21) is expressed in a matrix vector form gives the Matrix State Space Representation (MSSR) of the State Variable Equation (SVE) and hence the State Equation (SE) can be deduced in the usual form as:

$$\begin{pmatrix} \dot{D}_1 \\ \dot{D}_2 \\ \dot{D}_3 \\ \dot{D}_4 \\ \dot{D}_5 \\ \dot{D}_6 \\ \dot{D}_7 \end{pmatrix} = \begin{pmatrix} 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & -1 & 0 & -1 & 0 & -1 & 0 \\ -1 & 0 & -1 & 0 & -1 & 0 & -1 \end{pmatrix} \begin{pmatrix} D_1 \\ D_2 \\ D_3 \\ D_4 \\ D_5 \\ D_6 \\ D_7 \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \eta_3 \\ \eta_4 \end{pmatrix} h(t) \Bigg\} \tag{22}$$

Thus; the State Equation (SE) for the diagnosing process is given by equation (23):

$$\dot{D} = AD + Bh \tag{23}$$

By considering equation (12) and (15) to formulate another SVE as well as MSSR for the given described system to be decisively diagnosed. Thus; equation (24) below gives SVE for the described system as:

$$\left.\begin{aligned} & E_1 = A, \quad E_2 = E, \quad E_3 = \dot{A}, \quad E_4 = \dot{E}, \quad E_5 = \ddot{A}, \quad E_6 = \ddot{E} \\ & \dot{E}_5 = \dddot{A} \quad and \quad \dot{E}_6 = \dddot{E} \\ & SVE \\ & \dot{E}_1 = E_3 \\ & \dot{E}_2 = E_4 \\ & \dot{E}_3 = E_5 \\ & \dot{E}_4 = E_6 \\ & \dot{E}_5 = -E_1 - E_3 - E_5 + \eta_1 h_1 \\ & \dot{E}_6 = -E_2 - E_4 - E_6 + \eta_4 h_4 \end{aligned}\right\} \tag{24}$$

Again; if equation (24) is expressed in a matrix vector form gives the Matrix State Space Representation (MSSR) of the State Variable Equation (SVE) and hence the State Equation (SE) is also deduced as:

$$\begin{pmatrix} \dot{E}_1 \\ \dot{E}_2 \\ \dot{E}_3 \\ \dot{E}_4 \\ \dot{E}_5 \\ \dot{E}_6 \end{pmatrix} = \begin{pmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ -1 & 0 & -1 & 0 & -1 & 0 \\ 0 & -1 & 0 & -1 & 0 & -1 \end{pmatrix} \begin{pmatrix} E_1 \\ E_2 \\ E_3 \\ E_4 \\ E_5 \\ E_6 \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \eta_1 \\ \eta_4 \end{pmatrix} h(t) \Bigg\} \tag{25}$$

therefore; equation (26) gives the State Equation (SE) for the diagnosing process as:

$$\dot{E} = AE + Bh \tag{26}$$

Practical Illustration of an Expert System using Dynamic Control System

Output equations

From equation (18) suppose the input is say h_1 (Brakes Stop Car?) (Figure 4):

Suppose the response is 'yes'; then the resulting output equation becomes:

$$y = CE + DU \; y_1 = \alpha \frac{(CE + DH)}{\alpha + \beta}; \quad ie: C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \end{bmatrix}, E = \begin{bmatrix} E_1 \\ E_2 \\ E_3 \\ E_4 \\ E_5 \\ E_6 \end{bmatrix}, D = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \end{bmatrix} \Bigg\} \tag{27}$$

$$H = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \eta_1 \\ \eta_4 \end{pmatrix} \tag{28}$$

And the equivalence Expert System graphics output (Figure 5).

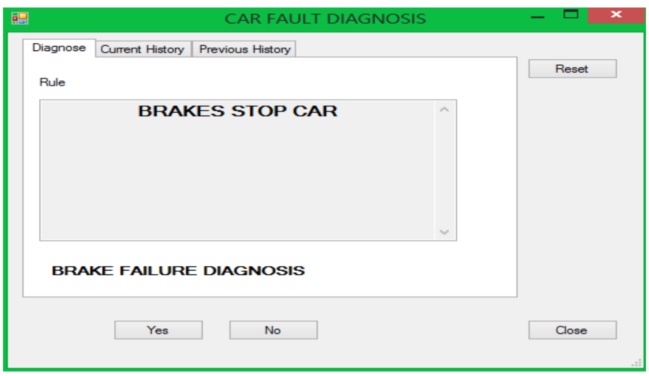

Figure 4: Interface trying to verify whether brake stops the car when applied.

Similarly, if the input/output (response implied) as h_2 (Parking Brake Failure?) is yes (Input Response) then the governing output equation becomes:

$$y = CE + DU\ y_1 = \alpha\frac{(CE+DH)}{\alpha+\beta};\quad ie: C = [0\ \ 1\ \ 0\ \ 0\ \ 0], E = \begin{bmatrix} E_1 \\ E_2 \\ E_3 \\ E_4 \\ E_5 \\ E_6 \end{bmatrix}, D = [0\ \ 0\ \ 0\ \ 0\ \ 0] \Bigg\} \tag{29}$$

$$ie: y_2 = h_2 = E_2$$

$$H = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \eta_1 \\ \eta_4 \end{pmatrix} \tag{30}$$

And the equivalence Expert System graphics output is given by Figure 6.

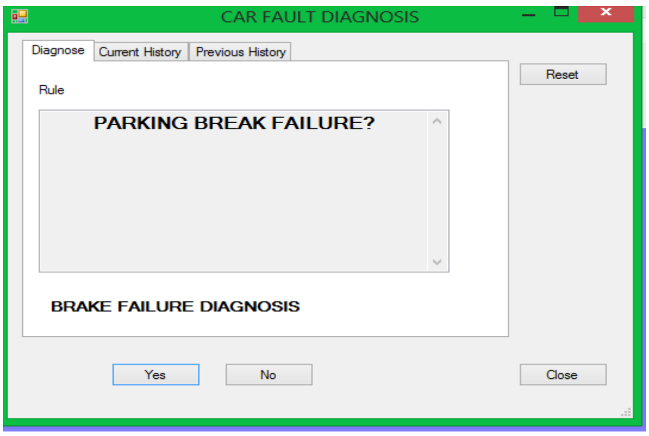

Figure 5: Sample interface displaying how parking brake faults can be detected.

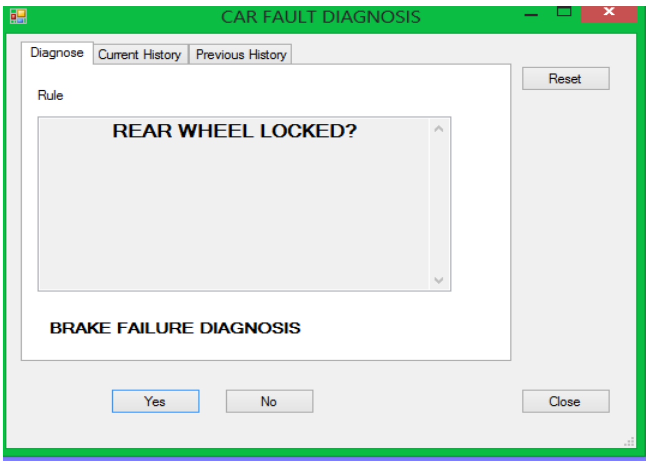

Figure 6: Interface displaying whether rear heel is locked.

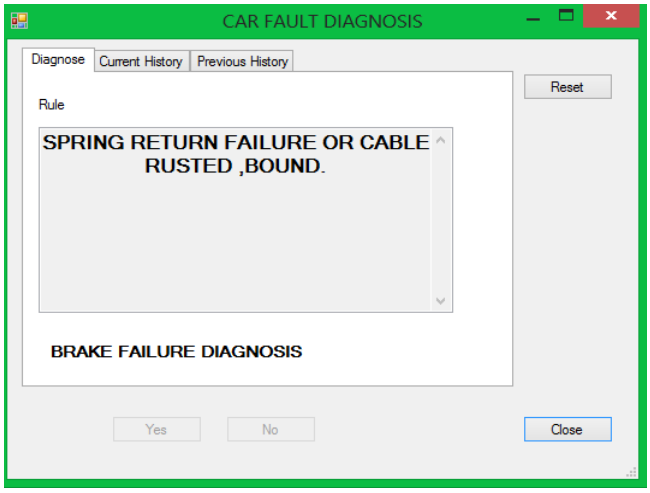

Figure 7: ES Interface trying to detect spring return failure.

Similarly, if the input (response implied) as h_3 (Rear Wheel Locked?) is yes (Input Response) then the governing output equation becomes:

$$y = CE + DU\ y_3 = \alpha\frac{(CE+DH)}{\alpha+\beta};\quad ie: C = [0\ \ 0\ \ 1\ \ 0\ \ 0], E = \begin{bmatrix} E_1 \\ E_2 \\ E_3 \\ E_4 \\ E_5 \\ E_6 \end{bmatrix}, D = [0\ \ 0\ \ 0\ \ 0\ \ 0] \Bigg\} \tag{31}$$

$$ie: y_3 = h_3 = E_3$$

$$H = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \eta_1 \\ \eta_4 \end{pmatrix} \tag{32}$$

Hence the output interface is thus given by Figure 7.

Thus; the suggested output in Figure 4 gives the general solution of the problem for the sequence of responses $_n$ (Yes). This is to say that the detected problem is either 'Spring Return Failure or Cable Rusted or Bound' as expressed in equation (32).

Conversely; if the response is NO for the inputs say h_1 (Brakes Stop Car?) in Figure1 then by equation (18) the output equation is thus formulated as:

$$y = CE + DU\ y_1 = \beta\frac{(CE+DH)}{\alpha+\beta};\quad ie: C = [1\ \ 0\ \ 0\ \ 0\ \ 0], E = \begin{bmatrix} E_1 \\ E_2 \\ E_3 \\ E_4 \\ E_5 \\ E_6 \end{bmatrix}, D = [0\ \ 0\ \ 0\ \ 0\ \ 0] \Bigg\} \tag{33}$$

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$$H = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \eta_1 \\ \eta_4 \end{pmatrix} \tag{34}$$

And the equivalence Expert System graphics output is given (Figure 8).

Similarly, if the input (response implied) as h_2 (Parking Brake Failure?) is No (Input Response) then the governing output equation becomes:

$$\left. \begin{array}{l} y = CE + DU \; y_1 = \beta\dfrac{(CE+DH)}{\alpha+\beta}; \quad ie: C = [0 \;\; 1 \;\; 0 \;\; 0 \;\; 0], E = \begin{bmatrix} E_1 \\ E_2 \\ E_3 \\ E_4 \\ E_5 \\ E_6 \end{bmatrix}, D = [0 \;\; 0 \;\; 0 \;\; 0 \;\; 0] \\ ie: y_2 = h_2 = E_2 \end{array} \right\} \tag{35}$$

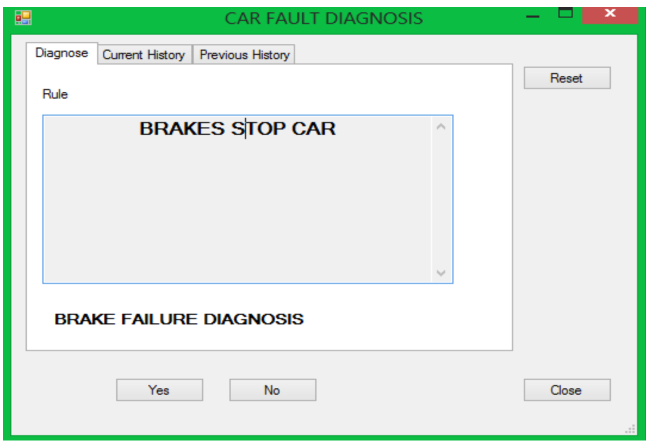

Figure 8: An interface trying to detect brake faults.

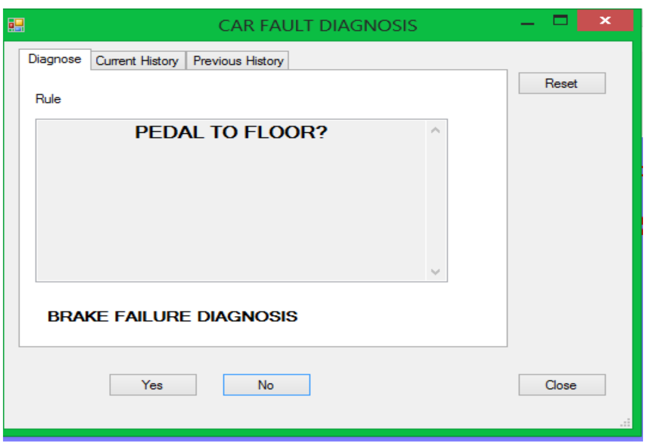

Figure 9: An interface displaying how pedal faults can be detected.

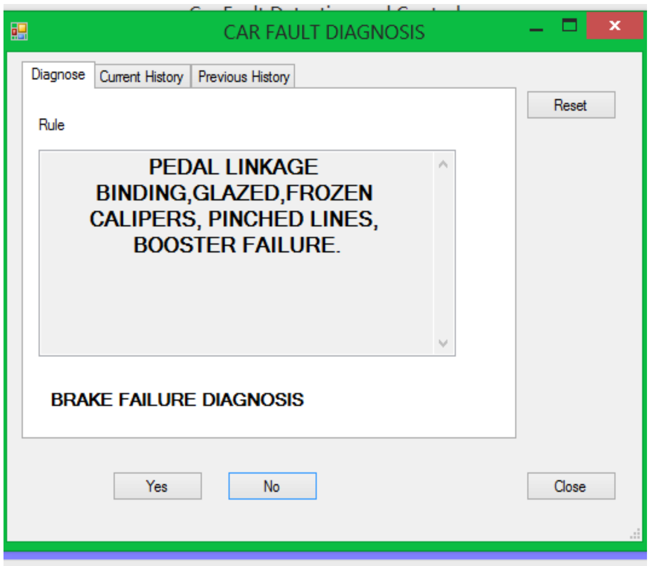

Figure 10: An interface displaying pedal linkage binding, glazed...finally detected.

$$H = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \eta_1 \\ \eta_4 \end{pmatrix} \tag{36}$$

And the equivalence Expert System graphics output is given by Figure 9.

Similarly, if the input (response implied) as h_3 (Rear Wheel Locked?) is yes (Input Response) then the governing output equation becomes:

$$\left. \begin{array}{l} y = CE + DU \; y_3 = \beta\dfrac{(CE+DH)}{\alpha+\beta}; \quad ie: C = [0 \;\; 0 \;\; 1 \;\; 0 \;\; 0], E = \begin{bmatrix} E_1 \\ E_2 \\ E_3 \\ E_4 \\ E_5 \\ E_6 \end{bmatrix}, D = [0 \;\; 0 \;\; 0 \;\; 0 \;\; 0] \\ ie: y_3 = h_3 = E_3 \end{array} \right\} \tag{37}$$

$$H = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \eta_1 \\ \eta_4 \end{pmatrix} \tag{38}$$

Hence the output interface is thus given by Figure 10.

This is to say that equation (37) and Figure 8 gives the general solution for τ_n responses.

Signal Flow Diagrams

In this section, signal flow diagrams of equations modelled in this paper will be illustrated as appropriate [31].

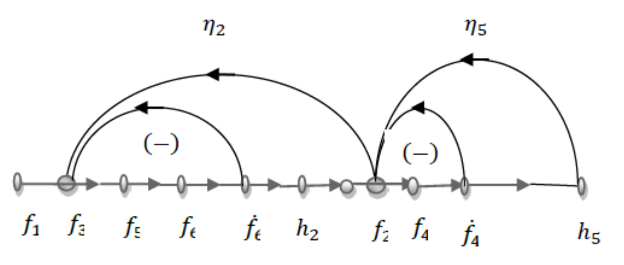

Figure 11: Signal flow.

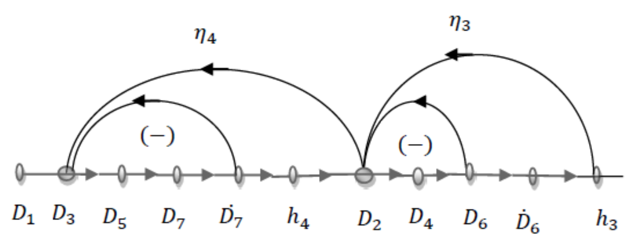

Figure 12: Signal flow diagram for equation 21.

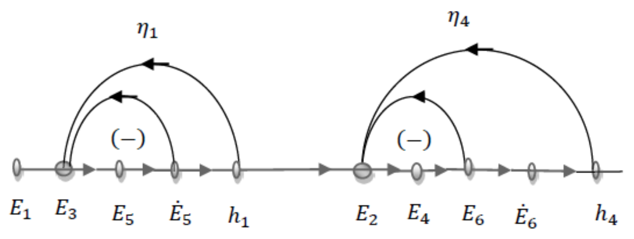

Figure 13: Signal flow diagram for equation 24.

Considering signal flow diagram for equations (18), (21) and (24) respectively below:

By equation (18) the signal flow is thus given in Figure 11.

Similarly, Figure 12 gives the signal flow diagram for equation (21):

Again, the signal flow diagram for equation (24) is deduced in the Figure 13.

Result and Discussion

A typical representation of an expert system has been displayed using the concept of Dynamic Control System as seen in the expressed differential equations. More so, through the use of block diagram representations, the governing differential equations of a DCS were deduced from the concept of an Expert System. It is therefore very clear to re capture the decisive process of converting decisions made from an Expert System to a DCS. Therefore a further DCS alternative general response can be deduced for both (Yes/No) decisions made by an ES using the symbol notations of ϑ and τ for Yes/No responses respectively. The equation below gives a general stage process of decision making for detecting car brake fault by an ES using a modelled DCS output general equation of the form:

$$\left.\begin{array}{l} y = CE + DU, \forall \text{ given input / output say } h_n \; y_n = (\alpha\beta)_n \dfrac{(CE+DH)}{\alpha_n+\beta_n}; \\ ie: C = [n \times n] \text{identity matrix} \end{array}\right\} \quad (39)$$

$$\left. E = \begin{bmatrix} E_1 \\ E_2 \\ E_3 \\ E_4 \\ E_5 \\ \vdots \\ E_n \end{bmatrix}, D = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \end{bmatrix} ie: y_n = h_n = E_n \; \forall n = 1,2,3,\ldots H = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \eta_1 \\ \eta_4 \end{pmatrix} \right\} \quad (40)$$

Figures 1-3 demonstrates how a control system can dynamically be used in multiple decisions of responses by a user say in an ES especially Figures 1 and 2. Conversely, Figure 3 gives a dynamic differential form of the entire processes of decisions made during the detection by an ES for a car engine brake faults.

Similarly, Figures 4-10 displays the graphical interface generated by an ES which by the use of signal flow diagrams gives the signal flow diagrams (Figures 11-13) through the modelled equations (18), (21) and (24) for detecting brake failure relative to decisions made by an ES for sequence (h_n, τ_n), α_n and β_n for Yes/No responses respectively**.**

Conclusion

A DCS has been used to describe the dynamical state of decisions made by an ES. Series of input and output equations were represented as the equivalence input/output of an ES. It is therefore noted that a DCS can be employed in diagnosing/detecting car engine brake failure in real life applications for any given ES through modelled dynamic system of differential equations, block diagrams and signal flow diagrams.

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