HIL TESTING METHOD ENHANCEMENT BASED ON ALGEBRAIC METHOD PREDICTION

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Abstract:The paper defines and implements a method of verifying if the testing system is suited for being implemented or not. In order to try and force a usability prediction on the whole testing process, we used algebraic calculus applied on a testing system, in order to see the correlation between the used signals, in various system nodes. For being successful in predicting the system stability, algebraic calculus was applied, the eigenvalues calculated, and then the correlation between the mathematical results and the real implemented testing system made. As a result of the work we can state from the beginning of test system implementation, if the system is suited or not for implementation. When deciding, the mathematical results back up the decision.

Keywords: *Testing system, Algebraic calculus, Eigenvalues, System stability.*

I. INTRODUCTION

Hardware in loop testing method is commonly used in automotive applications. The need to perform hardware functionality based on software processes is found at all levels in a development process. Utility is very high, due to its capability of discovering functionality failures during the process, allowing the adaptation in real time, action that saves the future of a project.

The work began when implementing a hardware-in-the-loop (HIL) testing system, using a dSPACE Expansion Box (Mid-Size Simulator). The idea of performing a short study before implementing the system turned into the applicationof algebraic calculus [1] [2] [3] [4] [5] in order to check the system's stability. By doing this, a tester can easily predict signal correlation, and can use in the testing device signals which are stable. By checking system's stability through algebraic calculus, one can see if the system is stable, unstable or at the limit of stability. By doing that, the signals will be more likely to interact as desired.

II. MODELING THEORY

A.MODELS

Every testing system uses a predefined model in order to implement and contain the system's variables and constraints. Defining a measurement system and model suited to a certain application becomes vital when discussing about large application with a big number of variables and implications. Hence defining a suited model to the testing system is a very important step in the procedure. There are several ways to model a system. Decisions about such things as complexity, modeling method and used simplifications have to be made. A section describing stability tests is also included in the paper [8].

B. COMPLEXITY

Complexity of the system should be taken into account when analyzing a system to be tested. The complexity appreciation can lead from the beginning to a first estimation of the speed and possibility of the complete system. Since the simulation environment is established as a HIL system by dSPACE, the model complexity has to be suited to the system. To be able to predict computation speed for each simulation step, the step-time has to be fixed. In order for it to run in real time, the whole model behavior must be computable in real time, at each step. This must be valid for all possible states, regardless of the input signals [7] [8] [9].

The HIL system simulation step-time h is adapted to the existing engine and vehicle models, which run smoothly at this value. It is important that the added auxiliary devices models do not interfere with this set step-time, and thereby slow down other parts of the system. Thus, the final real time tests must be done together with the engine and vehicle model in the HIL simulator.

III. METHOD AND TESTER WORKFLOW

A. MODELING METHOD

When it comes to choosing a modelling method, one has to take into account the interconnection between the injected signals and their outputs, or the values measured at certain points in the system. In order to do that, one can apply a short study of linear algebra and system stability calculus in order to check the system's stability. The study aims to check the interconnectivity of systems taking into account the variable places on the testing system, from where the signals measurements have been done. The workflow has to contain all the possible functionality cases that can be encountered. This would also include the special cases and the very complicated ones, in order to provide a full testing approach of the product. Realizing a workflow that is suited to a certain

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application requires experience in the field of functionality and also a good knowledge of the complete system and its implications. The tested device is being represented by a testing machine, used to verify the conformity of the device with given standards. In order to do that, a series of signals are being supplied to the device and the outputs are being constantly recorded. If the recorded outputs are within the given standards, then the device is fulfilling the requirements.

In the case of using a series of testing devices, we can use algebraic calculus, with stability verification, in order to make a pre-check of the whole system before implementing it into the real test. By using the stability check, we can roughly say if the system has a predetermined degree of success. If the analysis shows that the system will be stable in its evolution, then the signals implemented have been chosen correctly.

In order to perform the stability calculation, one has to create a matrix, in which we will find the relations between the signals. From there on, a calculation of the Eigenvalues shall be made. With the computed results, the data can be interpreted and the system classified before proceeding with any kind of real tests on a device. In order to have a pre-check of the used system, the calculation of the system's stability general model will be made, useable with many different sizes and properties of the auxiliary devices.

B. TESTER WORKFLOW

The HIL concept represents a convenient way for performing black-box software integration tests [10][11][12]. A HIL system is used to simulate the real environment where the ECU shall function. I/O signals and interaction with other ECUs are simulated with known good models. The goals of the HIL tests are to find errors in the early phases of the software development process and to support the development with regression tests. The used equipment simulates the environment of a double-clutch-gearbox ECU, connected to several position, pressure and speed sensors, as well as to the valves, as the output actuators.

The inputs of the ECU are stimulated with A/D and PWM signals provided by the dSPACE expansion box. Also, the communication with other ECUs is simulated with "virtual" models, which are configurable on the dSPACE specific boards.

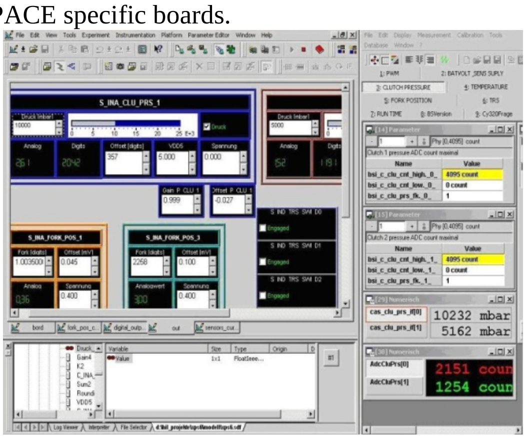

Figure 1. Screen capture of dSpaceapplication and signals that will be used in the algebraic calculus

IV. RESULTS AND CALCULATIONS

A. SYSTEM STABILITY PROBLEM

The problem of stability starts with a simpler model: the stability of a Linear-Time Invariant (LTI) system can be analyzed according to the BIBO stability concept (Bounded Input – Bounded Output).The concept behind this theory is that a certain system can be considered stable, if for every finite value of the input vector, the output of the system will be finite as well (e.g. the output does not oscillate).

We do not want to take into consideration the time duration of the test, but we want to describe the system in complete way, therefore the problem shall be transferred in a state space representation. The result is a mathematical model of the physical system, with a set of input, output and state variables, related between them with a set of first-order differential equations, expressed as vectors. If the system is linear and time invariant, all equations can be written in matrix form [7].

The most general form of a MIMO (Multi Input Multi Output) continuous-time variant system in the state space representation is:

$$\begin{aligned} \dot{x}(t) &= A(t)x(t) + B(t)u(t) \\ y(t) &= C(t)x(t) + D(t)u(t) \end{aligned} \quad (1)$$

Where:

$x(\cdot)$is the vector containing the n states of the system, $x(t) \in R^n$

$y(\cdot)$is the vector containing the q outputs of the system, $y(t) \in R^q$

$u(\cdot)$is the vector containing the q outputs of the system, $u(t) \in R^p$

$A(\cdot)$is called the "state matrix" of the system, with $\dim|A(\cdot)| = n \times n$

$B(\cdot)$is called the "input matrix" of the system, with $\dim|B(\cdot)| = n \times p$

$C(\cdot)$is called the "output matrix" of the system, with $\dim|C(\cdot)| = q \times n$

$D(\cdot)$is called the "feed forward matrix", with $\dim|D(\cdot)| = q \times p$

And:

$$\dot{x}(t) := \frac{d}{dt}x(t) \quad (2)$$

The stability of the system can be proven starting with the first relation in (1), after applying the Laplace transform to both sides of the equation.

The initial condition is set as$x_0 = 0$:

$$s \cdot x(s) = A(s)x(s) + B(s)u(s) \quad (3)$$

We then subtract AX(s) from both sides:

$$x(s)(s1 - A(s)) = B(s)u(s) \quad (4)$$

Assuming $(s1 - A(s))$ us nonsingular, we can multiply both sides by the inverse:

$$x(s) = (s1 - A(s))^{-1} B(s)u(s) \tag{5}$$

Using the relation by which we obtain the inverse matrix from the adjoin matrix:

$$A^{-1} = \frac{adj(A)}{|A|} \tag{6}$$

Equation (5) becomes:

$$x(s) = \frac{adj(s1 - A(s)) \cdot B(s)u(s)}{|s1 - A(s)|} \tag{7}$$

The system stability limit is reached when the denominator:

$$D(s) = |sl - A(s)| = 0. \tag{8}$$

If we make the substitution $s = \lambda$, the resulting relation is the characteristic polynomial of the matrix A. The roots of (8) are the eigenvalues and the system's transfer function's (7) poles. The poles determine whether the system is asymptotically stable or marginally stable. The zeroes found in the numerator of (7) determine whether the system in minimum phase.

The system may be BIBO stable even if the poles show it is unstable. This is the case when we force the unstable poles to be cancelled out by zeroes [5].

In order to have a stable system, in the S domain, it is required that all the poles of the system be located in the left-half plane, and therefore all the eigenvalues of A must have negative real parts.

B. APPLICATION

The following values were used during the measurements and shall be considered as inputs for the algebraic calculation method:

1. "Klemme 15"(as voltage) → ignition signal - this signal corresponds to the start of the engine, derived from the battery voltage.(12V)
2. Clutch pressure (as voltage) → the signal gives information about the functionality of the clutch.(9V, 13V, 17V)
3. Hydraulic oil temperature(as voltage) – the temperature of the hydraulic oil (9V, 13V, 17V)
4. Mechatronic system temperature (4V)
5. Shift rail positions (2V, 8V)
6. Sensor supply (5V)
7. High Side Driver Voltage (7.5V)

The calculation method uses the following values:

$$Matrix1 = \begin{bmatrix} 3.000 & 1.000 & 1.750 \\ 1.500 & 1.000 & 1.250 \\ 3.000 & 0.000 & 0.000 \end{bmatrix} \tag{9}$$

$$Eigen\ values1 = \begin{cases} (4.726, 0.000i) \\ (-1.033, 0.000i) \\ (0.307, 0.000i) \end{cases} \tag{10}$$

The resulting Eigen vectors are:

$$Eigen\ vectors1 = \begin{cases} (-0.749, 0i)(-0.308, 0i)(0.045, 0i) \\ (-0.461, 0i)(-0.323, 0i)(-0.896, 0i) \\ (-0.476, 0i)(0.895, 0i)(0.442, 0i) \end{cases}$$

And:

$$Matrix2 = \begin{bmatrix} 14.000 & 4.000 & 4.000 \\ 5.000 & 2.000 & 5.000 \\ 12.000 & 0.000 & 0.000 \end{bmatrix} \tag{11}$$

$$Eigen\ values2 = \begin{cases} (18.571, 0.000i) \\ (-1.286, 2.470i) \\ (-1.286, -2.470i) \end{cases} \tag{12}$$

The resulting Eigen vectors are:

$$Eigen\ vectors2 = \begin{cases} (0.775, 0i)(0.058, 0.142i)(0.058, -0.142i) \\ (0.385, 0i)(-0.736, 0i)(-0.736, 0i) \\ (0.501, 0i)(0.425, -0.505i)(0.425, 0.505i) \end{cases}$$

Using the theory from [1], [2]we can analyze the stability of the system using only the state–space representation of its mathematical model. What we are trying to accomplish is proving that the system will have predictable stable behavior when a set of controlled input signals are provided.

The state space representation of the mathematical model has the following system matrix:

$$Matrix3 = \begin{bmatrix} -7.000 & 2.000 & 3.000 \\ 1.000 & -3.000 & 0.000 \\ -8.000 & 3.000 & 3.000 \end{bmatrix} \tag{13}$$

$$Eigen\ values3 = \begin{cases} (-4.300, 0.000i) \\ (-2.000, 0.000i) \\ (-0.690, 0.000i) \end{cases} \tag{14}$$

The resulting Eigen vectors are:

$$Eigen\ vectors3 = \begin{cases} (0.528, 0i)(-0.405, 0i)(0.745, 0i) \\ (1.000, 0i)(1.000, 0i)(1.000, 0i) \\ (0.473, 0i)(0.205, 0i)(0.856, 0i) \end{cases}$$

We compute the eigenvalues for the matrix and we obtain the following values:

$$\lambda_1 = -4.30$$
$$\lambda_2 = -2.00 \quad (15)$$
$$\lambda_3 = -0.69$$

All values are negative. Based on the rule described in the previous chapter, we can conclude that the matrix corresponding to the state space mathematical representation is associated with a system that is stable according to the BIBO definition. This means that given any combinations of finite inputs, the internal energy of the system will converge to 0, as the system is stabilizing into a so-called *equilibrium point*.[13] [14] [15]

The same method can be applied to other systems [16], [17], in order to verify their stability.

V. CONCLUSION

During tests, measurements have been done on the above mentioned signals and by pre-checking through the algebraic calculus, we could observe that in the cases where the calculus leads to a stable system, there weren't any overflows in the program and no error occurred concerning the measurement method. Though, where the system turned out to beunstable or at the limit of stability, the signals tend to have unexpected results concerning the other new calculations applied on them, as the requirements were asking [18].

By using our method, the possibility of avoiding unexpected results, and the approximation of possible failures during measurements are possible. Also, by applying the calculus, time is being saved, observing from the beginning which direction of measurement is to be avoided.

The current method does not content a minimization process when implementing the variables to be tested. Common method implements the variables and performs a series of steps in order to prove the functionality or the errors that can appear. From this approach, the method includes a high degree of novelty concerning the hardware in loop testing method approach.

Nevertheless, the system has its limitations. The application of the method is complicated and will require additional research for integration. The research should consider the complete system and its input and output interconnections, including the type of information that they are carrying [11] [12].

Appling such an approach to a hardware in loop system implements a will from the producers side to implement a research process meant to enhance the available hardware in loop system, thing not easy to do taking into account the current economic rush towards getting projects ready.

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