



Simulating Faults for Efficient Fault Recognition Training: an Implementation of Educational Automotive Board

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ABSTRACT

Keywords

Automotive Training
Engine Electrical
Fault Simulator
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As vehicle technology advances and complexity increases, effective automotive education requires practical training methods to develop competent human resources. This research addresses this need by transforming a standard electronically fuel-injected vehicle into reliable engine electrical laboratory equipment, utilizing an STM32 microcontroller and FreeRTOS for rapid data processing and precise control within a fault simulator. This system enhances automotive training by minimizing component damage and expediting fault scenario cycling through a personal computer-managed digital selector that controls 14 switches connected to critical engine sensors and actuators via a 50-pin ECU pinout for targeted fault injection and diagnostics. Ultimately, this specialized tool significantly improves operational efficiency, reduces diagnostic preparation time, minimizes component damage, and quantitatively enhances quality metrics, as evidenced by a reduction in Defects Per Million Opportunities (DPMO) from 208.33 to 69.44.

1. Introduction

The development of technology in vehicles makes vehicles more complex and has many electrical features. In the field of education this is a challenge in terms of developing human resources who are ready to face technological developments in vehicles. One method of developing human resources is the implementation of automotive education processes in practice. Through practice students experience the learning process directly and is useful for improving competence.

This research transforms a standard car unit into reliable engine electrical laboratory equipment, utilizing an STM32 microcontroller and FreeRTOS for rapid data processing and precise control in a fault simulator. This equipment enhances automotive training by adapting standard electronically fuel-injected vehicles, minimizing component damage and expediting fault scenario cycling. Its STM32 microcontroller-based digital selector, managed via a personal computer, controls 14 switches connected to critical engine sensors and actuators, enabling targeted fault injection and diagnostics through a 50-pin ECU pinout.

A specialized analytical tool is essential for comprehensive root cause analysis, as it significantly enhances operational efficiency, reduces diagnostic preparation time, minimizes component damage, and quantitatively improves quality metrics, as evidenced by a reduction in Defects Per Million Opportunities (DPMO) from 208.33 to 69.44 following its implementation in automotive diagnostics.

2. Literature Review

Teaching simulators in the automotive field is increasingly being developed, one of which is currently developing using virtual reality and fault simulator [1]. Fault simulator is one of the equipment in an engineering training center [2]. The automotive training center has some area of development, such as engine, transmission, chassis and electrical [3]. The automotive car itself is not designed to be used in training equipment. The high frequency of dismantling processes makes the





equipment become high risk potential. This research tries to find the way to create the industrial standard car unit to become a laboratory equipment.

The development area of this research is engine electrical. Due to the Universal Serial Bus (USB) connection with the computer and the motorized potentiometer controller, a system that can work quickly and reliably is needed. one system that can be used is a system with freeRTOS. A Real-Time Operating System (RTOS) is a type of computer operating system designed to be small and deterministic. RTOSes are frequently utilized in embedded systems that must respond to external events within stringent time limits, such as medical devices and automobile ECUs. There are usually just one or two requirements for this type of embedded system that require that degree of deterministic timing, and there are advantages to employing an RTOS even in cases where the embedded system has no strict real-time requirements at all [4].

Due to the number of pins in the control unit, a modern microcontroller system architecture and high data processing speed are required. STM32 series microcontroller used in this research. Based on the Arm Cortex®-M processor, the STM32 family of 32-bit microcontrollers is intended to give microcontroller users additional degrees of freedom. In order to retain complete integration and ease of development, it provides devices that combine very high performance, real-time capabilities, digital signal processing, low-power/low-voltage operation, and connection[5].

3. Method

The design of this equipment is to add system to standard vehicles so that they can be used in automotive training laboratories, minimize the damage potential and increase the speed of failure changing. The design of this equipment was initiated by creating a flowchart to define the program algorithm. This methodology ensured that the final product conformed to the conceptual design in **Error! Reference source not found.** [6].

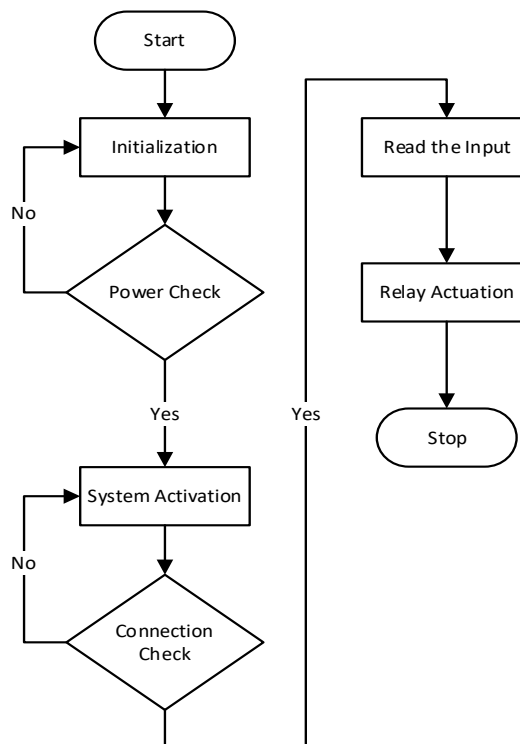


Fig 1. Design Flow

This Simulation board connected to the vehicle using electrical wire. This system comprises a digital selector, a pinout box, and a vehicle. The inclusion of a vehicle as a subsystem is necessitated by the current limitations of the training center, which lacks sufficient dedicated didactic automotive trainers in **Error! Reference source not found.**



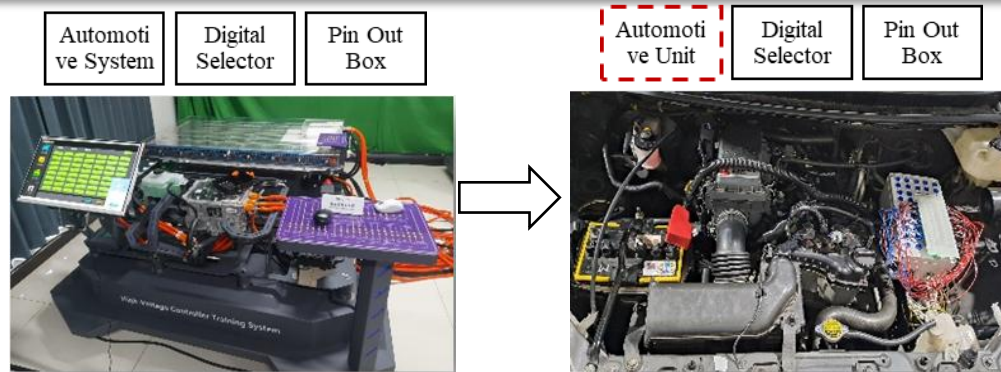


Fig 2. Equipment concept

The Digital selector using personal computer as a human interface and an electronics board to control the switch. The electronics boards using STM32 microcontroller to face the multipoint input and output. The main components of electronic board are: Microcontroller, Relay Blocks, Input/Output and USB Connector in **Error! Reference source not found.**[7].



Fig 3. Electronics Board (a) Microcontroller, (b) Relay block, (c) Input/Output, (d) USB connector

The prototype have 14 switches which controlled by the microcontroller. This switches connected to the component of the engine electric such as sensor and actuator. In a full feature the ECU itself consist of up to 100 pins of wiring. In this research the car that be used only consist of some features of this component.

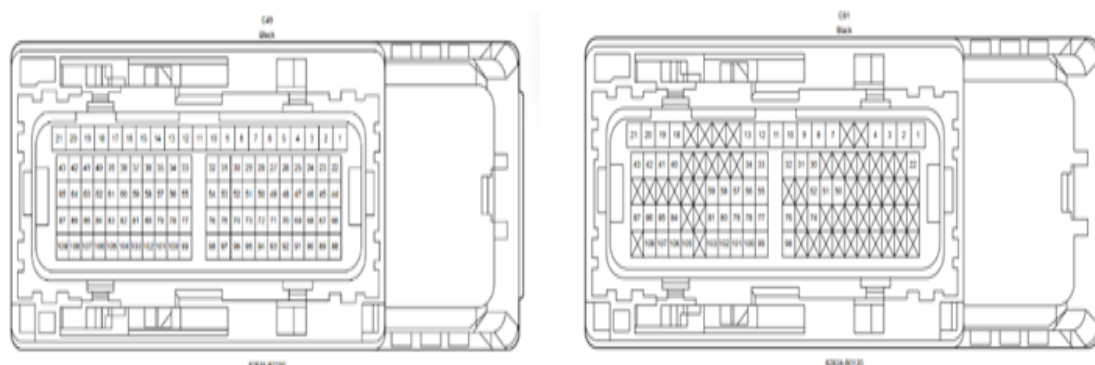


Fig 4. ECU socket full version and current version

The vehicles use a engine control unit and instrument cluster control unit as a main controlled area network (CAN) bus controller [3], [8]. This configuration make this control unit equipped with terminating resistor, the resistor value is 120 Ω each and with parallel configuration. The standard value of this can bus termination resistor become 60 Ω according to value and configuration in Figure 5 [9].

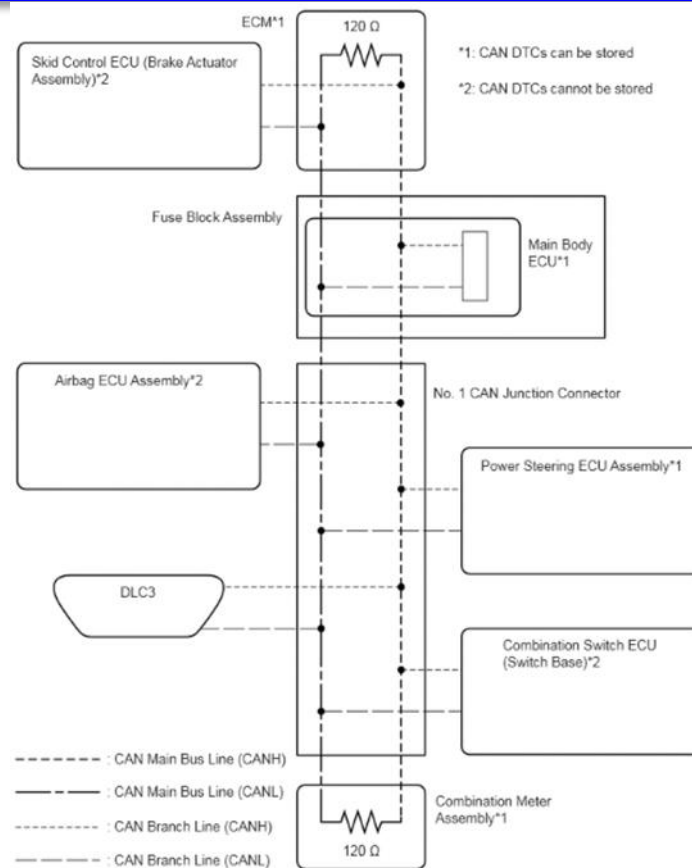


Fig 5. CAN BUS structure in a car (Source: Toyota) [9]

The device has electronically control unit (ECU) pinout with 50 pin and 14 fault selectors. The 14 fault selectors connected to vehicle and make possibility to connect and disconnect sensor or actuator of the car. The car that be used must have a electronically fuel injection (EFI) system. There are more than 100 pin of ECU itself, but in this case it used only from engine wiring diagram from Table 1 .

Table 1. Controlled Pinout

Color	Component	No Pin	Status
Blue	Th. Body Pin 1	1	Sensor
Grey	Th. Body Pin 2	2	Sensor
White-Black	Ground	3	Grounding point
White-Black	Ground	4	Grounding point
Blue	O ₂ Sensor pin 2	8	Sensor
Pink	Oil Control Valve	10	Actuator
Green	Oil Control Valve	11	Actuator
Grey	Oil Control Valve	12	Actuator
Purple	Oil Control Valve	13	Actuator

4. Results and Discussion

The troubleshooting equipment is installed within the vehicle, connecting to both the control system and a measurement pinout. The control system is specifically adapted for mini MPV vehicles. Given the ongoing advancements in vehicle technology, this programmable concept is well-suited for the dynamic evolution of car models. Furthermore, the measurement pinout ensures that the measurement process can be conducted without repeatedly unplugging the Electronic Control Unit (ECU) socket, there by enhancing durability in *Error! Reference source not found.*





Fig 6. Installed equipment in vehicle

The automotive training program is delivered through a multi-disciplinary approach that integrates key vehicle sub-fields: chassis, powertrain, engine systems, and automotive electrical and electronics. A core pedagogical element of this program is its focus on the electrical systems of modern vehicle engines, wherein practical learning is facilitated through the hands-on configuration and in-depth analysis of critical components such as the throttle body, oxygen sensor, and oil control valve.

A comprehensive root cause analysis (RCA) methodology necessitates a multi-faceted discussion encompassing several critical domains: extant policies, established procedures, influential external factors, the operational status of equipment, and the human element involving personnel. An examination of these interconnected aspects underscores the significant requirement for a specialized analytical tool. The imperative for such a tool is further amplified when considering its potential impact on operational efficiency and the practicalities of its implementation within existing frameworks [10].

The introduction of this dedicated tool is anticipated to yield substantial benefits. Primarily, it is projected to significantly reduce the preparation time typically associated with complex diagnostic processes. A key advantage lies in its capacity to minimize the risk of inadvertent damage to critical components during analytical or interventive procedures. This reduction in potential damage not only preserves asset integrity but also contributes to cost savings and enhanced safety protocols. The tool, therefore, represents a strategic investment towards optimizing analytical rigor, operational expediency, and resource protection within the domain of automotive diagnostics in **Error! Reference source not found.**

Table 2. Result

<i>Aspect</i>	<i>Before</i>	<i>After</i>
Average Duration (minute)	$Avg = \frac{449}{72} = 6,24$	$Avg = \frac{358}{72} = 4,97$
DPMO	$DPMO = \frac{15}{72} \times 1.000.000 = 208.333$	$DPMO = \frac{5}{72} \times 1.000.000 = 69.444$
Sigma Value	3	2

Quantitatively, the efficacy of this tool is further demonstrated by improvements in quality metrics. Initial assessments indicated a baseline performance level with a Defects Per Million Opportunities (DPMO) value of 208.33. Following the implementation and integration of this analytical tool, a significant enhancement in process quality was observed, with the DPMO value decreasing to 69,44. This marked reduction in defects signifies a substantial improvement in overall process capability and output quality, directly attributable to the enhanced diagnostic precision and preventative capabilities afforded by the tool. The average preparation time decreased from 6.24 minutes to 4.97 minutes after implementation, successfully falling below the 5-minute target duration based on **Error! Reference source not found.** [11].



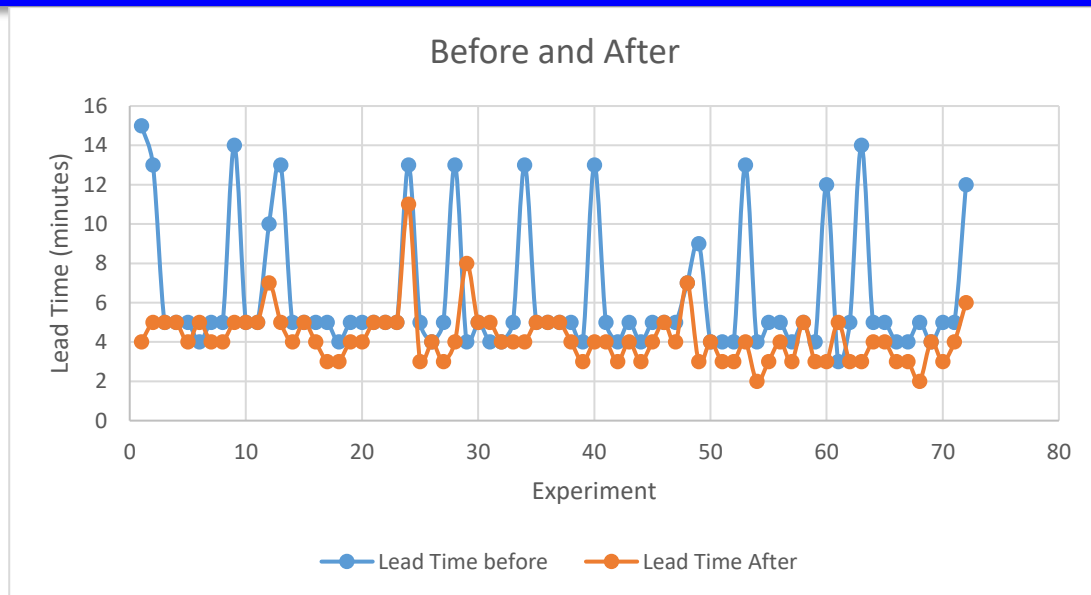


Fig 7. Lead time before and after

5. Conclusion

This equipment adapts standard vehicles for automotive training, minimizing component damage and expediting fault scenario cycling. Its design employs an STM32 microcontroller-based digital selector to manage 14 switches connected to critical engine sensors and actuators for targeted fault injection and diagnostics via a 50-pin ECU pinout.

This in-vehicle troubleshooting equipment, designed for mini MPV vehicles, integrates with the control system and utilizes a dedicated measurement pinout to facilitate diagnostics without repeated ECU socket disconnections, thereby enhancing durability and adapting to evolving vehicle technologies. The automotive training program adopts a multi-disciplinary approach, integrating chassis, powertrain, engine systems, and automotive electrical and electronics, with a particular pedagogical focus on practical learning through hands-on configuration and analysis of critical engine electrical components such as the throttle body, oxygen sensor, and oil control valve.

A comprehensive root cause analysis (RCA) necessitates a multi-faceted examination of policies, procedures, external factors, equipment, and human elements, underscoring the critical need for a specialized analytical tool to enhance operational efficiency and mitigate diagnostic complexities. This dedicated tool significantly reduces preparation time and minimizes the risk of component damage during diagnostic procedures, as evidenced by a quantitative reduction in Defects Per Million Opportunities (DPMO) from 208.33 to 69.44 following its implementation, thereby improving overall process quality and output.

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