DESIGN AND DEVELOPMENT OF HARDWARE-IN-THE-LOOP TEST EQUIPMENT FOR VEHICLE INSTRUMENT CLUSTER

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by

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LIST OF SYMBOLS

θ	*angle in radians*
ρ	*resistivity of a material*
Ω	*unit of resistance*
Hz	*unit of frequency*
V	*unit of voltage*
mm	*unit of length*
mm^2	*unit of area*
µm	*unit of length*

LIST OF ABBREVIATIONS

IPS	Institut Pengajian Siswazah
PPKEE	Pusat Pengajian Kejuruteraan Elektrik dan Elektronik
USM	Universiti Sains Malaysia
PDG	Perkakasan-Dalam-Gelung
KIK	Kluster Instrumen Kenderaan
PDGRK	Perkakasan-Dalam-Gelung dari Rak Komersial
PUD	Produk-Untuk-Diuji
COTS	Commercial-Off-The-Shelf
HIL	Hardware-In-the-Loop
BJT	Bipolar Junction Transistor
IDE	Integrated Development Environment
ANOVA	Analysis Of Variance
VIC	Vehicle Instrument Cluster
DUT	Device-Under-Test
CAN	Controller Area Network
ECU	Electronic Control Unit
RM	Ringgit Malaysia
SPI	Serial Peripheral Interface
HMI	Human-Machine Interface
SGC	Signal Conditioning Circuit
UCL	Upper Control Limit
LCL	Lower Control Limit

REKA BENTUK DAN PEMBANGUNAN ALATAN UJIAN PERKAKASAN-DALAM-GELUNG UNTUK KLUSTER INSTRUMEN KENDERAAN

ABSTRAK

Kajian ini menerangkan reka bentuk dan pembangunan alatan ujian Perkakasan-Dalam-Gelung (PDG) untuk menilai fungsi Kluster Instrumen Kenderaan (KIK). Alatan ujian ini dibangunkankan untuk menghasilkan satu set isyarat rangsangan untuk memperlihatkan paparan yang ditunjukkan pada KIK. Kos pembelian alatan ujian konvensional yang sedia ada oleh Perkakasan-Dalam-Gelung dari Rak Komersial (PDGRK) agak tinggi, mengandungi ciri-ciri yang tidak relevan dan seringkali tidak dapat dibangunkan dengan lebih lanjut disebabkan oleh lesen pemilikan dan hakcipta yang menjadikan pembangunan produk agak terhad atau berskala kecil untuk jangka panjang. Oleh itu, alatan ujian ini direka bentuk dan dibangunkan dari awal sebagai penyelesaian alternatif yang mampu memenuhi keperluan industri untuk ujian produk. Pelbagai isyarat dijana oleh alatan ujian yang dicadangkan ini bertanggungjawab untuk menghasilkan paparan komponen KIK seperti Meter Halaju, Putaran Enjin, Isipadu Bahan Api, dan Suhu Enjin dan isyarat-isyarat lain. Jig Lekapan direka untuk meletakkan KIK yang juga merupakan Produk-Untuk-Diuji (PUD) sebelum melaksanakan sebarang prosedur ujian. Hasil eksperimen telah menunjukkan bahawa reka bentuk bagi keluaran berdasarkan frekuensi dan rintangan telah ditingkatkan berbanding dengan kaedah sebelumnya. Ketepatan untuk penjanaan frekuensi telah dipertingkatkan sehingga 90.1% menggunakan AD9833 dan Modul SCC daripada ralat 0.517 Hz kepada 0.059 Hz, manakala sisihan piawai ketepatan telah meningkat sebanyak 88.89 % dari 1.004 Hz kepada 0.1044 Hz. Purata

ralat dari carta individu untuk fabrikasi papan litar bercetak juga telah menunjukkan perubahan ketara dari 5.48 Ω menjadi 0.4391 Ω yang berkurang sebanyak 91.99 %. Purata ralat seperti yang ditunjukkan dalam Julat Berubah juga berkurang sebanyak 94.38 % dari 0.99 Ω hingga 0.0556 Ω. Transistor BJT dipilih sebagai elemen suis penjana output digital untuk isyarat KIK, berikutan kemampuannya mencapai masa kenaikan yang lebih pantas pada 791.79 µs dengan kos pembelian paling rendah pada RM 1.62 seunit. Sebagai kesimpulan, penyelidikan ini telah berjaya merangka dan membangunkan alatan ujian PDG untuk KIK.

DESIGN AND DEVELOPMENT OF

HARDWARE-IN-THE-LOOP TEST EQUIPMENT FOR

VEHICLE INSTRUMENT CLUSTER

ABSTRACT

This research is about the design and development for Hardware-In-the-Loop (HIL) test equipment to evaluate the functionality of the Vehicle Instrument Cluster (VIC). The purpose of this test equipment is to generate a set of stimulus signals in order to display the corresponding output demonstrated in the VIC. Conventional solution provided by the Commercial-Off-The-Shelf Hardware-In-The-Loop Simulator (COTSHILS) is relatively expensive. It may contain unnecessary features and often non-extensible due to proprietary license which render the product to be less usable or scalable in the longer term. Hence, this test equipment is designed and developed from ground-up as the alternative solution capable to cater the industrial needs for product testing. Various signal are generated by this proposed test equipment which responsible to stimulate the display of VIC components such as Speedometer, Tachometer, Fuel Volume, and Engine Temperature and signal indicators of the VIC to be responsively displaying corresponding output. Test Jig Fixture is designed and fabricated to securely locate the VIC which is also the Device-Under-Test (DUT) before executing any test procedures. Experimental results had shown that the designs for frequency-based and resistance-based output has been improved compared to the methods of Tone Function and Preliminary Circuit, respectively. The mean of error for frequency generation has been improved up to 90.1% using AD9833 and SCC Module from 0.517 Hz error to 0.059 Hz, whilst the standard deviation of the error have increased by 88.89% from 1.004 Hz to 0.1044 Hz. The mean of error from the

individual chart for the Fabricated PCB also had shown significant changes from 5.48 Ω into 0.4391 Ω which improved by 91.99%. The mean of error as shown in Moving Range also improved by 94.38% from 0.99 Ω to 0.0556 Ω. BJT transistor is selected as the switching element of digital output generator for tell-tales, due to its capability of achieving faster rise time at 791.79 µs with the lowest cost of purchase at RM 1.62 per unit. In conclusion, this research has successfully designed and developed a HIL test equipment for VIC.

CHAPTER 1

INTRODUCTION

1.1 Overview

A vehicle withheld many complex systems such as gasoline or electrical engine system, transmission system, electronic or hydraulic steering system, cooling system, electrical and electronic system. These systems, as shown in Figure 1.1 work simultaneously and synchronously integrated to allow the vehicle to function as per normal condition.

Alongside with the aforementioned systems displayed in Figure 1.1, there are also features embedded with the purpose of continuous condition monitoring of those complex systems. This will prevent any undesirable event to occur due to the malfunction of the complex systems. These monitoring features are centralized in a single unit, known as the Vehicle Instrument Cluster (VIC). VIC is present in every vehicle and dedicated to present critical vehicle-related information to the driver (Osswald, Sheth, & Tscheligi, 2013). In earlier days, the VIC was limited to a few basic indicators such as speedometer and fuel gauge. With development of newer technology, more information is available to assist the driver for better driving (Narayana, Rao, & Ganesan, 2013).

Figure 1.2 demonstrates the VIC display, in which the driver will be informed with the current condition of the vehicle comprising current speed on which the vehicle is travelling, the tell-tales signal, the amount of petrol that is left, the temperature of the

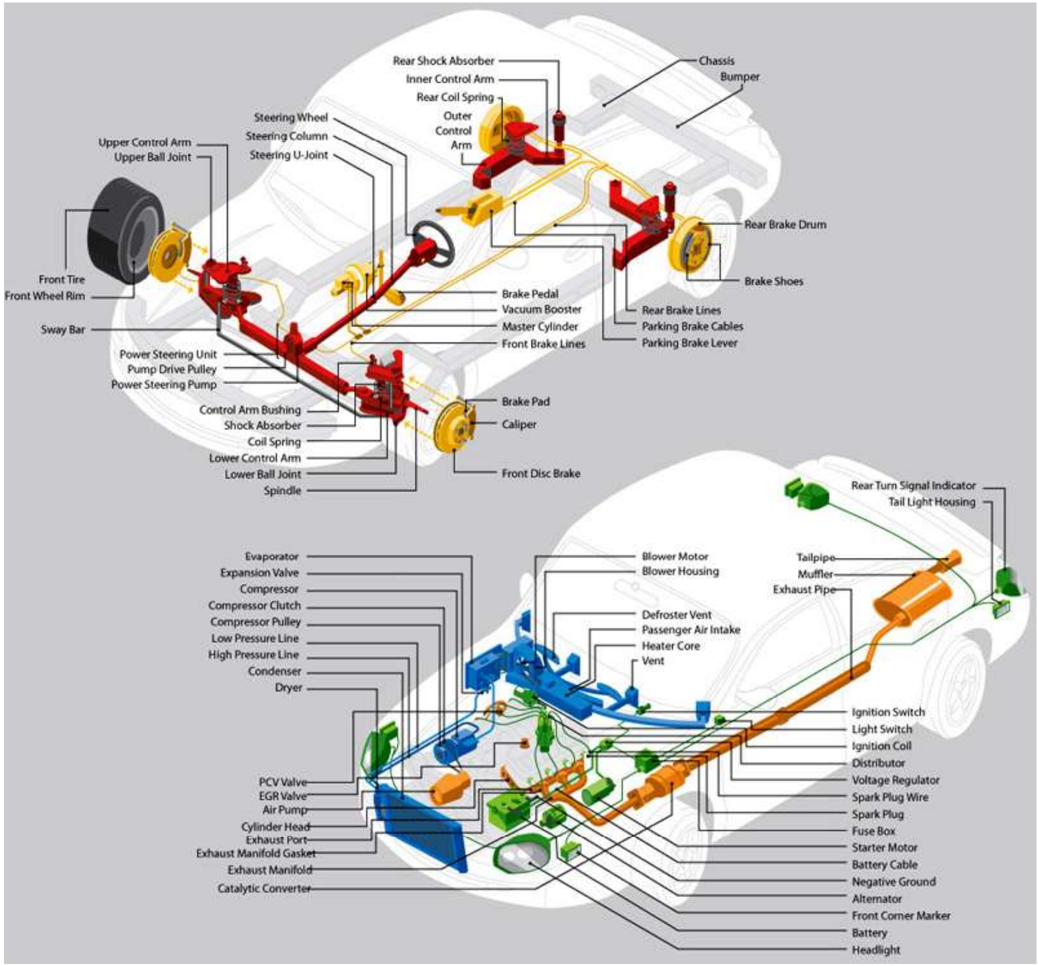

Figure 1.1: Overall Automotive System in Modern Cars (Zettwoch, 2009)

engine and other important information. Hence automotive electronic control devices must quickly and accurately process all kinds of information to be displayed by VIC (J. Dai & Song, 2011). This will allow the drivers to make an appropriate decision at appropriate time in various driving conditions. This is important for the safety of the driver and also other road users.

It is essential for the functionality of the instrument cluster to be tested before it is incorporated into the designated vehicle for manufacturing. False information conveyed by the VIC to the driver may harm the vehicles' drivers, the occupants, other road users and the vehicle itself as well as highlighted in Table 1.1.

Figure 1.2: VIC displaying various vital information to the driver (Honda, 2012).

Table 1.1: The importance of the VIC information and the effect caused due to malfunction

VIC Information	Display Function	Adverse Consequences
Speedometer	Vehicle speed	Misinformation/unaware of overspeeding.
		Endanger the occupants and other road user if high-speed collision occur.
Tachometer	Engine revolution	Engine overheat due to prolonged over-revolution.
Fuel Volume	Volume of fuel left inside the fuel tank	Vehicle sudden stop on the road.
Engine Temperature	Temperature of the engine coolant	Engine damage due to prolonged overheat.
Handbrake Indicator	Handbrake is lifted	Brake wear and tear
Left/Right Turn Indicator	Left/Right Turn is switched 'ON'	Other pedestrian/motorists unaware of vehicle's behaviour
		Prone to motor-vehicle accident.
Battery/Charge Indicator	Check battery	Car sudden stop on the road due to low battery / empty state of charge.

With the awareness of having the VIC tested, validated and verified its functionality and reliability, engineers have developed appropriate test equipment for the VIC. The test engineers started by using manual test box to trigger some of the tell-tales display as shown in Figure 1.3, while frequency generator is connected to frequency-related gauges such as Speedometer and Tachometer to stimulate the VIC display accordingly. Current test system comprises the VIC as the Device-Under-Test (DUT) and Hardware-In-the-Loop Simulator (HILS) as the Test Equipment, together with PC and several communication devices between PC and the HILS.

Figure 1.3: VIC Test Box consisting of digital input to test tell-tale signals (Asymtek, 2018)

The application of HILS has been widely practised by the industries as a mean of simulation and monitoring in other different field of interest. Hassine and Pietruschka (2016) developed HILS for medium-scale parabolic through collector system, used for steam boiler in meat factory in Austria. W. Dai, Zhou, Zhao, Lu, and Chai (2016) developed HILS to monitor the mineral grinding process. HILS has also implemented as testing purposes as mentioned by Tiancai et al. (2015) whom developed real-time HILS test platform for fuel cell backup system.

HILS also took a major role in the testing of automotive components such as for the Vehicle Control Unit for low-level control coordination and torque management (Xia et al., 2016), Electronic Control Unit of Dual-Clutch Transmission (Chen, Mi, & Tan, 2012), Electronic Speed Limiter (Taksale, Vaidya, Shahane, Dronamraju, &

Deulkar, 2015), Motor Control Units (Lee, 2012) and others (Mouzakitis, Copp, Parker, & Burnham, 2009; Wang, Wang, & Wang, 2015).

Most of the industrial automated test system relies the HILS application heavily from the Commercial-Off-The-Shelf (COTS) instrumentation products which are generally very expensive (Xia et al., 2016). Furthermore, the system and the software architecture are fixed or 'closed' which makes the solution rigid. Further feature expansion and necessary customization are not possible due to the 'closed' technology. A solution which does not promote extensibility be it hardware or software, will limit the design choice of the user thereby, may lead to the discontinued usage of the purchased product leading to further loss. Hence this research aims to embark in developing a relatively cost-competitive HILS as an automated test equipment which automates the testing of VIC using HIL concept.

1.2 Problem Statement

Designing and developing of the HILS as the test equipment requires careful consideration of various signal generation input based on the VIC's specification as outlined by the industrial standard. Emulating the real signals emanating from the automotive sensors such as Hall-Effect sensor for speed detection and float sensor for fuel volume measurement on a vehicle are one of the major challenge.

Such emulated signal demands high resolution of 0.1Hz of digital frequency signal ranging from 0Hz to 800Hz to be delivered to the VIC input port before one can see the accurate effects on Speedometer. The same nature of emulated signal is applicable for signal originating from the engine revolution sensor. This is eventually picked up by the Tachometer on the VIC. From the view point of a vehicle technology, the amount of remaining fuel in a vehicle tank is measured by complex instrumentation (usually by virtue of capacitive sensor) delivering resistance of low value. The resistance-based signal generated by the resistive sensor in accordance to the amount of fuel left is transmitted into the Fuel gauge hence displaying the current fuel volume of the vehicle. The resolution of the resistance signal need to meet 1 Ω/step specification before it is being fed to the VIC input port showing the Fuel gauge information. Similar stimulus signal which is based on resistance is needed to be produced by the temperature sensor, sensing the current state of the coolant temperature of the vehicle's engine. Tell-tales requires specific signal generation to trigger the corresponding indicators. Tell-tales or indicators such as Left and Right Turn are triggered with a Digital-High signal, meanwhile the stimulation of the Brake signal requires the connection towards the input pin to be grounded. Some tell-tales are also deemed to be connected to the power supply to allow signal stimulation such as the Upper Beam indicator.

1.3 Research Motivation

COTSHILS is superior in terms of having a wider bandwidth and finer resolution since it is served for universal application with the specification consisting of wider range of parameters (National Instruments, 2010).

Inarguably COTSHILS is a universal product as it covers wide range of application not just for automotive section, but for medical and military application as well. COTSHILS manufacturer serves its product to meet with diverse specification demand upon broad field of interest.

Despite the superiority of COTSHILS, certain feature provided by such sophisticated technology is unusable by the industrial collaborator, hence purchasing the COTSHILS is inefficient and not feasible for implementation.

Our technology complies with the industrial standard as set and advised by the industrial collaborator (Hanafi, 2017). Furthermore, it is to note that one of our product feature which is programmable potentiometer is potentially capable of giving better or at par performance compared to COTSHIL specifically based on the expected resistance error. Reference of the specification can be observed in Figure C.1 and Figure C.2 in the appendix.

COTSHILS offered very broad features to fit with wide range of applications. However, since the product covers wide range with a very fine resolution, the price of the product is much higher. In addition, the wide range of specification is unnecessarily counterproductive as we pay at higher cost without maximizing the utilisation of the COTSHILS. The proposed HIL test equipment provides adequate range to be implemented in testing and evaluation of VIC.

1.4 Research Objective

The objectives of this research are listed as below:

- To design, develop and verify a HIL interfacing module incorporating of necessary instrumentation technique for signal generation responsible for the display of Speedometer, Tachometer, Fuel Volume, Coolant Temperature and Tell-tales presented by the VIC.

- To design, develop and verify a DUT simulator program with incorporated stimulus test subroutines which simulates the display of the VIC as mentioned beforehand.
- To design of a test jig to accommodate the modules and DUT.

1.5 Research Contribution

Upon completion of this research, the HILS can successfully execute the test procedures towards the DUT with human intervention only involving the judgement of the test result to be pass or fail. The completed HILS also contributes to the knowledge of signal conditioning design prior to generation of low-range frequency-based signal which is generated 0 Hz to 707.8 Hz whilst low range resistance-based signal which is generated from 0 Ω to 182 Ω. Design of the test jig with enclosure permits installation of camera hence this research can be further integrated with machine vision system to produce fully automated test system.

1.6 Scope of Research

This research covers the HIL system which comprises of the software framework for the Human Machine Interface (HMI) design of the Graphical User Interface (GUI) and the test program; and the hardware framework in designing a testing setup and the circuitry as shown in Figure 1.4. Vision system used to validate the image output demonstrated by the VIC is considered out of the scope for this research. Nevertheless it is also an integral part beneficial in closing the loop thus creating an automated test solution for vehicle instrument cluster. This research also covers the integration of both hardware and software framework.

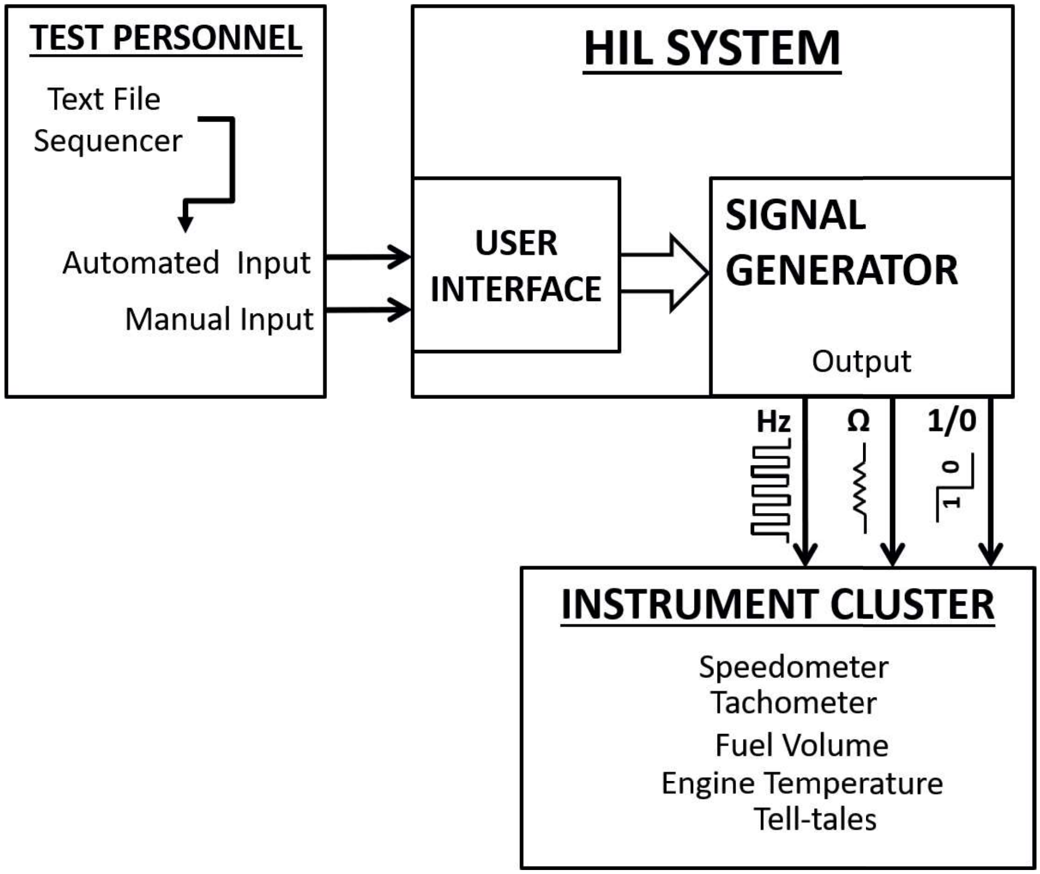

Figure 1.4: Function Block of the Proposed Test Equipment

As mentioned by Balasubramanian (2015), VIC consists of two categories which are CAN VIC which uses Controller Area Network communication protocol to deliver related information into the VIC; and non-CAN VIC which obtains vehicle information directly from automotive sensors. This test system is developed to test the functionalities of a non-CAN VIC which are Speedometer, Tachometer, Fuel Volume, Coolant Temperature and Telltales (Left-Turn, Right-Turn, Upper Beam, Charge, and Handbrake Signal). CAN network is not utilised and developed for testing in this research. The VIC assigned as the DUT for this research consists of Electronic Speedometer and Tachometer which reacts to the signal input of frequency-based, Coolant Temperature and Fuel Volume which reacts to the signal input of resistance-based (current-induced) and tell-tales which reacts to the signal of

Logic High (+5V), Ground, and direct Power Supply (+12V). This research involves with utilising Arduino Uno as the microcontroller of the mechatronic hardware system. HMI is applied for designing the test subroutine scheduling program using Notepad++ and the GUI test program for the DUT using Qt Creator.

This work involves in implementing cost-competitive solution to design and develop the test system, which means any licensed and proprietary software will not be included in this research scope.

1.7 Thesis Organization

The thesis is organized into five chapters. Chapter 1 consists of the general overview of the VIC and the importance of testing the VIC, problem statement, objectives, scope of research and the thesis organization.

Chapter 2 covers the literature review, which is related mostly to the VIC, HILS and the tester equipment design. In this chapter, the working principle of Speedometer, Tachometer, Fuel Volume, Coolant Temperature and Tell-tales are also discussed. Previous works conducted by the researchers are discussed and highlighted in this chapter. Since the research is to develop a cost competitive system, budgetary price of the testing equipments is also presented.

Chapter 3 discusses the methodology of this research, which is on how to achieve the objective as stated in Chapter 1. The hardware and software frameworks of this system which held accountable for the signal generation leading towards the VIC displaying corresponding visual output are also presented.

Chapter 4 focuses on the results, which have been obtained from the simulation and measurement results from the methods explain previously in chapter 3. Analysis based on the results is discussed in this chapter.

Finally, chapter 5 contains the conclusion based on the experimental results. The contributions of this research are clearly highlighted. Some recommendations for future works are suggested at the end of this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter presents the literature review of this research covering some background knowledge about the importance of instrument cluster in the perspective of automotive industry, the principle of instrument cluster, the standard of VIC functionality and its testing procedure. Previous development, in particular, the adoption of HIL system in the testing of VIC are also reviewed. In the section 2.2, worldwide vehicle production volume for 18 years of vehicle manufacturing is presented. In the section 2.3, the working principles of the main gauges and indicators in the VIC are explained. In section 2.4 various testing approaches of the VIC is discussed and explained. Section 2.5 describes the utilisation of COTS HILS in previous research as a testing equipment and simulation. Section 2.6 explains the previous research conducted to perform testing of VIC using COTS HILS. Section 2.7 describes the previous work of the designing the digital potentiometer. Section 2.8 justifies the budgetary prices of the available COTS HILS should this project continue to utilise it as the test equipment. Section 2.9 will discuss regarding the current test framework setup performed by the industrial collaborator which is from ‘Company A’ to conduct test and evaluation of their product. This section will also perform comparison with the test environment conducted by the previous research work.

2.2 Worldwide Vehicle Manufacturing Statistics

The global automotive manufacturing from 2000 to 2017 is illustrated in Figure 2.1. 73.46 million passenger cars were produced worldwide in 2017. This figure transcribes into an upturn of around 2.4%, compared with the previous year which manufactured around 72.11 million cars. Statista (2018) stated that China, Japan, Germany, and India were the 4 largest manufacturers of passenger vehicles in 2017. Passenger vehicles are motor vehicles with at least four wheels, used for the transport of passengers, and comprising no more than eight seats in addition to the driver's seat (Statista, 2018). Collins (2018) describes commercial vehicle as the vehicle that is licensed to be used for the transportation of goods or materials rather than passengers. Cambridge University Press (2018) describes car as a road vehicle with an engine, four wheels, and seats for a small number of people.

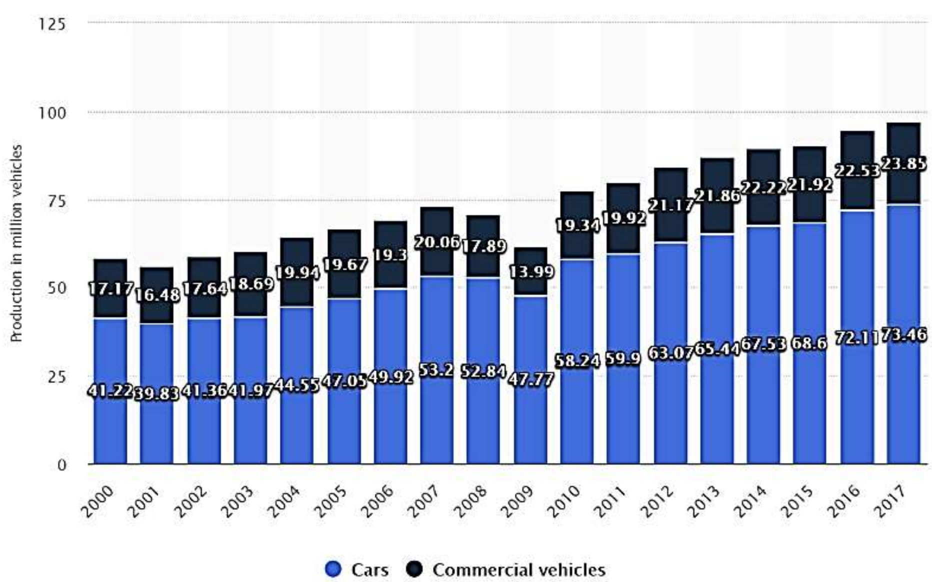

Figure 2.1: Worldwide automobile production from 2000 to 2017 in million vehicles (Statista, 2018)

Excluding the decrements on 2008 and 2009 caused by economic crisis impacting the automotive sector (Pavlínek, 2015), Figure 2.1 also translates an almost linear growth of car manufacturing since 2000 until 2018. The increase in production of VIC will go side by side with the growth of the worldwide car manufacturing. As the demand gets higher, automotive industry is deemed to find solutions to increase throughput. In the field of product testing and quality assurance, switching from performing manual test via human intervention to an automated test system does provide the solution of higher throughput. One should have an in-depth knowledge on the DUT to be tested, i.e. VIC so that the tester specification is outlined to really suit the requirement of stimulus signal to be sent to the VIC. Next section, the working principle of an instrument cluster is presented.

2.3 Working Principle of Instrument Cluster

The basic instrument cluster nowadays consists of several main gauges incorporated inside the VIC such as the Speedometer, Tachometer, Fuel Volume, and Coolant Temperature (Huang et al., 2008). Besides the aforementioned gauges, VIC also consists of tell-tales which are the indicators and warning lights such as right and left turn, upper beam signal, handbrake signal, etc.

2.3.1 Speedometer

Speedometer is the gauge used to display the current speed of the vehicle based on related signal emanating from the vehicle speed sensor when the vehicle is driven. Depending on the regional version of the vehicle unit to be marketed, the speed gauge displays either in SI (km/h) or imperial unit (miles/h)(Hanafi et al., 2016). To measure the speed of the vehicle, it is required to understand how the vehicle can move at the first place.

Initially, the burning fuel-air mixture inside the engine caused the piston engines to move upward and downward repeatedly, converting the reciprocating motion of the pistons into a rotary motion by a crankshaft. The crankshaft turns the flywheel which the power is then transmitted through the driveshaft and to the wheels which resulting the vehicle to move.

Thus, the vehicle speed is measurable through the rotational speed of the wheels or the transmission. In most cars, measurement takes place in the transmission and the job of measuring the rotational speed generated by the transmission falls to something called a drive cable (William Harris, 2007).

2.3.1(a) Mechanical Speedometer Gauge

Mechanical-type speedometers measure the vehicle speed by the mechanical connection between the speedometer and the gearbox output shaft, since the shaft's rotation speed is independent from the gear changes as shown in Figure 2.2.

The output shaft inside the gearbox consists of a gear wheel which rotates together with the shaft. This shaft drives a speedometer chive pinion which is linked to a speedometer cable.

Speedometer cable consists of an inner cable with a squared-end, allowing to securely fit into the squared holes in the chive pinion. As the pinion rotates when driven by the gearbox output shaft, the inner cable rotates as well (Myor, 2007).

Figure 2.2: The speedometer is mechanically connected towards the gearbox output shaft via drive cable as explained by Myor (2007)

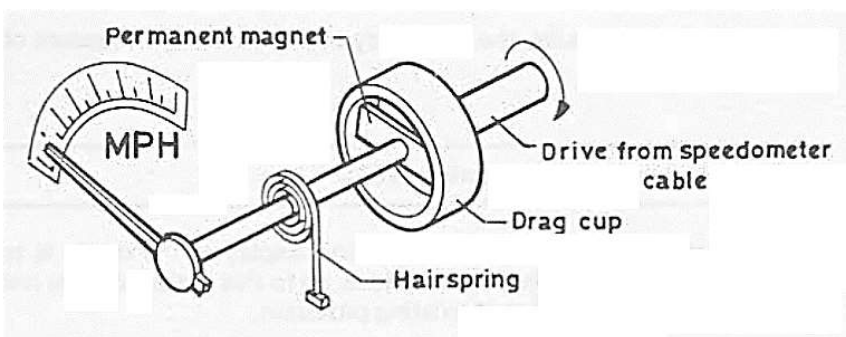

Figure 2.3: Components of a mechanical speedometer as explained by Tranter (1990)

Based on Figure 2.3, the other end of the cable fits to a drive shaft leading into the speedometer attached to a drag-cup. A magnet is installed at the end of this shaft, together with a drag cup with a slight clearance gap. The magnet is attached to the needle which gives the reading on the dial. To hold the needle at zero position, a small coiled hair spring is installed. Since the drag-cup is attracted by the magnet, the drum turns, generating induced current and drags the magnet to turn. The faster the car is travelling, the faster the gearbox output shaft rotates, causing the inner cable to rotate faster. Thus, the greater the drag of the magnet by the drag-cup which moves the needle further round the dial. This also increases the restraining force of the hair spring. When the forces of the spring and the magnet is similar, the needle stops turning and displays a steady reading.

2.3.1(b) Electronic Speedometer Gauge

Electronic Speedometer gauge detects and displays the speed using a sensor which consist of a Hall-Effect element. In place of the toothed wheel, a magnetic sensor ring is fitted comprising magnets installed with alternating poles. The sensor element is placed adjacent to the ring. The general arrangement is shown in Figure 2.4 (Hillier & Rogers, 2007). The sensors can also be installed near to the gear in the output shaft of a gearbox as shown in Figure 2.6 (Myor, 2007).

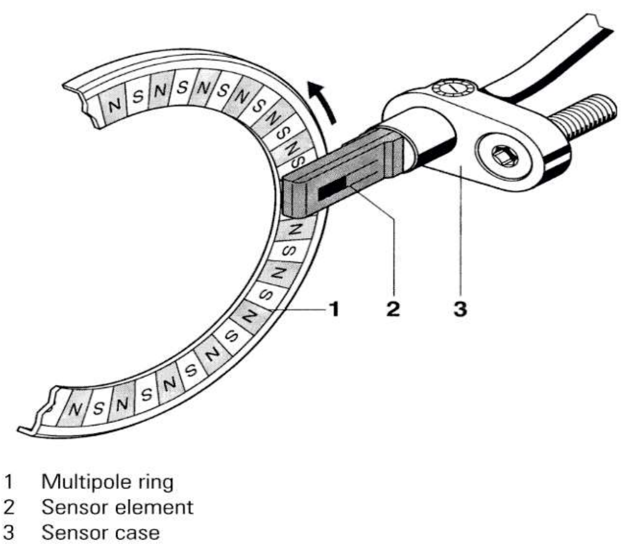

Figure 2.4: Wheel Speed Sensor (Hillier & Rogers, 2007)

The sensor detects the rotary movement of the multipole ring mounted on the drive shafts hence changes the magnetic field or flux in the sensor the moment when the multipole ring changes polarity from North to South and vice versa based on Figure 2.4. This changing flux is then converted into a frequency-based signal proportional to the rate of the flux change.

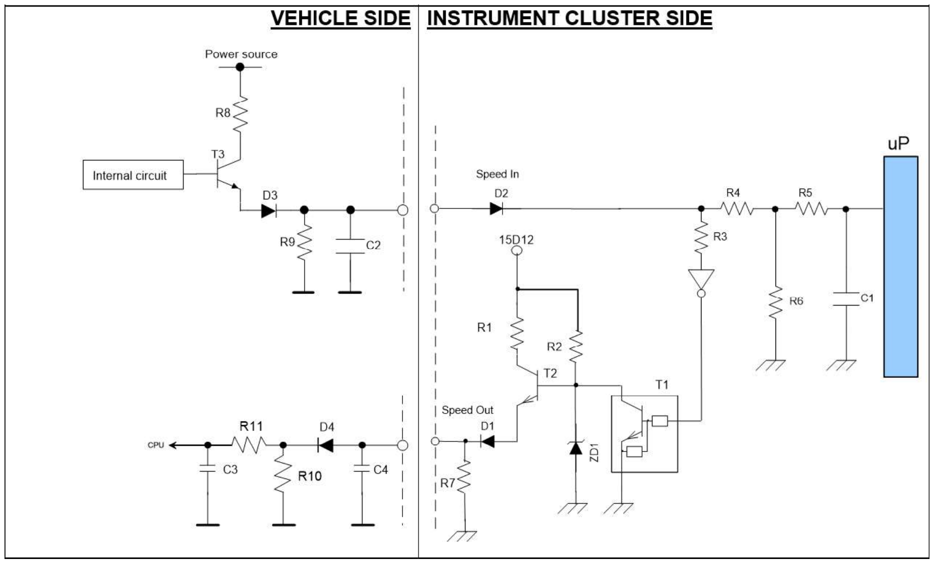

Figure 2.5: Schematics for Speedometer Gauge (Ghani, 2008)

As shown in Figure 2.5, for the Speedometer gauge to successfully display the current speed of the vehicle, the frequency-based signal is required to be transmitted by the Vehicle Side from the internal circuit which comes from the speed sensor. The frequency-based signal is received and measured by the microprocessor which drives the stepper motor. This stepper motor which is mechanically connected to the pointer gauge then moves the pointer to the position corresponding to the pulse frequency.

2.3.2 Tachometer Gauge

Brodgesell and Liptak (2003) described a tachometer, also known as RPM counter or rev-counter is a gauge used to display the rotation speed of a shaft or disc . Hillier and Rogers (2007) explained in automotive, it is in dial shape used to indicate the actual engine revolution, alerting the driver if there is any engine over-revving and keeping the optimum engine speed at appropriate gear selection. Electronic Control Unit (ECU) receives the crankshaft revolution from the speed sensor and processed it before transmitting the frequency-based output signal to the VIC.

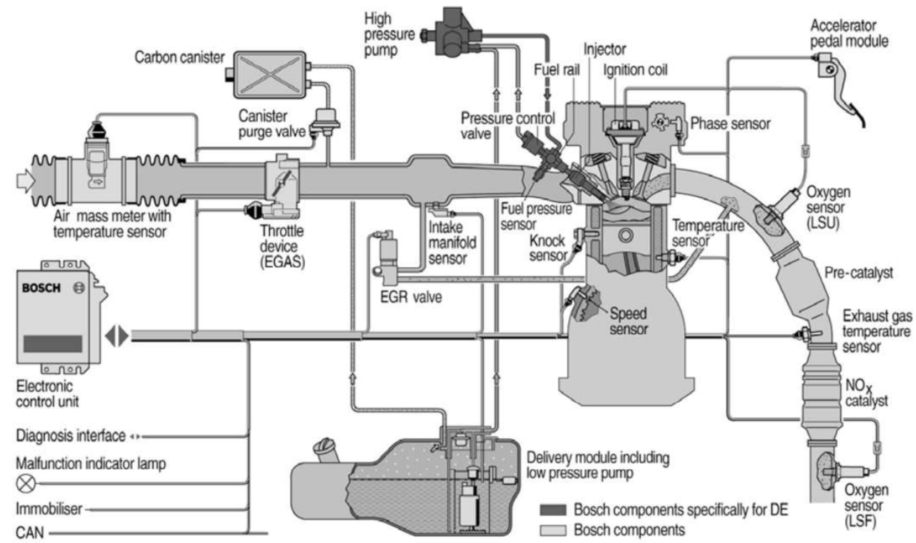

Figure 2.6: Components used in a typical modern electronic computer controlled vehicle system (Hillier et al., 2006)

Similarly to the speedometer, tachometer gauge consist of a microprocessor which measures the frequency of the pulses received from the ECU and drives the stepper motor as shown in Figure 2.7 to a position dependent on the frequency Ghani (2008).

2.3.3 Fuel Volume Gauge

Early gauge design for Fuel Volume in the early years adopted moving-iron mechanism with cross-coil types which is similar to a construction and operation of a simple ammeter. The sensor unit installed within the fuel tank is a variable resistor. The sensor is activated by a floating mechanism as shown in Figure 2.8. The fuel level

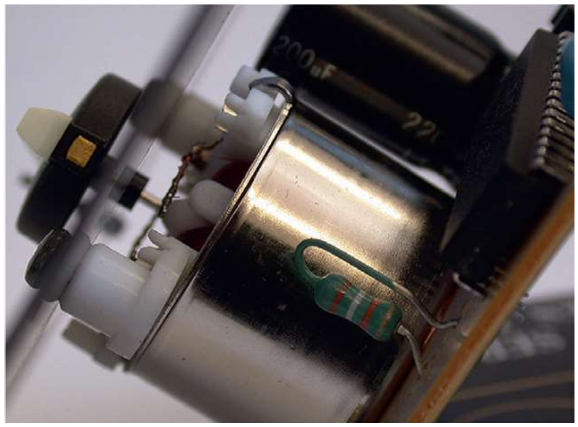

Figure 2.7: Stepper motor installed for tachometer display (Denton, 2011)

inside the tank varies the current flow into the gauge circuit. Thus, the current is measured and displayed by the gauge as fuel contents. As the fuel level changes, the position of the wiper as shown in Figure 2.9 also changes and this alters its resistive value. Hence the current flowing in the gauge circuit changes and the gauge display reacts accordingly. Previously, simple wire-wound resistive elements were used. For modern sensor units, Printed Circuit Board (PCB) which employs thick film resistors are utilised. These can be tuned accurately to consider the complexity of the tank shape hence the accuracy of the fuel level indication can be improved (Hillier et al., 2006)).

Figure 2.8: Sensor with floating mechanism installed inside the fuel tank(Denton, 2011)

Soon after, the fuel sensor is developed further and the floating mechanism was outmoded by the thermal-type since it is low cost and less sensitive to sudden movement of the fuel inside the tank. Based on Figure 2.9, the current flowing in the gauge circuit heats a bi-metal element in the gauge to deflect the display needle (Hillier et al., 2006). Hillier et al. (2006) mentioned that the more current flowing, the hotter the bi-metal becomes and the further the needle was deflected. To prevent any drastic change of the displayed value, this thermal-type fuel measurement system has inherent damping to handle any sudden changes of measurement value inside the fuel tank.

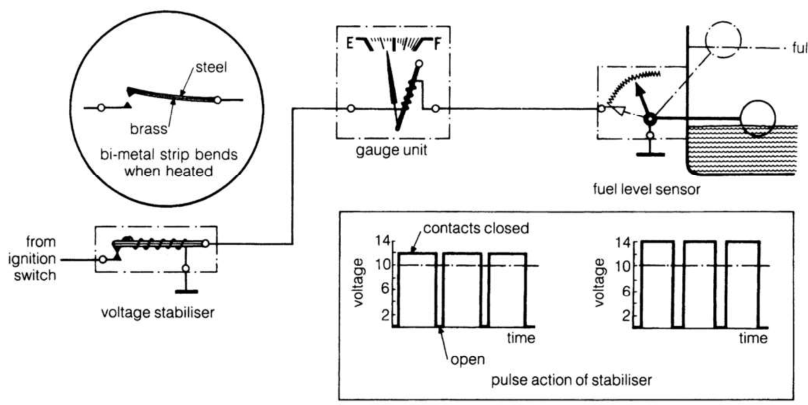

Figure 2.9: Thermal Type Fuel Level Gauge(Denton, 2011)

Current flow is dependent on voltage and constant voltage value is deemed for fuel gauge measurement. To prevent gauge fluctuation caused by a voltage spike, voltage stabiliser is used which regulates the voltage supplied to the gauge assembly to a low level. Bi-metal element is applied in the voltage stabiliser to switch the supply voltage 'ON' or 'OFF' at a certain threshold value, generating a mean voltage at the appropriate level. This stabiliser unit have been completely replaced by electronic units which accurately regulate the supply voltage with minimal ripple. Thus, the microcontroller will process the resistance value obtained from the fuel sensor before displaying the amount of the fuel volume as displayed in Figure 2.10.

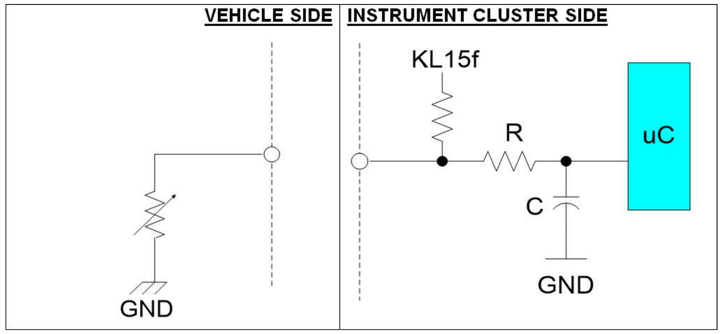

Figure 2.10: Schematic for Fuel Volume and Coolant Temperature Gauge Measurement (Ghani, 2008)

Based on Figure 2.11, the fuel sensor provides measurement of the fuel tank level and the microprocessor measures the analogue input for the resultant voltage. The input value will be filtered by a damping filter defined by the software written and coded inside the microprocessor, thus minimizing the sudden changes or perturbation of fuel display while in normal driving condition.

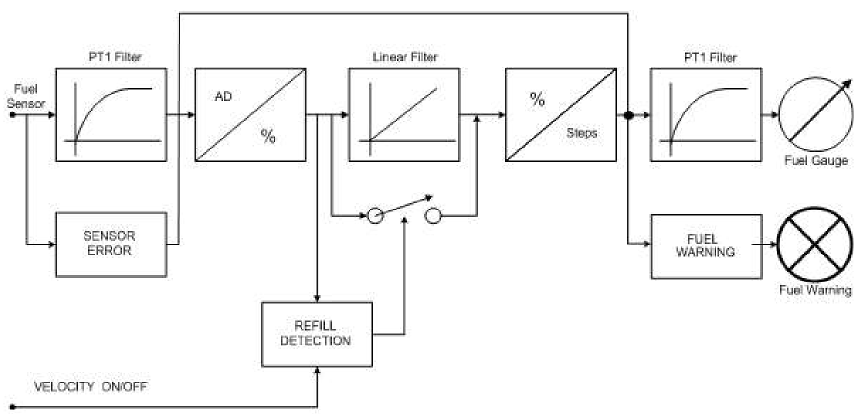

Figure 2.11: Block Diagram for Fuel Gauge(Ghani, 2008)

To eliminate any sudden changes during driving while accelerating or deceleration of the car, a damping filter is applied. A second filter stage with a high linear damping is used for a smooth change of the pointer after the fuel has been refilled (Hanafi et al., 2016).

2.3.4 Engine Coolant Temperature Gauge

Hillier et al. (2006) explains that similarly to fuel gauge, the same gauge development technology was applied. Voltage stabilizer was also installed for Engine Coolant Temperature gauge. However, the sensor is a Negative Temperature Coefficient (NTC) resistor element attached in a brass screw-in body shown in Figure 2.12, which is mounted in the engine where it is exposed to coolant temperature. The NTC element is sensitive to temperature changes and alters the resistance value as the temperature changes. If the engine temperature increases, the resistance of the NTC element decrease thus allows a higher current flow along the gauge circuit hence deflecting the display needle further across the gauge display towards maximum based on Figure 2.13 (Hillier et al., 2006). For the latest development as described by Ghani (2008), the resistance value obtained from the thermistor is connected to a filter and a microcontroller for further processing before displaying into the VIC.

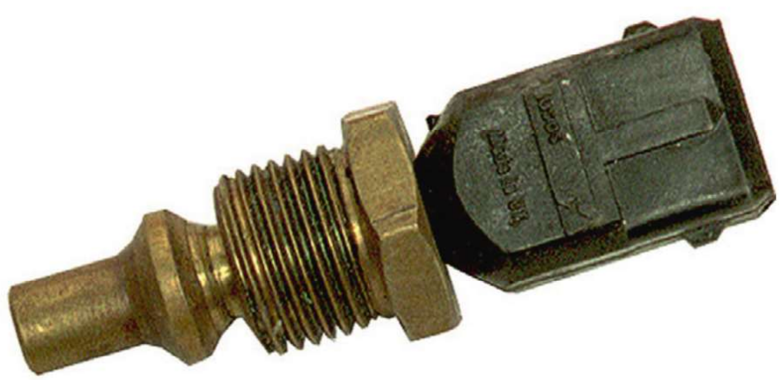

Figure 2.12: Temperature Sensor(Denton, 2011)

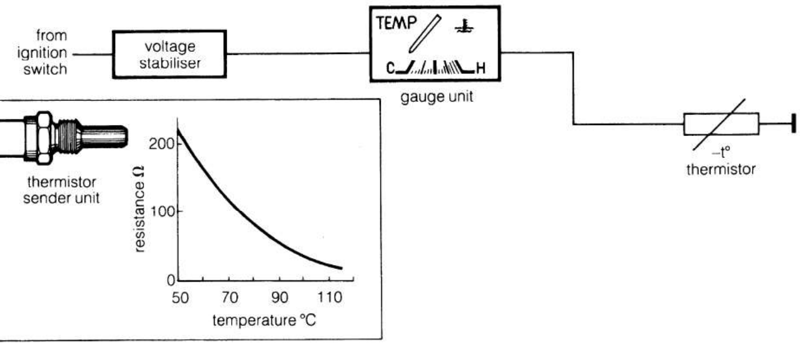

Figure 2.13: Thermal-type engine temperature gauge (Hillier et al., 2006)

The resistance-based sensor measures the engine coolant temperature and the microprocessor processes the analogue input for the resultant voltage. Depending on the received resistance value and the stored gauge characteristics, the temperature gauge stepper motor is driven to a defined pointer position (Hanafi, 2016). Similar to the aforementioned gauge, damping filter is applied for a smooth change of the pointer movement.

2.3.5 Tell-Tales / Indicators

The tell-tale display or also mentioned as indicators are used to remind and ensure the awareness and alertness of the driver upon the vehicle's current conditions such as 'Fuel Level Low', 'Oil Pressure Low', 'Engine Pressure High', 'Check Battery Condition', 'Check Engine Condition', 'High Beam Light Turned ON' and 'Left-Turn Switched ON'.

These tell-tales are able to monitor various vehicle condition. Based on Kershaw, Ed, and Halderman (2007), the tell-tales are activated and turned 'ON' via four means of activation which are Voltage Drop, Ground Switch, Ground Sensor and Fiber Optics.