Abstract

With the introduction of emission standards automobile manufacturers have been using electronic control units (ECUs) to affect dynamic engine control to achieve higher efficiency. This trend has been expanded to all other facets of the automobile including in-car entertainment. Further, all these modules are tied together through a common communicating medium so that they can be controlled by a single input from the user or another module. However with usage, the components of the modules wear out or malfunction. While the offending module may be isolated using On-board Diagnostics, the exact cause of the malfunction is not easy to isolate without specialized testing; hence, the module is usually replaced at considerable cost to the user/original equipment manufacturer (OEM). These units may be effectively remanufactured at a fraction of the cost of a new module by replacing the failed electronic components. To determine the exact point of failure and ensure they are fully functional, these units are tested at various stages and to levels prescribed by the OEM. This paper discusses a test procedure to analyze and qualify automotive electronic modules.

Keywords
Electronic Control Units, On-board Diagnostics, LabVIEW, remanufacturing, automotive testing

1. Introduction

The Automotive Parts and Remanufacturers Association (APRA) of the United States defines remanufacturing as the process of restoring a worn out part of an automobile to a “functioning equivalent” of a new part [1]. The word rebuilt is also used interchangeably with remanufacturing. The scope of remanufacturing according to APRA includes a complete disintegration of the original part, cleaning, inspection for worn out and faulty and missing components [1]. After this appraisal, the components will be assembled again by replacing missing and faulty components with functioning components [1]. Sometimes remanufactured parts are modernized to bring them to comparable scale with modern trends [2, 3]. APRA explains that the cost of remanufactured auto parts are 25% to 50% cheaper compared to a new parts, and also come with the same warranty [1].

It is believed that in the United States alone remanufacturing helps to recuperate about 50% of the raw material which saves over 8 million gallons of crude oil in steel manufacturing, 46720 and 5443 metric tons of iron ore, copper and other metals respectively [1]. APRA further explain that the worldwide savings derived from remanufacturing is equivalent to the amount of electricity produced by 5 nuclear plants [1]. Remanufacturing also minimizes manufacturing cost [1, 4]. Andrew et al. explain that compared to traditional manufacturing, remanufacturing provides 20% - 80% in cost savings [5]. The environmental and economic benefits of remanufacturing has made it very popular in various industries with about $53 billion of annual sales [6]. In 2000, Guide at al. observed that over 73,000 firms in the U.S. have adopted remanufacturing [7].

Consumer perception about product quality is intuitively skewed towards new products. The concern for safety in an area as critical as the automobile industry may outweigh the economic benefits of using recycled equipment. Liability is of equal concern as the remanufacturing companies are generally smaller in scale than the original equipment manufacturers (OEMs) and may not be able to absorb the financial setback from recalls. Hence the need for effective and rigorous testing is acute and costs incurred may be prohibitive to the low volume business model of the remanufacturing industry.
To lower costs without compromising on testing, a test system built on Commercial off the Shelf (COTS) technologies has been developed. This system uses automotive protocols (such as J1850 and CAN) and analog and digital signals from the module to conduct functional tests. A PC based LabVIEW program is being used to acquire and analyze the signals and to determine if the module passes or fails the test.

2. Literature Survey

2.1 Product life cycle

Growing interest in climate change and sustainability has necessitated the efficient utilization of renewable and non-renewable resources. This has helped to direct world leaders’ focus to sustainable production and consumption which has been adopted worldwide [8] as a tool for developing economies. According to Admas [9] sustainability has been of great concern to humanity for over 3 decades. Sustainable development is defined by the Brundtland Report as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [10]. One way to meet the needs of sustainable development is the product life cycle thinking [6]. This system of thinking tracks products through their entire life cycle; with this, companies are held responsible for any adverse effect on the environment caused by manufacturing, usage, and disposal of their products [11]. According to Sergio et al. [12] the product life cycle primarily starts from extraction of raw material, manufacturing, usage, to end-of-life. These stages in product life cycle run in a loop with other secondary stages: repair, remanufacturing, reuse, recycle or disposal. Figure 1 shows the loops of all the stages in product life cycle thinking.

![Figure 1: A Generic product’s life cycle and various End-of-life strategies. Source: Adopted from [12].](image)

When a product no longer meets the needs of the end user, it is said to be at the End-of-life stage [6]. The secondary stages are known as end-of-life strategies. According to Ayres [13] the end-of-life strategies: reuse, repair, remanufacture and recycle are referred to as “closed loop” strategies [13] since they serve as a re-entry paths back into the product’s cycle. Disposal is an “open loop” strategy since it leads to permanent loss of resources either by cremation or land filling [6]. Pragam et al. [6] explain that the environmental benefits achieved from close loop strategies far outweigh the benefits from open loop strategy [6]. It is therefore, prudent to encourage the application of close loop strategies to meet the needs of sustainable production and consumption. Ijomah et al. [14] explain the major differences between the close loop strategies: recycling involves the processing of material to be used for the manufacturing of another product of the same type as the original product from which the material came from or an entirely new product; reuse involves the usage of a pre-owned product without anterior repair operations; refurbishing involves the renovation of the product to meet standards through processes such as painting; repair involves the fixing of a damage part of a product to make it functional; remanufacturing also involves the replacement of damaged parts of a product to bring it to the state of the original standard [6] [14].

2.2 Automotive electronics
Technological advancements in recent times have positively impacted the automotive industry. Automotive systems are made of sophisticated computerized systems that communicate in a complex environment. In order for all the individual components to perform satisfactorily, an efficient networking capability has been built into the system to optimally integrate all the subsystems [15]. Thomas et al. explain that automotive system consists of multiple subsystems with several ECUs. With about 70 ECUs in an automobile, over 2500 signals and variables are transmitted among the ECUs [16]. A typical Jaguar XK8 has 8 ECU modules in the body alone [17] as shown in figure 2.

To benefit from the expertise of various automakers and subcontractors several vehicle manufacturers utilize the services of common subcontractors. Since different subsystems are developed by different subcontractors which are installed in the vehicle by the major automaker, there is the need to ensure that the systems are connected so that they can communicate. This was mostly done by cabling; but it became more challenging to connect the ever increasing number of subsystems (applications) with cables [15]. This challenge was solved by the novel introduction of fieldbuses [15]. Bruce et al. explain that a fieldbus is a serial communication network for the integration of sensors and other electronic devices to computers [18]. It helps to exchange information among nodes (devices) integrated by the fieldbus [15]. Further, internationally recognized standards organizations such as SAE and ISO have developed communication strategies to ensure easy integration of units. Communication protocols that are currently in use include SAE J1850, Local Interconnect Network (LIN), ISO 11898 Controller Area Network (CAN) etc [15].

2.3 OBD II
On-Board Diagnostic System (OBD) has been in use in the automotive industry since 1988 when it became a requirement for all newer light vehicles and cars sold in the state of California. The California Air Resources Board (CARB) in 1985 first consented to the installation of OBD as a way to curb vehicular emission [19]. When it became a requirement in 1988 all newer light trucks and cars sold in the state of California were required to have OBD system to detect and segregate malfunctions in the engine control module. In 1996 OBD II specification was made mandatory for all cars manufactured in the United States and is the standard currently in use. To ensure accessibility of diagnostic data, the messages transmitted between the test equipment and the electronic modules either on or off the vehicle have been standardized. This is defined in the SAE J1979 (emission related diagnostics) [20] and SAE J2190 (extended non-emission related diagnostics) documents [21].

3. Testing of ECU
The following are important features of the testing process for ECUs:
1. Test equipment: The vehicular ECU is provided with a connector which is the hard wire interface to the remaining automotive system and this provides the link for analog, digital and serial data I/O. The connector comprises of many pins. Each pin is typically connected to a specific function provided by the module. Hence the ECU can be visualized in the form of a function block as illustrated in figure 3. The test process generally involves activating one or many functions of the module and analyzing the response. The
test equipment used is determined based on the module functions as seen in figure 3. COTS National Instruments’ (NI) hardware such as the NI DAQ (data acquisition system) chassis is being used along with analog, digital and fieldbus I/O.

2. Using OBD protocols for I/O: An effective method to test the ECU is by exciting specific functionality using the OBD protocols as defined in SAE J2190 [21]. Each function has been defined under a specific Parametric Identification Number (PID) and thus may be tested in isolation. By this method, a test query is transmitted to the module through the communication interface and the response is monitored using the fieldbus communication and also hard wired analog or digital signal output.

3. Using vehicular data communications in testing: Automotive ECUs are not designed to function in isolation and information essential to the functioning of the ECU is transmitted through the fieldbus continually. Hence bench testing the module requires that essential vehicular information be provided to ensure proper simulation of the working environment. To achieve this, fieldbus transmissions are captured during normal operation of the module (in the vehicle) and transmitted using the communication interface of the test set. Care is taken to mimic the steady-state and dynamic data environment, as observed in the vehicle, during testing.

4. Temperature Variations testing: For effective remanufacturing of the ECUs, a multi layered test approach is followed to simulate various external conditions the ECU may be exposed to. While the ECU is generally protected from the elements in the engine bay or the cabin of the automobile, it is susceptible to temperature fluctuations depending on seasonal/geographic changes. Hence the ECU is subject to variable temperature tests. The flowchart of the test procedure is shown in the figure 4 below.
5. Statistical process: The test program is equipped with automatic data storing protocols. Test results over multiple tests of fully functional ECUs are collected to develop a set of test limits. A 6 sigma deviation is applied to the mean data for each functional test to make up the limits

4. Testing using LabVIEW

A LabVIEW program has been developed to remanufacture ECUs keeping in mind the requirements of the automobile manufacturers and the business model of the remanufacturing industry. The test program has been developed to be accessible to skilled and unskilled labor. Some of the important functions provided by the test program as seen in figure 5 are:

- Single button Start/Stop: Enables the user to stop the program at any point during the process.
- Tabular data display: To report the malfunctions of the ECU, the first point of failure is recorded and the error is analyzed by a technician using the schematics. By providing a tabular display format with test results in engineering units, the troubleshooting process is made more efficient.
- Color coded controls: In a remanufacturing environment, unskilled and semi-skilled labor is normally used to conduct the test process. In such case color coded controls make it easier for training and operation of the programming sequence.
Test result pop-up display: To remove ambiguity of the end result of the test process, a pop-up display is provided. The operator must acknowledge the result before proceeding with reporting of pass or fail status of the ECU for the given test.

Stop on fail/continue on fail functionality: During testing of the ECU, the first point of failure is usually addressed with additional failures being rectified after consecutive testing. This is efficient as a single failure may be exhibited at different instances during testing depending on the ECU circuit. To ensure quick turnaround, a stop-on-fail option is provided. For extensive testing a continue-on-fail option also provided.

Figure 5: Front panel of testing program

5. Conclusions
Automotive electronic control modules, like many other electronic systems can be remanufactured at a considerably lower cost than that of a new product. However, it is important to maintain the quality levels of the OEM as safety is a major criterion. A multi-layered remanufacturing process with a LabVIEW based testing system has been developed. The LabVIEW program provides an effective GUI environment which may be used by skilled and unskilled labor to conduct the test process. This ensures that remanufactured parts that make it to the customer or market meets the requirements of the OEM while keeping costs down.

While the methods discussed in this paper are adequate for remanufacturing, the process may be improved by using a first order expert system [23]. To this end, a knowledge base may be generated to provide test limits which could be automatically updated based on the ambient conditions of the test.
References