Development of Wireless Safety System for Hybrid Vehicle Hazard Monitoring

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***Abstract*—The advent of advanced automobile technology has enabled the introduction of hybrid vehicle engine which is a combination of electric motor and gasoline fuel usage. Although the technology seems to support environment and provide ease of use to the consumer, the underlying risk associated with this is electrocution which could be fatal with the high rating of battery used in these vehicles. To minimise such risk, an economical and efficient monitoring system has been designed and developed to monitor voltage and current leakage from related cables on hybrid vehicles and warned stakeholders when the event necessitates it. Data collected shows alarming potential current leakage characteristic on overused cables when analysed.**

***Index Terms*—Hybrid Vehicle; WSN; Voltage Sensor; Current Sensor.**

I. INTRODUCTION

Wireless Sensor Networks (WSNs) is a crucial technology for monitoring and controlling of several process systems and can provide sensor measurements at high precision, low-cost and low-power consumption [1]. With the advancements in wireless communication, microelectronics and computer technology, wireless sensor networks show their strength in a variety of applications such as electronic industry, agriculture and automobile. A WSN is a system comprises of radio frequency transceivers, sensors, microcontrollers and power sources [2]. The WSNs are not only capable of sensing these physical parameters such as temperature, pressure, light intensity and humidity but also to communicate over a short distance wirelessly and perform data processing [2,3]. This allows the WSNs to be applied in surveillance or monitoring system.

Current or voltage leakage detection is a process of identifying the excessive current or voltage leaks using specified sensor system. The sensor system usually will employ an audible alarm or notification to alert people when a current or voltage level exceeds the safe level and cause danger. Typical sensors used are voltage sensor, current sensor and power sensor. All of these sensors are used widely in many applications such as treatment facilities, home and vehicles. Current/voltage leakage detector is a device used to detect failure of electronic equipment and interface with the control system so that the process can be shut down. For instance, an earth-leakage circuit breaker (ELCB) and residual current device (RCD) are safety devices used in electrical installations with high Earth impedance to prevent electric shock[4].

In recent years, wireless sensor network (WSN) has been subjected to many applications. Thus, there is significant interest in using WSN in communication links of the safety system. WSN with electric current/voltage leakage monitoring can be implemented in the equipment safety system such as automobiles. In conjunction with the environmental awareness and advancement in automobile technology, the advent of the hybrid vehicle becomes abrupt and with it the problem. The hybrid electric vehicle is a vehicle that combines the use of gasoline fuel engine and electric motors which could provide power and energy to assist the engine in driving [5]. The function of the hybrid car is still the same as the conventional car. The only difference is high voltage battery consumption, but smaller fuel engine needed compared to normal vehicles [5]. The battery pack of hybrid car rating is very high, and this poses a safety problem. For instance, the battery pack in the Honda Insight and Civic Hybrid at rated at 144 volts [6]. The 1st generation 2001-2003 Toyota Prius battery is rated at 273.6 volts while the 2nd generation 2004-2008 Prius is rated at 201.6 volts [6]. For current gasoline vehicles, the voltage in the battery is around 12/24V direct current, but the battery of hybrid electric vehicle nowadays is up to 650 V DC [7].

Data from 1998 CDC/NIOSH summarising electrocution fatalities in their data surveillance system indicates that during the decade of the 1980s approximately 7% of the average 6,359 annual traumatic work-related deaths were due to electrocution. This report also indicates that during the period from 1982 to 1994, twice as many fatal work-related electrocutions occurred with voltage levels greater than 600 volts [8]. Hence, hybrid vehicles introduce hazards such as electrocution, fire and electrotype spillage into the workplace and to those normally associated with the repair and maintenance of vehicles and other vehicle-related activities. This is due to the presence of high voltage components and cabling capable of storage of electrical energy with the potential to cause explosion or fire. Components also may retain a dangerous voltage even when a vehicle is switched off. Electric motors or the vehicle itself may move unexpectedly due to magnetic forces within the motors and manual handling risks associated with battery replacement [9]. Touching a hybrid vehicle that has been in an accident or during service will definitely put personnel at the high risk of danger and may cause death.

Hence, there is considerable interest in the development of safety system of these hybrid engine vehicles to prevent and minimise electrocution occurring in car service centre while dealing with wrecked hybrid vehicles. A monitoring and controlling system that can efficiently detect the leakage of electricity is needed for the vehicle service centre to protect personnel. This paper discusses the architectural design for a hybrid vehicle service centre monitoring system to prevent potential accident related to current/voltage leakage from hybrid battery. The system design is equipped with sensor node (voltage sensor and a current sensor), programmed to allow the processor to perform detection of the leakages and upload the data to a base station through WSN for monitoring purpose. The sensor nodes also serve as inputs for the microcontroller to operate the warning system.

II. HYBRID VEHICLES HAZARD

The major hazards regarding contact with energised sources are electrical shock and burns. Electrical shock occurs when the body becomes part of the electric circuit, either when an individual comes in contact with both wires of an electrical circuit, one wire of an energised circuit and the ground, or a metallic part that has become energised by contact with an electrical conductor. The severity and effects of an electrical shock depend on a number of factors, such as the pathway through the body, the amount of current, the length of time of the exposure, and whether the skin is wet or dry [12].

Occupational fatalities associated with electrocutions are a significant and ongoing problem. Data from the NIOSH National Traumatic Occupational Fatality (NTOF) surveillance system indicated that an average of 6,359 traumatic work-related deaths occurred each year in the United States from 1980 through 1989; an estimated 7% of these fatalities were due to electrocutions [11]. In 1995, the Bureau of Labor Statistics reported that electrocutions accounted for 6% of all worker deaths [12]. For the year 1990, the National Safety Council reported that electrocutions were the fourth leading cause of work-related traumatic death [13].

A. Potential Hazard Caused by Hybrid Vehicle Battery

Hybrid vehicles typically include high voltage batteries, and the presence of high voltage components creates a possible electrocution hazard. Figure 1 shows the battery of hybrid vehicles for different model

Manufacturer/Model/ Engine-Transmission Designation	Vehicle Type	Battery Size	Battery Type
Honda Civic Hybrid 4 cyl	Compact Car	158V	Ni-MH
Honda Insight 4 cyl, Auto(AV-S7)	Compact Car	101V	Ni-MH
Honda Insight 4 cyl, Auto(VGR)	Compact Car	101V	Ni-MH
Lexus GS 450h 6 cyl	Compact Car	288V	Ni-MH
Lexus HS 250h 4 cyl	Compact Car	245V	Ni-MH
Chevrolet Malibu Hybrid 4 cyl	MidSize Car	36V	Ni-MH
Ford Fusion Hybrid FWD 4 cyl	MidSize Car	275V	Ni-MH
Mercury Milan Hybrid FWD 4 cyl	MidSize Car	275V	Ni-MH
Nissan Altima Hybrid 4 cyl	MidSize Car	245V	Ni-MH
Toyota Camry Hybrid 4 cyl	MidSize Car	245V	Ni-MH
Toyota Prius 4 cyl (2001 – 2003)	MidSize Car	274V	Ni-MH
Toyota Prius 4 cyl (2004 – 2010)	MidSize Car	202V	Ni-MH
Mercedes-Benz S400 Hybrid 6 cyl	Large Car	126V	Li-Ion
Cadillac Escalade Hybrid 2WD 8 cyl	Sport Utility Vehicle 2WD	300V	Ni-MH
Chevrolet Tahoe Hybrid 2WD 8 cyl	Sport Utility Vehicle 2WD	300V	Ni-MH
Ford Escape Hybrid FWD 4 cyl	Sport Utility Vehicle 2WD	330V	Ni-MH
GMC Yukon 1500 Hybrid 2WD 8 cyl	Sport Utility Vehicle 2WD	300V	Ni-MH
Lexus RX 450h 6 cyl	Sport Utility Vehicle 2WD	300V	Ni-MH
Mazda Tribute Hybrid 2WD 4 cyl	Sport Utility Vehicle 2WD	330V	Ni-MH
Mercury Mariner Hybrid FWD 4 cyl	Sport Utility Vehicle 2WD	330V	Ni-MH
Saturn Vue Hybrid 4 cyl	Sport Utility Vehicle 2WD	36V	Ni-MH
BMW Active Hybrid X6 8 cyl	Sport Utility Vehicle 4WD	312V	Ni-MH
Chevrolet Tahoe Hybrid 4WD 8 cyl	Sport Utility Vehicle 4WD	300V	Ni-MH
Ford Escape Hybrid 4WD 4 cyl	Sport Utility Vehicle 4WD	330V	Ni-MH
GMC Yukon 1500 Hybrid 4WD 8 cyl	Sport Utility Vehicle 4WD	300V	Ni-MH
Lexus RX 450h AWD 6 cyl	Sport Utility Vehicle 4WD	300V	Ni-MH
Mazda Tribute Hybrid 4WD 4 cyl	Sport Utility Vehicle 4WD	330V	Ni-MH
Mercury Mariner Hybrid 4WD 4 cyl	Sport Utility Vehicle 4WD	330V	Ni-MH
Toyota Highlander Hybrid 4WD 6 cyl	Sport Utility Vehicle 4WD	300V	Ni-MH
Chevrolet Silverado 15 Hybrid 2WD 8 cyl	Standard Pickup Truck 2WD	300V	Ni-MH
GMC Sierra 15 Hybrid 2WD 8 cyl	Standard Pickup Truck 2WD	300V	Ni-MH
Chevrolet Silverado 15 Hybrid 4WD 8 cyl	Standard Pickup Truck 4WD	300V	Ni-MH
GMC Sierra 15 Hybrid 4WD 8 cyl	Standard Pickup Truck 4WD	300V	Ni-MH

Figure 1: Hybrid vehicle battery for various manufacturers [11]

Vehicle electrical systems generally conform to the applicable SAE (Society of Automotive Engineers) related standards. High voltage is indicated as any wiring system which contains one or more circuits operating between 60 Volts DC or Volts AC RMS, and 600 Volts DC or Volts AC RMS [11]. Potential hazardous voltage means any voltage levels that can harm humans through electric shock. Generally, recognised vehicle electrical current classes are [11]:

- Low – Up to and including 30 Volts DC or 15 Volts AC,
- Intermediate – Greater than 30 Volts DC or 15 Volts AC and less than and including 60 Volts DC or 30 Volts AC
- High – Greater than 60 Volts DC or 30 Volts AC

The most widely publicised fire incident involved a 2011 Chevrolet Volt after it was crash tested at MGA Research, in Burlington, Wisconsin, in June 2011. The Volt's lithium-ion battery caught on fire three weeks after being subjected to an 18 mi/h side pole test as part of the National Highway Traffic Safety Administration's (NHTSA) New Car Assessment Program (NCAP). The fire quickly spread to three adjacent vehicles. An extensive post-fire investigation later determined that a small amount of battery coolant penetrate the high-voltage battery case after the crash, causing the battery to short and eventually leading to a thermal runaway condition [14].

In 2012, Fisker Karma electric vehicles caught fire and were destroyed at a port in New Jersey after Hurricane Sandy. It is believed that flooding caused a short circuit in one of the Karma's lithium-ion batteries, leading to a thermal runaway condition. The fire then spread, eventually igniting the 15 adjacent vehicles [15]. In 2013, two Tesla Model S sedans caught fire while being driven in the United States. The first, in Washington State, occurred after the car struck a metal object on the road. The second occurred after the car ran over a trailer hitch lying on the road in Tennessee. In both cases, road debris punctured the floor and battery pack, leading to battery failure and thermal runaway [16]. In 2014, a fire occurred when the driver, a car thief, crashed the car at high speed, tearing the vehicle in two. The battery pack was ejected and caught fire. The driver later died in the hospital from injuries sustained in the crash [17].

III. SAFETY SYSTEM ARCHITECTURAL DESIGN

To address issues with electrocution as a result of failed or damaged battery especially during service, a safety monitoring system is designed and developed. The system consists of sensors capable of detecting leakage current and voltage connected to a processing module and wireless alarm system to inform relevant personnel of potential hazard whenever the threshold exceeded.

A. Sensor Selection

The initial data received come from the voltage and current sensors. Study on the working principle of the sensors need was done to understand the operation and the behaviour of the sensors.

The voltage of the risky cable connected to the battery in hybrid vehicles is crucial as one of the inputs for decision-making algorithm. Using voltage sensor in this project can reduce the complexity of constructing complicated voltage divider circuitry. The voltage sensor can detect the supply voltage from 0.0245V to 25V and is Arduino compatible. The operating voltage output is 3.3V – 5V while the input voltage range 0.0245V ~ 25V.

The Allergro ACS712 provides a precise and economic AC and DC current sensing. The current sensor is used in this project to measure the current flow through the risky cable that connected to a car battery in hybrid vehicles to monitor whether the leakage of electricity occurs. Table 1 shows the specification of current sensor used in this research.

Table 1
Specification of the Current Sensor

Parameters	Specification
Supply voltage	5Vdc Nominal
Measurement Range	-20 to +20Amps
Voltage at 0A	2.5Vdc
Scale factor	100mV per Amp
Chip	ACS712ELC-10A

B. System Operation

The system consists of monitoring portion and triggering portion. The output voltage from current and voltage sensor will be delivered to the processor of the system (Arduino System on Chip). When the current sensor and voltage detect the presence of current and voltage, the analogue signal is sent to an analogue-digital converter (ADC) within the Arduino, and this signal is processed, and data will be sent to the monitoring system, and relevant personnel could access the data real time. At the same time, the processor will also analyse the data signal and compares with the defined threshold value for both current and voltage measured. When the current or voltage level exceeds the threshold value, an alarm message will be triggered and send the personnel service mobile phone via SMS.

This ensures the potential electrocution due to leakage current or voltage could be avoided when service personnel are attending to the vehicle. Data stored could be reviewed periodically to identify potential leakages from measured current and voltage values. Figure 2 shows the working architecture of the system.

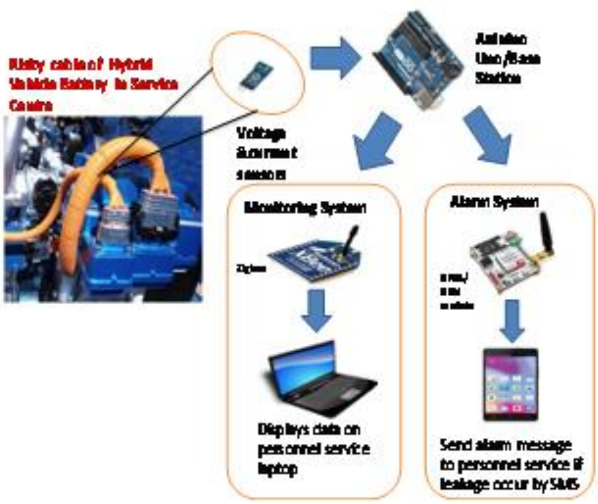

Figure 2: System architecture design

IV. Results and Discussion

This section discusses the results obtained from the limited measurement performed using the system. The results are presented based on the measured voltage and current values at a specified period of time.

Figure 3 shows the measurement of voltage over time taken continuously on a power line running at 9V voltage source. The voltage measured on this line consistently showing measurement below 9V although there seem to be some fluctuations after 2 to 3 minutes of measurement. With measured data and fluctuations within the expected control limit, this data shows there is no leakage observed on this line.

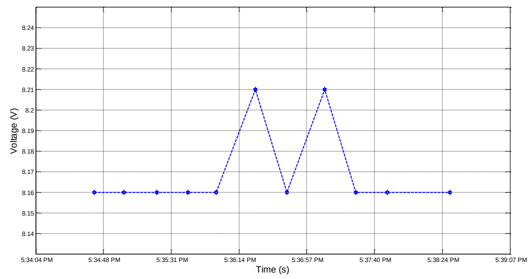

Figure 3: Voltage measurement on 9V line

Figure 4 shows a measurement of current over time taken continuously on a power line running at 3.3A current source. Voltage levels were not consistent with this line. However, all of them are within 3.3A control limit thus no leakage observed. A measurement of out of control limit would signify a leakage, and as the threshold overstepped, an alarm would be sent to the specified party.

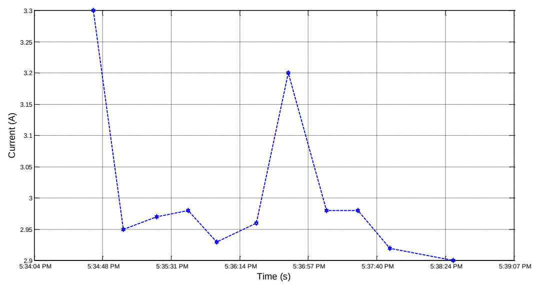

Figure 4: Current measurement

Voltages measured shown in Figure 3 has a mean value of 8.17V which shows almost steady voltage supplies. The standard deviation for this measurement is around 0.02. Small standard deviation and closer to specified expected value show solid and good insulation for this cable which would potentially take some time before a leakage could occur. On the other hand, calculated mean for current measurement is at 3.01A, and the standard deviation is at 0.13 which shows a large fluctuation in current level flowing through the cable which could be an indication of soon-to-occur leakage. This, however, depends mainly on the wear and tear of the cable as well as the frequency the cables are used.

V. CONCLUSION

This paper reviews the potential fatal electrocution due to high-risk cables installed on hybrid vehicles. The hazard is observed mainly on vehicle service centre which affects the technician attending to the vehicle. To minimise the risk, a system to monitor and provide alarm is designed and developed. The system consists of voltage and current sensors connected to a processor, and the data and alarm are transmitted to database and cellular phone through WSN whenever needed. Although there a no data from actual hybrid vehicle collected, data collected on experimental cables so far reveals, a potential leakage might occur on certain cables as the behaviour of the measurement shows. This could be used as a precautionary action to avoid the risk of electrocution if the leakage occurs.

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