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Design of Intelligent SoC Controller for Engine Oil Sensing and Monitoring System

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ABSTRACT

The demand for engine oil monitoring system has increased recently due to the awareness of used engine oil pollution and as a cost reduction measure for the customer. Previously, many automotive manufacturers advised the customers to change their engine oil at a constant time (i.e., during service) or according to the mileage interval. There is a possibility that the engine oil is changed before the end of its lifetime which will incur higher maintenance cost to the customer. Furthermore, this situation will give bad input to the environment due to the excessive engine oil waste. This review paper described a potential mechanism for engine oil monitoring so that the oil is changed when deemed necessary. The research consists of data analysis, statistical analysis, intelligent system development, System on Chip (SoC) design, fabrication and testing. A statistical analysis of Multiple Linear Regression is used to predict the worst condition of the engine oil. Total Acid Number (TAN), Total Base Number (TBN), viscosity and oxidation level were chosen to be the main parameter for condition based monitoring purpose. A complete SoC design with Verilog Hardware Description Language (HDL) and FPGA implementation has been reviewed as a potential technique for the engine oil monitoring and changing time prediction system.

Key words: Engine oil, optical, fuzzy logic, multiple linear regression, VHDL, system on chip

INTRODUCTION

Engine oil is used as lubricant for various internal moving parts for the combustion engines in the vehicles. It also helps to clean, performance of the engine, it has a finite lifetime and needs to be changed in order to protect the engine. The finite life time of the engine oil is caused by the changes in physical and chemical properties which will degrade according to time and usage. TAN of mg KOH g^{-1}, TBN of mg KOH g^{-1} and viscosity of centistokes (Cst) are the main parameter in determining the oxidation level and the condition of lubricant. Contamination of wear particle from metal surface of engine will influence the degradation of lubricant. Department of Toxic Substances Control (DTSC) reported that, 2.1 billion gallons of soil is sold annually in US in year 2001. The demand of soils are increase yearly and about 420 million gallons are never recycled and goes into an environment. The automobile activities influencing the number of waste soils increased because of the requirement from customers (DTSC, 2001). Hence, a sensing and monitoring technique in mechanical part of engine, prediction algorithm and lubricant analysis become widely needed to improve the efficiency of vehicle operation and reduce used oil waste.

The main concern in predicting the oil life is the sensing technique and prediction algorithm. Dielectric Spectroscopy (DS) and optical sensing are the new approach to monitor the degradation behaviour of lubricant. The dielectric values of lubricant can be determined using ring capacitor while optical technique gives the percentage of light through the samples of used oil. The variation values of dielectric and percentage of light transmittance shows the degradation of lubricant due to the contamination after running condition. Therefore, this variation values will be analyzed using statistical analysis to predict the oil life and an algorithm can be embedded for effective prediction. Even though the previous analysis can predict the oil life, it still lacked in decision making of the suitable time to change the engine oil (Guan *et al*., 2011; Jun *et al*., 2006). Hence, it is important to develop an intelligent system for determining the time of engine oil change is really needed.

Therefore, the present study was undertaken in order to determine the suitable time to change the lubricant and focused on lubricant engine oil. The condition based monitoring of degradation are the main consideration so that the oil is changed at the necessary time. This may reduce the yearly automobile activities and also reduce the number oil wasted lubricant engine oil. In developing the engine oil monitoring and prediction system, it is necessary to identify the main parameters that influencing the oil life. Here, we will do it by identifying the relation between optical properties of engine oil with the result from chemical experiments. Data of degradation parameters will be analyzed and characterized on five important parameters namely viscosity, TAN, TBN, oxidation, soot and water contamination using statistical analysis of discriminant and regression analysis. The result of the analysis will be used to predict the engine oil condition. Hence, instead of offline analysis of engine oil degradation, we propose an intelligent controller for condition based monitoring in real time condition. As for intelligent controller, Fuzzy Logic will be developed to analyze the input data according to the statistical analysis for monitoring and prediction purposes. Lastly, SoC will be implemented using Silterra's 0.13 μm technology.

ENVIRONMENTAL ISSUE IN USED ENGINE OIL POLLUTION

Nowadays, increasing amount of used lubricant from million numbers of vehicles due to maintenance activities became a global environment issues. Utusan Malaysia's 8th December 2011 reported that, about 150 million liters of used lubricant oils produced in Malaysia from this maintenance activity (Afiq, 2011). Department of Toxic Substances Control also reported that 15.5% from the 2.1 billion gallon of oil sold annually in the US is never recycled and goes to the environment. This situation occurred because many automotive manufactures or dealers advise the customers to change their engine oil at a constant time or according to the mileage interval. So, there is possibility that the engine oil could be changed before reaching at the end of its lifetime and cause waste in money and also give bad impact to the environment (DTSC, 2001).

Recently, the waste from automobile activities including hydraulic fluid, lubricant oil and stripped oily sludge were dump into land. This poor activities and disposal practice increased the contamination of surface water, sediment and groundwater with petroleum hydrocarbon (Iwegbue *et al*., 2008). This groundwater contamination by hydrocarbon also effected on the growth and early seedling performance of planting activities (Kayode *et al*., 2009). He found that the growth inhibition increased with proportional to the concentration of used engine oil pollution. Therefore, it is unsafe for drinking water and irrigation purposes (Kamaruddin *et al*., 2011).

PAST RESEARCH WORKS

Many research works have been done previously for monitoring the current engine oil and towards the extent of monitoring the engine condition. Table 1 shows the comparison study of previous research in monitoring and analyzing technique for lubricant engine oil. It shows the different type of sample have been used, kind of monitored parameters, sensing technique and monitoring technique. Our proposed technique shown in the bottom row of the table to show that our approach is different with others.

According to the Table 1, the physical degradation of engine components due to the lubricant has been studied by Chun (2011). The focus of this study is to predict the real time variation in wears of piston-ring surface, ring-groove and cylinder bore due to the engine oil. There are many factors of engine oil parameters that will influence the condition of the engine components and it has been studied by Guan *et al.* (2008) proposed to focus on identifying grade of engine oil

Table 1: Comparison study of previous work

Analysis/sensing technique	Monitoring technique	Type of sample	Parameter's study	References
Gas flow	Prediction nsing wear equation	Not reported	Piston-ring, ring-groove, cylinder	Chun (2011)
Dielectric spectroscopy and interdigital capacitor sensor	Support vector machine	Multigrade (15-40 W, 15-50 W, 10-40 W), monograde (30, 40, 50 W)	Viscosity	Guan *et al.* (2008)
FTIR (absorbance)	Not reported	Multigrade (20-50 W, 15-40 W) and monograde (50 W)	Viscosity, TBN, pour point	Al-Ghouti and Al-Atoum (2009)
Viscometer	Using statistical result	Lubricant in diesel engine	Viscosity, soot	George *et al.* (2007)
Linear regression	Using statistical result	Biodiesel	Viscosity	Tesfa *et al.* (2010)
Optical colour sensor (blue LED)	Electronic circnitry	Engine oil	Viscosity, pH	Kumar *et al.* (2005)
Complementary electrochemical (EC) and titration method	Using statistical result	SJ, SAE 5-30 W	TAN, viscosity, oxidation	Wang (2002)
Alumina plate	Control and display unit	SAE 5-30 W (mobil and peunzoil)	TAN	Wang (2001)
Wear particle image processing	Computer aided system	Image of wear particles	Segment of image	Yan *et al.* (2005)
Factor, discriminant, classification technique	New predictive algorithm	Automotive engine oil	Viscosity, soot, TAN, TBN	Jun *et al.* (2006)
IR spectroscopy, statistical analysis	Partial least square (PLS) to monitor TAN	Lubricant of gas engine	TAN	Felkel *et al.* (2010)
Electrochemical impedance spectroscopy (EIS) and multivariate data analysis	LCR meter and statistical result	Diesel's engine oil	Soot and diesel contamination	Ulrich *et al.* (2007)
FTIR, MATLAB, PLS	Using statistical result	Synthetic aviation engine oils	TAN, antioxidant concentration	Adams *et al.* (2007)
MIR/NIR (absorbance), multiple linear regression	New algorithm for statistical analysis	TURBO 15-40 W	Viscosity	Caneca *et al.* (2006)
SPSS, MATLAB/optical sensor	Fuzzy logic, SoC	Full synthetic engine oil of gasoline engine	TAN, TBN, viscosity, oxidation	Proposed technique by author

between monograde or multigrade by using dielectric spectroscopy technique while (Al-Ghouti and Al-Atoum, 2009) focuses on the different characteristics between virgin and recycled engine oil. George *et al.* (2007) used statistical analysis to investigate the effects of soot and lubricant oil additives and their interactions on engine oil viscosity.

In monitoring the condition of engine oil, the most important parameter must be determined to make it as the key parameter and will be given highest priority for the engine oil optimization. According to the manufacturer recommendation, the need to change is based on a mileage and classification of engine oil whether it is synthetic or mineral base. A classical technique to check the current condition of engine oil by observing a colour of engine oil on the dipstick is still used by most of the people. Previously, Yan *et al.* (2005) developed an information system such as management database, to do a particle analysis for oil monitoring. They found that, the combination of information technology and oil monitoring can increase the speed of oil analysis, manage the information conveniently and obtain analysis conclusion more precisely in relation to practical application. Other than that (Jun *et al.*, 2006) has developed a predictive algorithm to determine the suitable time to change the automotive engine oil. They use oil sensor and embeded information with on-board computers to monitor the engine oil. Unfortunately, their finding was limited in statistical analysis without able to predict the trend of degradation status of engine oil over time.

Statistical analysis has been used in any field of research for prediction purposes, determining the correlation, probability of future effects, determinant analysis etc. This statistical analysis can also be applied on the any types of lubricant or liquid such as liquid acid, petroleum, diesel and water. Tesfa *et al.* (2010) used a linear regression and correlation to identify the effect of temperature on density and viscosity in biodiesels engine. Hassan *et al.* (2011) also developed a linear programming to get the better result of blending problem in the case of the oil refinery studied as compared to the results obtained by commercial software. As for the prediction purposes, a neural network will give better result as compared to multiple linear regression because it gave a better correlation coefficient and Mean Square Error (MSE) (Roy *et al.*, 2011) while a linear regression analysis will give a better correlation between the estimated value and the predicted value from the actual data (Mohamed *et al.*, 2008).

An intelligent system for monitoring and prediction have been used widely in any field of research. A Fuzzy Logic is the most popular tools for prediction purpose and making decision. Artificial Neuro-Fuzzy Logic Inference System has been used in predicting the pollution of microbiological pollution in fresh water (Bouharati *et al.*, 2008). The reasons of using the fuzzy logic are the data can be formulated in if-then rules which are commonly used in a daily expressions and also can be used to describe a system`s behavior and inference system. The other usage of fuzzy logic was introduced by Alfaouri *et al.* (2009). With used of spatial algorithm for assigning representative input, it resulted to more accurate and flexible in predicting the fluids reservoir. The new modification in defuzzification step also gives the very close result between the predicted values and the actual core values. Moreover, the advantage of Fuzzy Logic that can be embedded with the MATLAB Simulink resulted in very high efficiency through the simulation study in an early stage of system model development (Dehini *et al.*, 2012).

Although, many publications have dealt with the sensor characterization and predictive algorithm, there are still some limitations. Even though some works mentioned the sensing technique and prediction algorithm, only a few works dealt with developing the online monitoring and prediction algorithm that can give us a perfect guideline in predicting the oil life. Nevertheless, non of them gives the degradation of engine oil over time. To take this point into consideration, in

this study, we focus on developing an intelligent system for online monitoring and predict the time for the engine oil to be changed.

NEW PROPOSE DESIGN OF ENGINE OIL MONITORING SYSTEM

Figure 1 shows the current block diagram of monitoring system with proposed intelligent system. The first two blocks have been developed (Kumar *et al*., 2005; Wang, 2002; Guan *et al*., 2011). They focused on sample characterization and sensor development while this work is proposed an additional system for monitoring the condition of engine oil.

In the Fig. 1, the samples of used engine oil were collected in different mileage and has been analyzed using spectroscopy equipment (Kumar *et al*., 2005; Guan *et al*., 2011) and alumina plate sensor (Wang, 2002). The standard method of sample collection and analytical approach are ASTM D664 and ASTM D2896 for TAN and TBN respectively. This test method covers a procedure for the determination of basic constituents in petroleum products and lubricants. Unfortunately, the method covered the monitoring technique of the current condition of lubricant. The monitoring system of engine oil consisted of a sampling unit and data has been converted into electrical signal using Data Acquisition System (DAQ). The important part in this block is to get the accuracy of voltage, proportional to the lubricant parameter. The more samples taken with different mileage will get better accuracy for the whole system. The ADC will then convert the electrical signal into digital forms. Hence, this research focused on development of an Intelligent System of SoC that have a Fuzzy Logic system as the main controller to analyze, monitor and predict the lifetime of engine oil. The system is expected to be able to inform users about the current condition of engine oil and predict the lifetime by displaying the condition using electronic display system.

Figure 2 shows the diagram of the proposed systems. The parameters namely viscosity, TAN, TBN, oxidation, soot and water have been chosen as the main parameter for monitoring

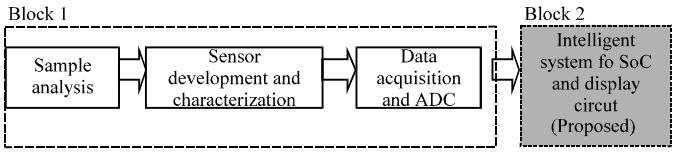

Fig. 1: Block diagram of proposed intelligent SoC system with current monitoring system

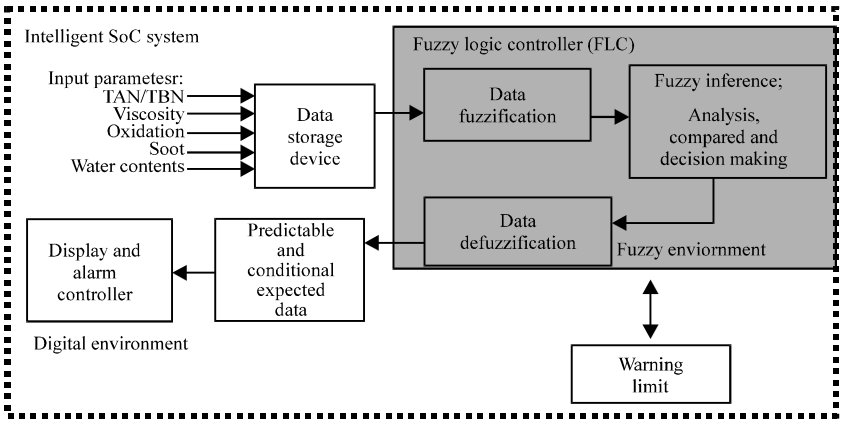

Fig. 2: Propose block diagram of the intelligent SoC system

purposes. These data were recorded in a data storage device continuously at a certain mileage. Then, data fuzzification block in fuzzy environment became a translator to translate the real variable of parameters into linguistic variables. Once all input variable values are translated into corresponding linguistic variable values, the fuzzy inference step are executed to make an analysis of data, comparing, predicting and making decision of changing the engine oil. The decision making is based on warning limit set in the stored data which is taken from the lubricant standard data . Then, the linguistic are translated back into a real value as a predictable and conditional expected data in defuzzification block. Finally, the data is transmitted into display block and alarm controllers. Both digital environment and fuzzy environment are fitted into SoC and tested in a real situation.

IMPLEMENTATION PROCESS FOR SOC DESIGN OF THE ENGINE OIL MONITORING SYSTEM

Figure 3 shows the overall works in SoC development. According to the flow chart shown in Fig. 3, the research is started by collecting a data of used engine oil's parameters from previous research to support the input data to the SoC.

A statistical analysis such as correlation, multiple linear regression and ANOVA that have been reviewed will then simulated using MATLAB software. After data has been characterized and simulated in MATLAB, a Fuzzy Logic controller is developed for the monitoring and prediction purposes. TAN and TBN were chosen as the main parameters in determining the degradation of engine oil and an intelligent system is required for decision making of changing the engine oil.

The proposed design of SoC is planned to be fabricated on SoC as a new device. Therefore, the flow of design works has been reviewed to be compatible with the software and design library. The entire algorithm that has hierarchical performance and sensitivity as well as good functionalities properties is coded into Verilog HDL for SoC development. The Quartus II version 8.0 and ModelSim 6.0 were chosen as the best tools for accomplish this work. The generated layout in GDS file from Synopsis or Mentor Graphic is the main requirement for fabrication purposes. Hence, the design rules from Silterra 0.13 μm were chosen as a guideline for chip fabrication.

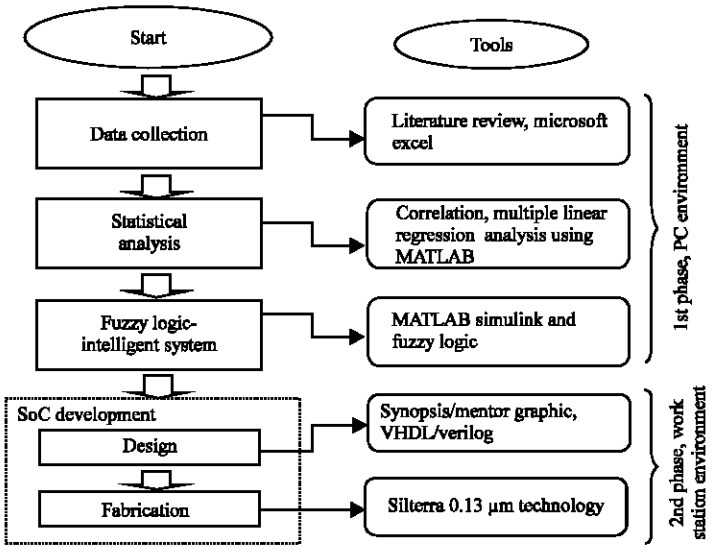

Fig. 3: SoC development work flow

CONCLUSION

Based on the reviewed of degradation parameters in engine oil and sensing technique, a complete development of an intelligent SoC with intelligent fuzzy logic controller has been proposed. The chemical parameters such as TAN, TBN, viscosity and oxidation have been chosen as the degradation parameters to be monitored. As for prediction analysis, the statistical analysis is applied to get a better prediction result. As a result, the developed system is able to alert users the suitable time to change their engine oil in condition based monitoring. The proposed technique also demonstrated that the unnecessary wasted engine oil can be reduced and allowing more efficient condition-based replacement to the vehicles.

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