Simcom A7600c1 LTE Module for Intelligent and Realtime Precision Maintenance Scheduler on a Volvo In-Line D16C610 Engine

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2022 8th International Conference on Wireless and Telematics (ICWT) | 978-1-6654-5122-2/22/$31.00 ©2022 IEEE | DOI: 10.1109/ICWT55831.2022.9935392

***Abstract*—The intensive usage of the engine requires a real time and intelligent approach on how or when to perform a daily maintenance. Volvo in-line D16C610 engine is specifically installed on a FH16 prime mover truck head dragging a single or double trailer (vessel) weigh about 136.4 – 140 metric ton for each vessel. Unfortunately, the parameter used for the maintenance schedule is depend only on hour-meter (HM) which shows running hours of the engine regardless the speed, load, or temperature of oil. This faulty parameter therefore made the maintenance schedule inefficient and faulty. A Simcom A7600c1 LTE Module is installed on an ECU as transmitter to feed the data to the central maintenance planner. Based on the data collected by the system such as engine oil temperature sensor (EOTS) and Crankshaft Position Sensor (CPS). The data for precision maintenance schedule based on real time condition of the engine is recorded via Blynk cloud IoT server and exported to a csv file for further process. The device prototype has been installed and tried in a real-world environment and has been proved to raise the value for MTBF about 1.8 hour, which means the unit is failed more rarely. However, the adjustment of HM value has made MTTR value about 0.6 hour, which means the unit needs more time in maintenance session. The oil analysis result using ASTM D5185-18 method also proved that the status changed from mostly "attention" to "normal" due to the change of the oil is now happen more frequent whenever the unit runs the engine faster than the recommended cruising speed given by the factory**

Keywords—Volvo D16C610 engine, A7600c1 LTE Module, Blynk cloud service

I. INTRODUCTION

Volvo in-line D16C610 engine is a 16.1-liter engine producing 610 HP or 449 kW at 1600 RPM [1]used for intensive works such as coal mechanical hauling or coal transport. The intensive usage of the engine requires a real time and intelligent approach on how or when to perform a daily maintenance. This type of engine is specifically installed on a FH16 prime mover truck head dragging a single or double trailer (vessel) weigh about 136.4 – 140 metric ton for each vessel [2]. The machine is expected to work 24 hours nonstop in a coal mine working environment transporting approximately 200 m^3 coal in total to a tipping point located 90-100 km away from loading point [3]. Unfortunately, the parameter used for the maintenance schedule is depend only on hour-meter (HM) which shows running hours of the engine regardless the speed, load, or temperature of oil. This faulty parameter therefore made the maintenance schedule inefficient and faulty [4]. A Simcom A7600c1 LTE Module is installed on an ECU as transmitter to feed the data to the central maintenance planner. Based on the data collected by the system for example engine oil temperature sensor (EOTS), Crankshaft Position Sensor (CPS), Engine Oil Pressure Sensor (EOPS), Camshaft Position Sensor (CMPS), Engine Coolant Temperature Sensor (ECT) and others [1], a precision maintenance schedule based on real time condition of the engine is possible. The data is recorded via Blynk cloud IoT server and exported to a csv file for further process. The project is tested on a real Volvo FH16 coal hauling service truck head number PM-829 in a mining site for a week on January 2022 at PT Bayan Resources Tbk, Senyiur, Kec. Muara Anclong, East Kutai, Indonesia.

II. EXISTING MAINTENANCE PROCESS AND PARAMETER

A. Daily Monitoring Breakdown (DMBD) and Hour Meter

DMBD is an xls file type document created each day to monitor brake down of a hauling unit. This document consists of minimum 6 columns recording the date, the unit code, hour meter, brake down type of a unit, service start hour and service end hour [5] [6]. The hour meter can be accessed via operator dashboard on a FH16 prime mover truck head under vehicle data menu shown on Fig. 1.

Fig. 1. Hour Meter shows engine has been running for 20724 hours on a FH16 Truck Head

This data is taken from a digital timer recording how many hours the engine has been running. However, it does not record the load of the engine, the rotational speed of crankshaft, or the temperature of the engine oil, therefore the data cannot describe the real metal wear or oil wear happen to the engine.

B. Key Performance Indicator : MTTR and MTBF

MTTR (Mean Time to Repair) and MTBF (Mean Time Between Failure) is a Key Performance Indicator (KPI) on how good or how effective a maintenance is. The timing when and what to perform during engine maintenance is crucial to this KPI. Therefore, the implementation of the proposed method on how to the maintenance process is carried out is expected to be observed using MTBF parameter. MTBF is the average time between engine breakdown shown in (1).

$$MTBF = \frac{\sum(Up\ time - Down\ time)}{number\ of\ failures} \tag{1}$$

The ideal value of MTBF is in match with engine lifetime which is 22000 hours. The down time parameter is calculated from DMBD data specifically on service start hour column and service end hour column. The up-time parameter is taken from standby hour of the unit. MTTR and MTBF of Volvo unit number PM-829 shown in Fig. 2, on the left is calculated in a week period from 8 December 2021 – 14 December 2021 taken from [2]. The graph shows that each machine unit has different parameter and value. It could be concluded that the lowest MTBF is PM-829 with value 20.3 hours, which means the failure occurs every 20.3 hour in a week period. The value for MTTR is 0.7 hour which means it only need 0.7 hour for each repair in every failure for this week.

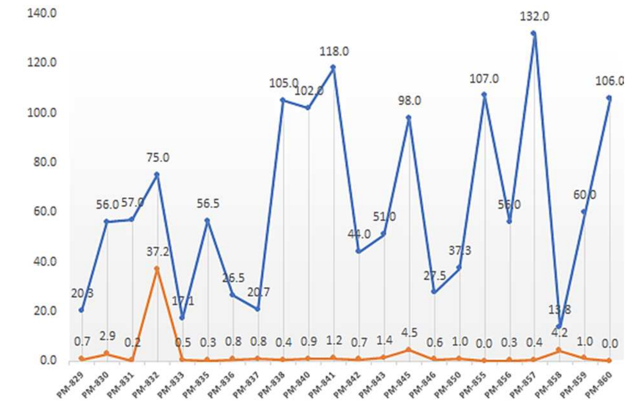

Fig. 2. Graph Showing MTTR (orange line) and MTBF (blue line) of Volvo machine in week 49, year 2021

C. *Engine Oil Analysis using ASTM D5185-18*

The engine oil analysis is a method of analyzing the metal wear in ppm (part per million). The analysis shows the direct effect of maintenance including oil change, oil filter change, operation behavior, and other. By using the data from this analysis, the efficiency of the proposed method could be further observed and inspected. ASTM D5185-18 is a document of standard procedure or test method for multielement determination of used and unused lubrication oils and base oils by inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) [7]. The oil analysis detects metal elements such as aluminum, antimony, boron, cadmium, chromium, copper, iron, lead, magnesium, molybdenum, nickel, silicon, silver, sodium, tin, titanium, tungsten, and zinc that shows wear indication of engine parts. The wear metals indications based on elements found in a used oils are shown in Table 1.

TABLE I. WEAR METALS (ELEMENTS) IN USED LUBRICATIONS OILS

Elements	Wear Indication
Aluminum	Piston, bearings, push rods, air cooler, pump hosing, oil pump, gear castings
Antimony	Crankshaft and camshaft bearings
Boron	Coolant leakage in system
Cadmium	Bearings
Chromium	
Copper	Ring wear, cooling system leakage, chromium-plates parts in engines, cylinder liners, seal rings
Iron	Bushings, injector shields, coolant core tubes, thrust washers, valve guides, connecting rods, piston rings, bearings, sleeves, bearing cages
Lead	Engine block, cylinder, gears, cylinder liners, valve guides, wrist pins, rings, camshaft, oil pump, crankshaft, ball and roller bearing, rust
Magnesium,	Bearings, fuel blowby, thrust bearings, bearing cages, bearing retainers
Molybdenum	Cylinder liner, gearbox housings
Nickel	Bearing alloys, oil coolers, piston rings
Silicon	Bearings, valves, gear plate
Silver	Dirt intrusion from improper air cleaner, seal materials
Sodium	Wrist pin bearings, silver plotted spline of lubricating pumps
Tin	Antifreeze leak
Titanium	Bearings and coatings of conrods and iron pistons
Tungsten	Titanium elements (if any)
Zinc	Bearings
	Neoprene seals, galvanized piping

Data of oil analysis in [8] and [9] show that in a range of a year (January 2021 – December 2021) presented in Fig. 3, the engine oil unit PM-829 has spent 96.66% of its total running hours in "attention" status, 3.33% in urgent status. This means in a year, the engine is in danger, abnormal state for about 96% of its running hours and only 4% in healthy condition. If condition like this continues for another year, the engine will not be able to achieve its normal lifetime.

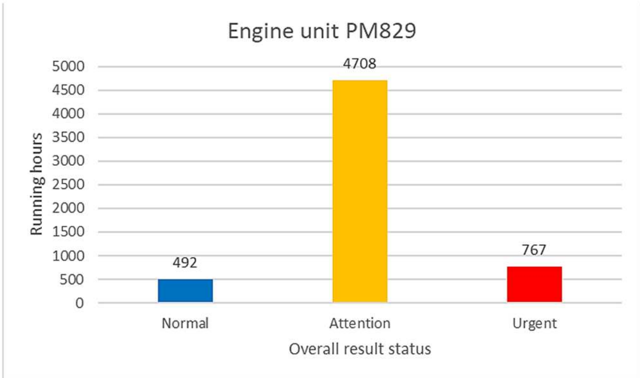

Fig. 3. Graph of engine unit PM-829 running hour spent in a normal/attention/urgent state from engine oil analysis using ASTM D5185-18 by PT United Tractor

D. *Periodic Service*

The periodic service is a service that implemented every specific hour of unit running. They are repetitive program of replacing and or cleaning a part of a unit including engine. Fig. 4. taken from [10] shows that engine oil, and engine oil filter replaced in every 250 hours, and fuel filters are replaced every 500 hours respectively. The replacement, however, based on hour meter only, regardless engine RPM, oil wear, oil temperature, and load, therefore it does not accurately represent the actual wear inside the engine components. Evident shows that in overall performance of the maintenance periodic service program, the unit engine is in healthy condition, but in some engine for instance unit PM-829, the oil analysis shows unhealthy condition even though the periodic service program is carried out timely.

No	ACTIVITY	PS 250	PS 500	PS 1000	PS 2000	PS 3000	PS 4000	PS 6000
Engine - air intake & exhaust system								
	Air intake system rehose							
	Inner Air Cleaner				replace		replace	replace
	Outer Air Cleaner			replace		replace	replace	replace
	Valve & Injector Adjustment							PROGRESS
	Turbo condition Checking			PROGRESS	PROGRESS	PROGRESS	PROGRESS	PROGRESS
Engine - Lubricating System								
	Engine Oil	replace	replace	replace	replace	replace	replace	replace
	Engine Oil Filter 3 pcs	replace	replace	replace	replace	replace	replace	replace
Engine - Fuel System								
	Racor Filter	replace	replace	replace	replace	replace	replace	replace
	Water separator		replace	replace	replace	replace	replace	replace
	Primary Fuel Flter		replace	replace	replace	replace	replace	replace
Engine - Cooling System								
	Cooling system rehose							
	Fan Hub							

Fig. 4. Timetable of PS (Periodic Service) program used by a hauling company at PT Bayan Resources Tbk

III. Materials and Methods

The project utilizing NodeMCU Lua Esp8266 as controller. It will be programmed via USB serial to feed Blynk cloud database with engine sensor data specifically Crankshaft Position Sensor (CPS) and Engine Oil Temperature Sensor (EOTS) in order to accurately predict when is the correct time to replace oil, or engine oil filter. By correctly adjust the accurate timing of maintenance schedule or periodic service, a better engine condition based on MTTR, MTBF, oil analysis is expected.

A. Sensor Circuitry on Volvo D16C610 ECU

Sensor circuitry on Volvo D16C610 is shown in Fig 5. The schematic pin position for Crankshaft Position Sensor (CPS) is labeled B04 pin 1 and pin 2 is attached to ECU pin EA37 and EA38 respectively. The Engine Oil Temperature Sensor (EOTS) is labeled B119 pin 3 is attached to ECU pin EA31.

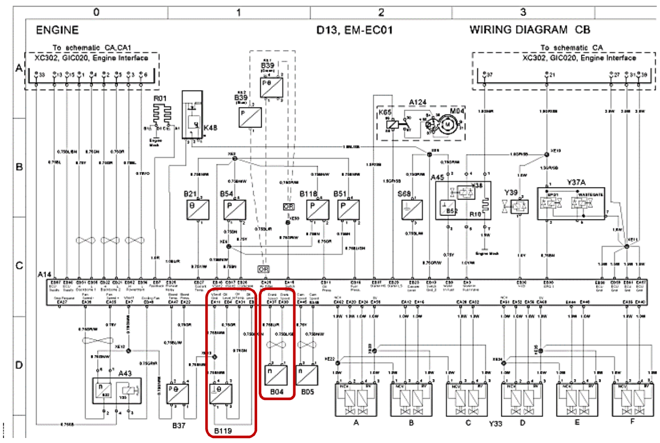

Fig. 5. Schematic shows wiring diagram of Volvo D16C610 Engine sensor circuit page 19 section CB, EM-EC01

B. NodeMCU Esp8266 V3 for Transmitter Controller

NodeMCU is an open source Lua based firmware for the ESP8266 WiFi SOC from Espressif and uses an on-module flash-based SPIFFS file system. NodeMCU is implemented in C and is layered on the Espressif NON-OS SDK [11]. The controller has 11 digital IO pins, and 1 analog input pin. Other controller function is shown on Fig 6.

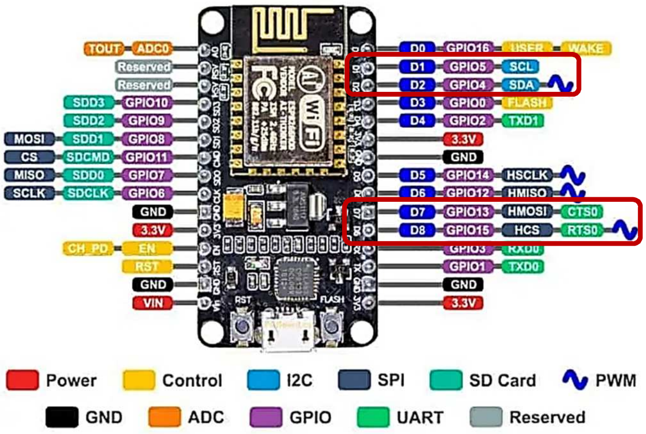

Fig. 6. NodeMCU Lua Esp8266 Pinout Schematic Diagram

[12] indicated that nodeMCU runs on 3.3v therefore it needs DC to DC converter for the IO pins. The Crankshaft Position Sensor (CPS) sensor signal data (ECU pin EA37 and EA38) and Engine Oil Temperature Sensor (EOTS) signal data (ECU pin EA31) is connected to NodeMCU via DC to DC converter and placed inside the dashboard of the unit shown in Fig 7.

Fig. 7. Engine interface port inside the Volvo FH16 dashboard of unit PM-829

The system module is powered using DC to DC converter to convert 12v truck head accumulator to 3.3v shown in Fig 8. RTC or real time clock is attached to D2 and D1 NodeMCU pins for serial communication. The RTC is used to timing the data transmission to Blynk cloud. Simcom A7600c1 LTE Module is connected to D6 and D7 (MOSI and MISO) NodeMCU pins respectively for internet connection via Telkomsel cellular networks. Further pin position can be observed in Fig 6. in red rectangular area. The network card is selected due to its best signal available on the site based on [13].

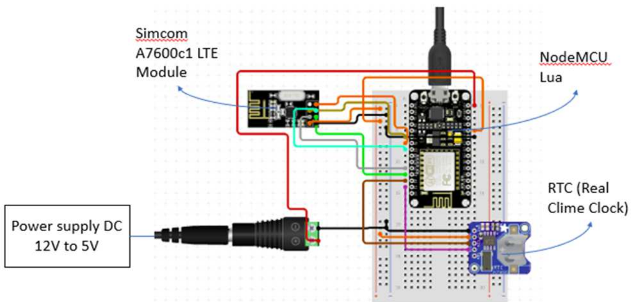

Fig. 8. Block diagram showing wiring connection of the system

The controller is programmed by C language to perform communication MOSI/MISO and I2C function using algorithm presented in Fig 9.

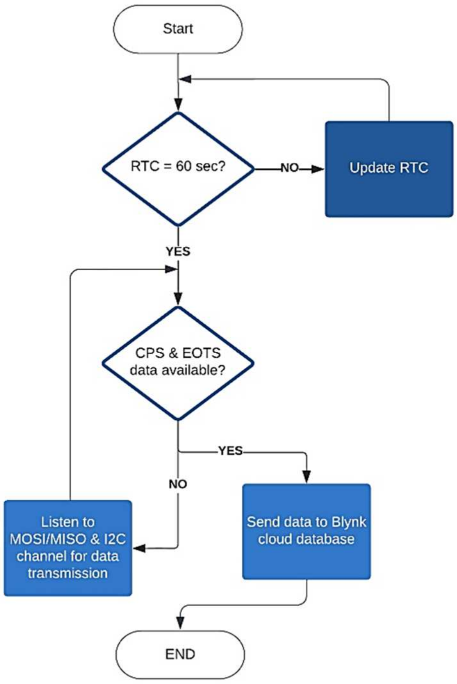

Fig. 9. Flowchart showing algorithm programmed to NodeMCU

C. Blynk Apps Interface

Blynk apps is an IoT interface that has cloud database service. The interface is used to download the data collected by NodeMCU. [14], [12], [15], [16], [17], [18] and [19]indicated that Blynk has ability to stored frequent data send to its cloud server and export them to a csv file type for further process. The design interface of the app named Precision MS apps is shown in Fig 10.

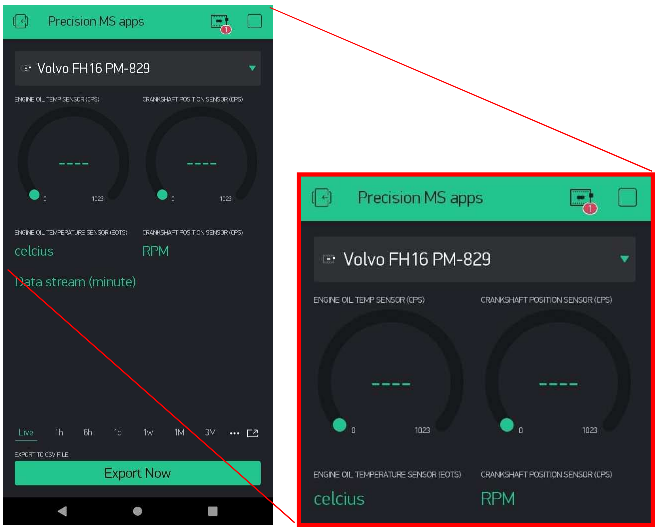

Fig. 10. Interface design of Blynk app developed using Blynk Development Software

D. Simcom A7600c1 LTE Module

This module is a wireless communication module that connects the controller NodeMCU to the Blynk cloud for data transfer. It is controlled via communication channel available in the module using AT command.

IV. Proposed Maintenance Process and Parameter

A. Precision Maintenance Scheduler

The scheduler is an excel based program that used data specifically Crankshaft Position Sensor (CPS) and Engine Oil Temperature Sensor (EOTS) to properly adjust the Hour Meter value to ensure the periodic maintenance activities are carried out based on the crankshaft RPM and oil temperature inside the engine. The hour meter parameter can be observed in Fig. 4. such as PS250, PS500, PS1000 is labeled according to the hour meter achieved and or the multiplication of the stated hour limit by the unit. The hour meter data is proposed to be taken using CPS and EOTS data instead of hour meter shown by the truck head unit in Fig 1. The conversion formula as shown in (2) is the average RPM engine for an hour converted to more accurate HM.

$$HM(Hour\ Meter)_{conv} = \frac{\frac{1}{60}\sum_{i=1}^{60} RPM_i}{1500} \qquad (2)$$

If the unit average RPM is 2000 for an hour, then the HM_{conv} calculated using (2) is 1.33 hour. Using this conversion, the hour meter calculated labeled as HM_{conv} will be determined by the rotation speed of the engine, thus when the engine unit is running for an hour in higher RPM, the HM achieved will be higher than another engine unit running for an hour in lower RPM. The value 1500 is the maximum recommended cruise speed range of Volvo engine D16C610 [1].

V. Results and Discussion

After the implementation of the system for several days, the result shows significant differences of HM compare to HM_{conv}. The adjusted value is more precise to the metal wear prediction inside the machine.

A. MTTR and MTBF

MTTR and MTBF of Volvo unit number PM-829 shown in Fig. 11. on the left. The parameter is calculated in a week period from 9 January 2021 – 16 January 2022 taken from [20]. The graph shows that the lowest MTBF is PM-829 with value 21.8 hours, which means the failure occurs every 21.8 hour in a week period. The value for MTTR is 1.3 hour which means it needs 1.3 hour for each repair in every failure for this week. Compare to the parameter before the implementation, value for MTBF is getting better about 1.8 hour and worse in MTTR about 0.6 hour

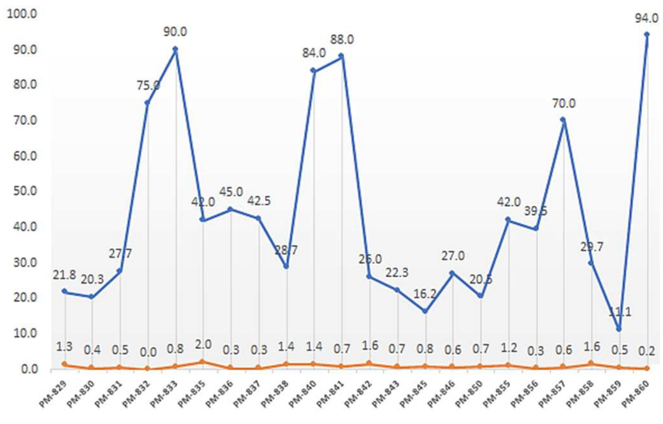

Fig. 11. Graph Showing MTTR (orange line) and MTBF (blue line) of Volvo machine after the implementation of real time precision maintenance scheduler

B. Engine Oil Analysis Result

Data of oil analysis in [8] and [9] show that in a period of a month in January 2022 in Fig. 3, the engine oil unit PM-829 has spent 100% of its total running hours in “normal” status. Compare to year 2021, the engine oil analysis results healthier condition.

VI. CONCLUSION

The Simcom A7600c1 LTE Module for Intelligent and Realtime Precision Maintenance Scheduler utilizing Blynk cloud as database has been designed, constructed and demonstrated to work. The device prototype has been installed and tried in a real world environment and has been proved to raise the value for MTBF about 1.8 hour, which means the unit is failed more rarely. However, the adjustment of HM value has made MTTR value about 0.6 hour, which means the unit needs more time in maintenance session. The oil analysis result using ASTM D5185-18 method also proved that the status changed from mostly “attention” to “normal” due to the change of the oil is now happen more frequent whenever the unit runs the engine faster than the recommended cruising speed given by the factory. It is also important to note that the project does not measure the cost efficiency for the hauling service. The project clearly will consume more oil for oil change compare to the original HM parameter.

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