METHODS USED TO MEASURING FUEL CONSUMPTION DURING OPERATION OF TRACTORS BY TELEMATICS SYSTEMS

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Abstract

Nowadays agricultural companies routinely use mainly two ways of measuring fuel consumption through telematics systems namely fuel consumption data from CAN–BUS and capacitance probe in the fuel tank. After turning on the ignition system, control unit starts up from sleep mode, it will start to measure and store data into memory and connects to the server. Experiment involved brand of tractor manufacturers John Deere. This brand was represented by 11 tractors.

The aim of this paper is to compare the methods of fuel consumption measuring through the CAN–BUS and utilization of capacitive fuel probe. The purpose of this paper is to prove or disprove the hypothesis that measured fuel consumption is statistically significant between measuring through CAN–BUS compared to capacitance probe during operation of tractors.

Key words: telematics system, fuel consumption, capacitance probe, CAN-BUS.

INTRODUCTION

Tractors are the basic machines for agricultural company and the task for company is to carry out all planned activities with the lowest operating costs, which affects the overall efficiency of operations (PEXA ET AL., 2014). Fuel consumption is a significant part of operating costs that companies constantly observe (KOTEK ET AL., 2015).There are various methods for measuring fuel consumption, which are based on detection of the fuel level in fuel tank. These methods for example include measurements using mechanical floats, ultrasonic sensors, digital rulers with mechanical float, pressure sensors, relay floats. Mentioned methods of measuring fuel level have a number of disadvantages. Mechanical floats are often unreliable due to the use of mechanical components. Ultrasonic sensors may have difficulty with obtaining a proper signal at wavy surface of fuel level and are also more expensive. Pressure sensors have problems with the accuracy of measurement when overpressure occurs in the fuel tank due to temperature changes. Measuring accuracy of relay floats is relatively low (PARTNER MB, 2010).

Nowadays agricultural companies routinely use mainly two ways of measuring fuel consumption through telematics systems with respect to the acquisition price, reliability, accuracy of measuring and control of unfair methods of treating fuels.

By default, the fuel consumption data are transmitted from CAN–BUS which does not always coincide with the value of the real fuel consumption. Another possible way of fuel consumption monitoring is realized via installation of capacitance probe mounted directly into the fuel tank (LI X. & FAN Y, 2007). The principle of measurement of these two methods is different, and each method has its own specifics. For instance, a capacitive probe enables detection of non-standard decreases of fuel level in the fuel tank.

The data from both of these methods are transferred telematics systems and via web interface are available in real time (DANIEL ET AL., 2011).

The purpose of this paper is to prove or disprove the hypothesis that measured fuel consumption is statistically significant between measuring through CAN–BUS compared to capacitance probe during operation of tractors.

MATERIALS AND METHODS

Principle of telematics system of machinery is widely known (CAI ET AL., 2011; GESKE, 2007), therefore there are only briefly described issues related to this paper. Telematics system is an technology which merges telecommunications and informatics. This blending of wireless telecommunication technologies along with computers is done ostensibly with the goal of conveying information over vast networks to handle tractor information. The entire system consists of TeCU (Telematics Control Unit) which is called

Gcom, server and webpage application to monitor and to sense ample information's received from tractor. Telematics Control Unit (TeCU) has to be designed and developed, which could be used in real time and off time monitoring, tracking and reporting system (DHIVYASRI ET AL., 2015).

After turning on the ignition system, control unit starts up from sleep mode, it will start to measure and store data into memory and connects to the server. After connecting the control unit sends quickly the recorded data, clears the memory and subsequent data sends at specified intervals. Data about fuel level in the tank were transmitted each 120 s from capacitance probe CAP04. From the CAN–BUS were transmitted data with the same period, but fuel rate was recorded by Gcom each 1 s.

Observed tractors for experiment were chosen from a agricultural company, which has a 25 tractors. From the total number of tractor were selected tractors with operating time of more than 1,000 hrs over a period of six months.

Records of re-fueling are continuously downloaded from the fuel dispenser and also were compared with records from tractor re–fueling measured by capacitance probe. The differences were up to ± 1.5% which is not statistically significant.

Principle of measuring fuel consumption via CAN-BUS

It seems as a convenient solution is obtaining information about fuel consumption via CAN–BUS. This information is contained in the messages of engine diagnostic interface or in the messages of on–board bus of tractor.

Currently, some of tractor manufacturers voluntarily comply the standardization in field CAN–BUS according to the standard SAE J1939. These standards contain information about the instantaneous fuel rate to the engine (SAE INTERNATIONAL, 2015).

Instantaneous fuel rate depends on the designers of engine control system. Usually instantaneous fuel rate is measured by length of the injection and it is conversion to fuel rate.

CAN is a serial communication protocol that allows distributed management of systems in real-time with transmission speed up to 1 Mbit/s and with a high degree of security of transmission against errors. CAN protocol ensures that a message of higher priority is preferentially delivered in case a collision of two messages. For the realization of the physical transmission medium is usually used a differential bus that is defined according to ISO 11898. CAN-BUS comprises two wires, which are called CAN_H and CAN_L, where dominant or recessive level on the bus is defined by the differential voltage of the two conductors.

CAN protocol specification defines four types of messages: Data Frame, Remote Frame, Error Frame, Overload Frame.

CAN protocol uses two types of data messages. The first type is defined by specifications 2.0A (Standard Frame), while 2.0B specification defines Extended Frame (J1939). The only significant difference between the two these formats is the length of the message identifier which is 11 bits for a Standard Frame and 29 bits for the Extended Frame.

The data link layer describes the general characteristics of the CAN–BUS as a structure of data frame identification, transport protocol for transmitting messages that contain more than 8 bytes and encoding parameter groups.

Standard SAE J1939–71 (Vehicle Application Layer) defines groups of parameters and contained therein signals, for example engine coolant temperature, engine oil temperature, fuel rate etc. Groups of current parameters are transmitted in the data message. Each group of parameters is defined by a unique PGN (Parameter Group Numbers) (Fig.1). This number consists of two parts in the message identifier. The first part is the PDU format and the second is a specific PDU.

For transmitted values are defined attributes: length of data, variables type (default or specific), range of incoming data, distribution of physical quantities, diagnostic data.

0x00FEF2					PGN Hex
65 266					PGN
100 ms					Rep. Rate
Data Byte 1	Data Byte 2	Data Byte 3	Data Byte 4	Data Byte 5-8	Byte No.
8 7 6 5 4 3 2 1	8 7 6 5 4 3 2 1	8 7 6 5 4 3 2 1	8 7 6 5 4 3 2 1		Bit No.
Fuel Rate	Fuel Rate	Instantaneous Fuel Economy	Instantaneous Fuel Economy	Not used for (BUS) FMS standard	Name Name
0.05 l/h per bit	0.05 l/h per bit	1/512 km/l per bit	1/512 km/l per bit		Values
0 offset	0 offset	0 offset	0 offset		Values
0 to 3,212.75 l/h	0 to 3,212.75 l/h	0 to 125.5 km/l	0 to 125.5 km/l		Values
SPN 183	SPN 183	SPN 184	SPN 184		SPN

Fig. 1. – Parameters CAN-BUS according SAE J1939 (SAE INTERNATIONAL, 2015)

Principle of measuring of fuel level in the tank by the capacitance probe CAP04

The principle of measuring of fuel level by the capacitance fuel level sensor is based on the fact that diesel is electrically non–conductive liquid. Capacitive probe CAP04 consists of two tubes of different diameter, which are the electrodes of capacitor. The dielectric is composed of electrically non-conductive material, specifically with a fuel and air. The relative permittivity of air is ε_r = 1, during refuelling the air is replaced with diesel which has relative permittivity ε_r = 2 and due to this fact the capacity of the capacitor increases. The capacitive sensor measures the position of the boundary between air and diesel fuel (Fig.2) (PARTNER MB, 2010).

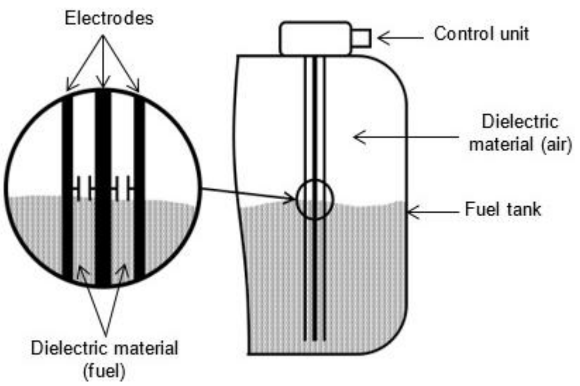

Fig. 2. – Principle of measuring of fuel level in the tank by the capacitance probe

The probe is also equipped with thermometers to sense temperature of fuel and the surface temperature of the fuel tank. The processor evaluates data according to the actual capacity of the probe to match the measured volume of diesel at a reference temperature 15°C. This method ensures that the reported amounts of fuel are not distorted by thermal expansion of diesel. Furthermore, the probe measures the tilt of the tank in two axes. While driving terrain when the level of diesel fluctuates rapidly and strongly, the probe indicates stable signal. This is achieved through suitable filters of the signal e.g. adaptive moving average depending on the tilt of fuel tank (PAVLU ET AL., 2013; ALES ET AL., 2015).

Experiment involved brand of tractor manufacturers (John Deere). This brand was represented by 11 tractors. Tractors were operated in agricultural companies focused on crop and livestock production (tillage, seedbed preparation, forage harvesting, forage wagons). The observation period of operation of tractors was determined for the second half of year 2015. Average operational time of one tractor was around 1,240 hours.

RESULTS AND DISCUSSION

Collected data from the telematics system must always be properly processed. Data on fuel consumption measured via CAN–BUS are in incremental format and do not include information about refuelling. Calculation of cumulative trend of consumption is simple (dotted line in Fig. 3). In terms of capacitance probe each user has continuous information about consumption and refuelling (referenced to the distance travelled). This data represents a saw–tooth pattern in Fig. 3. Such data must be converted into cumulative form. For this purpose, a complex code in Visual Basic for Applications was created. Program code can reliably distinguish between consumption and refuelling or other factors as may be fuel tank tilting or fuel theft. The linear trend of cumulative consumption with linear equation (Fig. 3). Slope of linear equation represents consumption of a tractor for 1 operational hours.

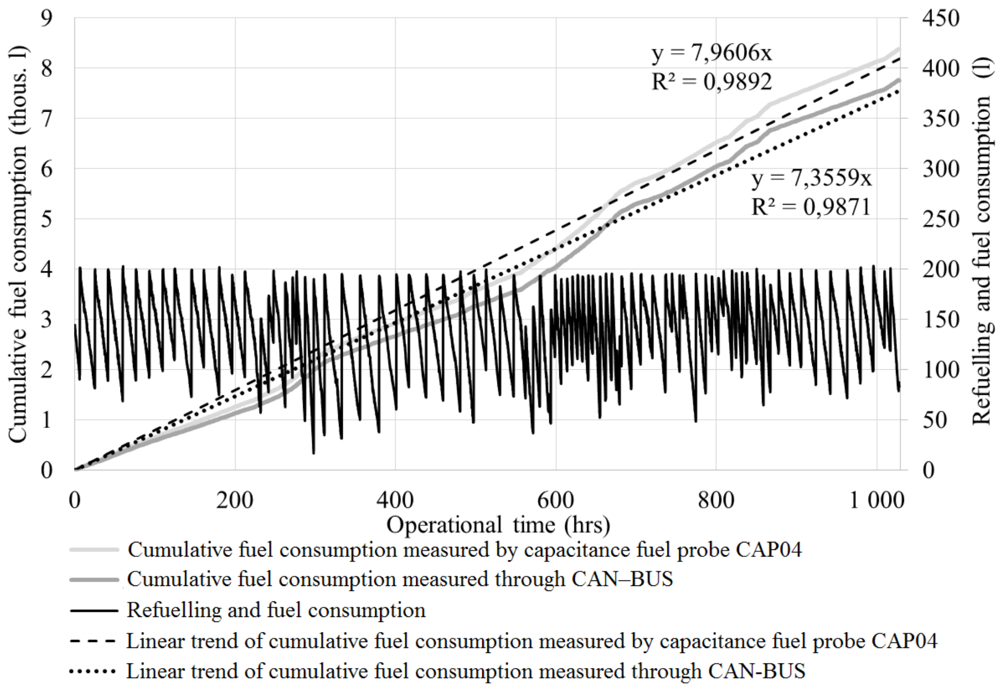

Fig. 3. – Measured and calculated data of fuel consumption –John Deere 6630

Results calculated from obtained data are for John Deere of tractors (Tab. 1). Results show the average values of specific values of fuel consumption, both from the CAN-BUS and capacitance probe. The last column shows the difference between the fuel consumption compared methods in the tables.

Tab. 1. – Results of calculated data from telematics systems – John Deere

Number of tractors	Type of tractors	Operational hours (hrs)	Average values of fuel consumption CAN-BUS (l/hrs)	Average values of fuel consumption capacitance probe (l/hrs)	Difference of fuel consumption (l/hrs)
1	**John Deere 6630**	**1,028**	**7.3559**	**7.9606**	**0.6047**
2	John Deere 6630	1,158	11.594	12.377	0.783
3	John Deere 6630	1,257	8.807	9.986	1.179
4	John Deere 6630	1,023	7.247	7.776	0.529
5	John Deere 6630	1,268	10.58	11.392	0.812
6	John Deere 6530	1,087	11.698	12.61	0.912
7	John Deere 6530	1,587	8.837	9.903	1.066
8	John Deere 6530	1,698	8.356	8.929	0.573
9	John Deere 6430	1,147	12.546	13.259	0.713
10	John Deere 6430	1,158	10.458	11.431	0.973
11	John Deere 6430	1,236	7.549	8.623	1.074

* - measured and calculated data of fuel consumption (Fig. 2)

From the calculated data can be determined null hypothesis H_0: there is no statistically significant difference between consumption measured via CAN-BUS and capacitance probe. Wilcoxon Signed-Rank non-parametric test (Equation 1–2) was used to verify this hypothesis (MOSNA, 2015). Significance level was set at α=0.05 and two-tailed hypothesis was chosen.

$$Z = \frac{\min\left(W^{+};W^{-}\right)-\frac{1}{4}n\cdot(n+1)}{\sqrt{\frac{1}{24}n\cdot(n+1)\cdot(2n+1)}} \quad (1)$$

$$Z = \frac{\min(66;0)-\frac{1}{4}11\cdot(11+1)}{\sqrt{\frac{1}{24}11\cdot(11+1)\cdot(2\cdot 11+1)}} = -2.934058 \quad (2)$$

where: W – sum of the signed ranks ($^{+}$positive, $^{-}$ negative); n – sample size

The Z-value is -2.934058. The p-value is 0. The result is significant at p≤ 0.05. That can be concluded that nullhypothesis$H_0$is rejected. Therefore, there is statistically significant difference between consumption measured via CAN-BUS and capacitance probe.

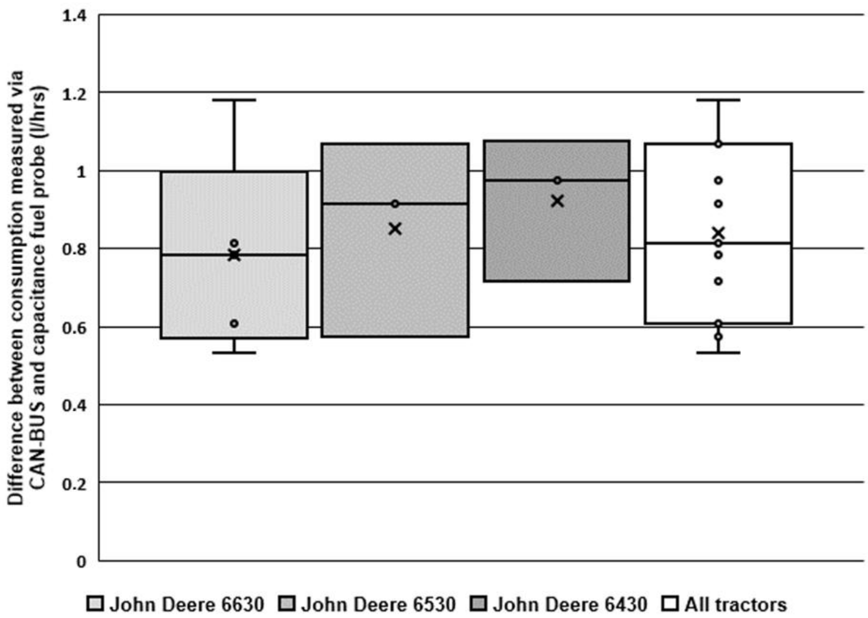

Fig. 4. – Box plot representing measured difference between consumption measured by capacitance probe and CAN–BUS

All results of difference between fuel consumption measured via CAN-BUS and capacitance probe are shown in box plot in Fig. 4. The average difference between compared methods for all tractors under consideration was 0.86 l/hrs of fuel consumption.

Besides, similar results were reported in a pilot study that there was a difference (up to a 6.22% error) between data collected using the machine controller area network (CAN) bus Society of Automotive Engineers (SAE) J1939 standard fuel rate and data collected from a physical measurement system utilized by the Nebraska Tractor Test Laboratory (NTTL) (MARX ET AL., 2015).

CONCLUSIONS

Fuel consumption of tractors is an important part of the economy of operation of entire company. Tractors are equipped with various systems for measuring fuel consumption. The aim of the paper was to prove or disprove the hypothesis, if there is statistically significant difference between described methods of measuring fuel consumption.

Designed experiment involved 11 tractors. Tractors were operated in agricultural companies focused on crop and livestock production (tillage, seedbed preparation, forage harvesting, forage wagons). The observation period of operation of tractors was determined for 6 months. Average operational hours of one tractors was around 1,240 hrs. Fuel consumption was monitored for each tractors using two methods via CAN-BUS and capacitance probe. Collected data was transmitted through telematics systems and then processed based on an algorithm created in Visual Basic for Applications. Results were statistically processed in order to accept or reject the hypothesis. Null hypothesis H0 was rejected, it means, there is statistically significant difference between consumption measured via CAN-BUS and capacitance probe. Created box plot shows that average difference between compared methods for all tractors under consideration was 0.86 l/hrs of fuel consumption. The results confirm the general opinion that the fuel consumption measured via CAN-BUS shows lower values compared to real fuel consumption. In practice, this means that data from the capacitance probe correspond to the real fuel consumption and addition through capacitance probe may control of unfair methods of treating fuels.

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