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Algorithm for measuring gears implemented with general-purpose spreadsheet software
Original Research Article

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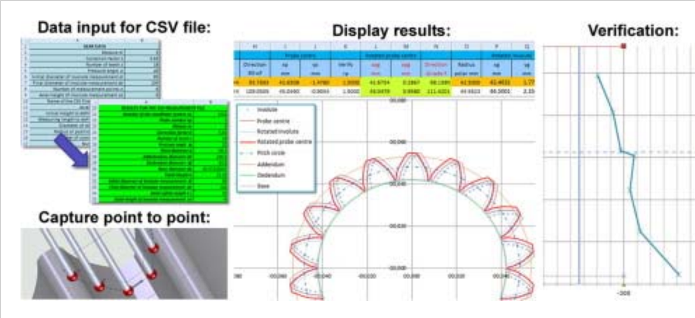

Reliability and sensitivity of a novel dynamic balance test for alpine skiers
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Andrej Panjan, Matej Supej, Jernej Rosker, Nejc Sarabon

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Highlights

- Novel dynamic balance test is sensitive to alpine skier's expertise level.
- Application of cross correlation method for analysing rhythmic COP movements.
- Trained alpine skiers present superior balance with an additional loading.
- Trained alpine skiers are more accurate in controlling lateral COM shift.

Vibration signal modeling of a planetary gear set with transmission path effect analysis
Original Research Article

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Libin Liu, Xihui Liang, Ming J. Zuo

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- A comprehensive vibration signal model for a planetary gear set is proposed.
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- Transmission path contains two parts: inside the gearbox and along the casing.
- Vibration amplitude is a function of the relative length of the transmission path.

Implementation of ANN-based Selective Harmonic Elimination PWM using Hybrid Genetic Algorithm-based optimization
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3D measuring and segmentation method for hot heavy forging Original Research Article
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Highlights

- We describe a method for measuring the dimensions of hot heavy forgings.
- A sequence of 2D laser scans generates a point cloud dataset.
- The item of interest is isolated from the background via cluster analysis among other techniques.
- The processed dataset can yield accurate three dimensional measurements.
- This process has been experimentally verified in the laboratory and the workshop.

Design and modeling of an intelligent temperature to frequency converter Original Research Article
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Naveen Kumar Vaegae, Venkata Lakshmi Narayana Komanapalli, Bhujanga Rao Annepu
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Highlights

- Modeling of intelligent temperature to frequency converter using thermistor.
- Hybrid technique is developed with improved linearity and sensitivity.
- Levenberg–Marquardt algorithm trains multilayer perceptron neural network.
- Implementation of ANN modeling uses ATmega 328 microcontroller unit.

Cutting force analysis to estimate the friction force in linear guideways of CNC machine Original Research Article
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Highlights

- Guideways are significant parts in CNC machines to yield precision and accuracy.
- Friction in guideways is a major factor that prevents more accuracy and precision.
- The friction forces are modeled using the analyzed cutting forces on guideways.
- Coefficient of frictions are measured experimentally at dry lubrication condition.
- The friction force is estimated using the identified coefficient of friction.

Application of two-output port fiber coupler as gasoline level sensor Original Research Article
Pages 80-87
Samian, Y.G.Y. Yhuwana, A.H. Zaidan, Supadi, Sujito
Abstract | Close research highlights | Purchase PDF

Highlights

- New method to detect gasoline level using two probes from single fiber coupler.
- The sensor mechanism is simple which is based on hydrostatics pressure principle.
- Results show working range increase two fold compare to sensor using single probe.

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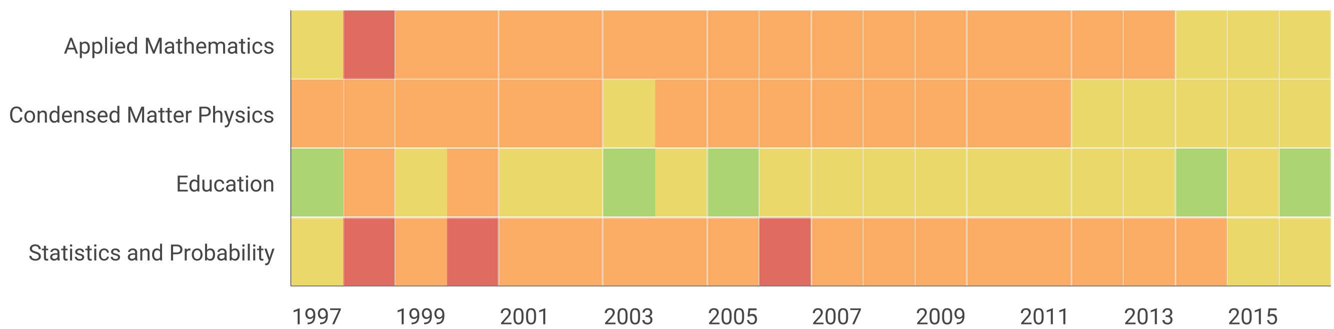

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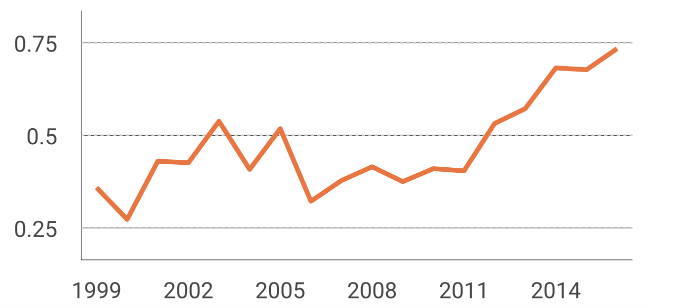

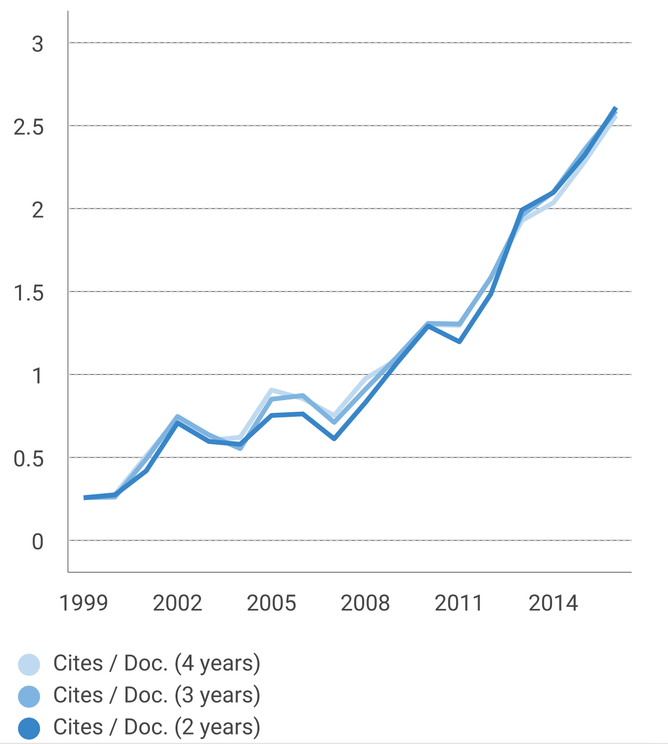

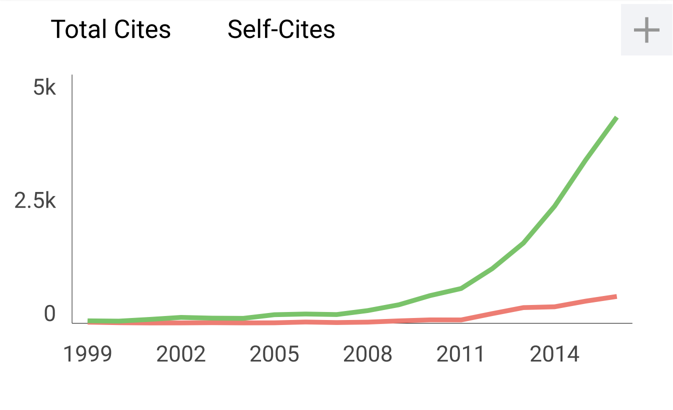

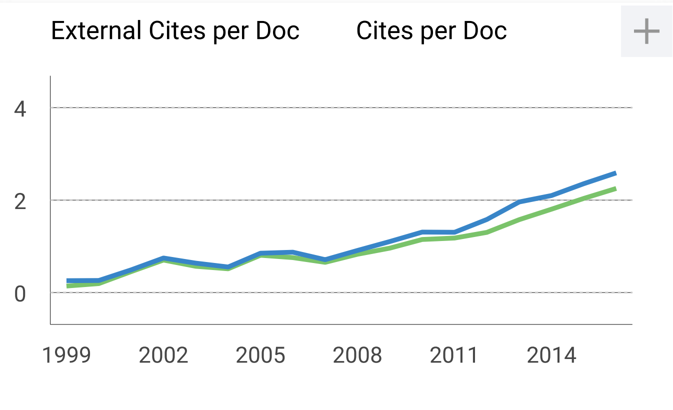

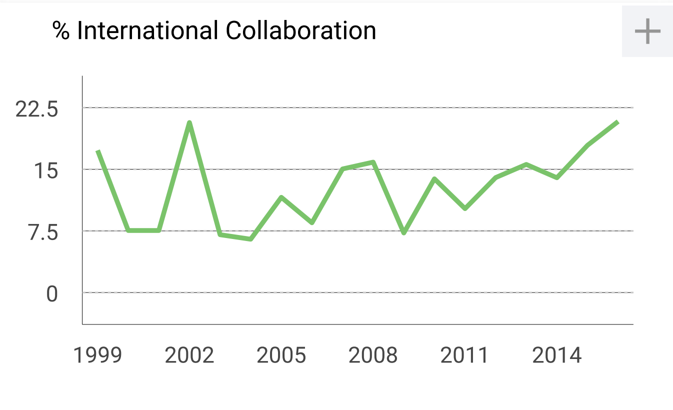

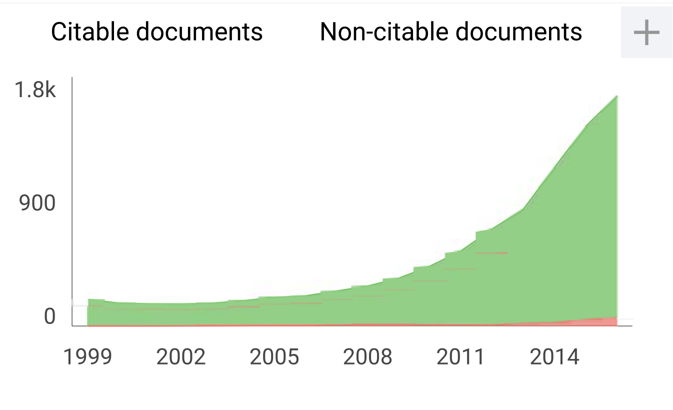

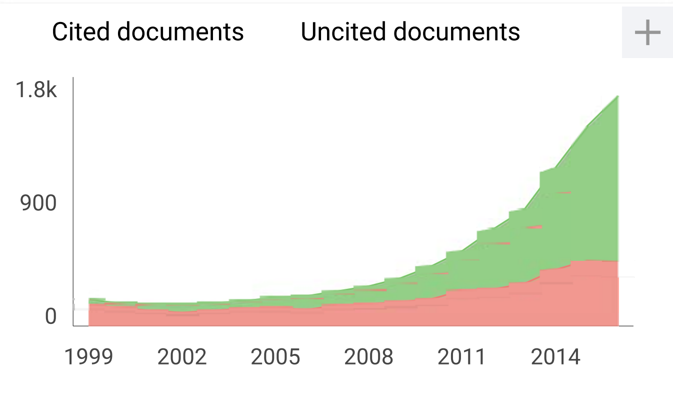

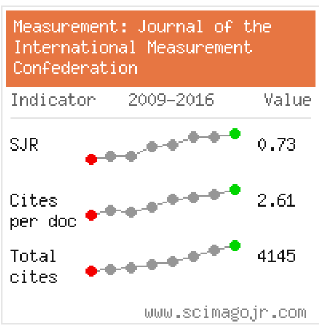

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Application of two-output port fiber coupler as gasoline level sensor

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ABSTRACT

Detection of gasoline level can be done in a safe and simple way using two output port multimode fiber coupler with a structure of 2 × 2 as a sensor. Two output ports (sensing port) are connected with two reflector displacement device (RDD) and functioned as two probes. These probes are placed on the wall of gasoline tank in a storied and work interchangeably or together depending on setting of these probes. Detection mechanism of the system is based on changes in intensity of reflected light from the reflector RDD that shifts due to changes in level of gasoline (hydrostatic pressure principle). Changes in intensity of light coming into the sensing port are then forwarded to the optical detector. Experiments performed by varying the location of the second probe as 45 cm, 50 cm, and 55 cm above the first probe to detect the level of gasoline in the process of filling and emptying the tank. Experimental results show the process of filling and emptying the tank have small differences of 6% with the dynamic range, the linear region, and resolution are 100 cm, 70 cm, and 0.4 cm respectively. Sensor sensitivity in filling and emptying process of the tank are 2.7 mV/cm and 2.8 mV/cm respectively. These results were the best performance of the sensor, which occurs when the level of the second probe was 55 cm above the first probe.

1. Introduction

Detection of liquid level using optical fiber (optical fiber liquid level sensors) can be done in two methods, i.e. direct and indirect contact between the optical fiber with liquid. The second method can use other devices as a probe or utilizes change in the trajectory of light due to changes in liquid level. For the first method, direct contact between optical fiber with liquid can be made using polished plastic optical fiber [1], spiral side-emitting optical fiber [2], as well as the use of long period fiber grating [3]. All three use the principle side-emitting optical fiber. The use of a Prism as a probe that is connected with optical fiber [4], the float is connected to the cantilever which contained fiber Bragg grating [5], the lever (have buoyancy) connected with fiber interferometer [6], the system of membranes and reflectors (RDD) connected with fiber coupler [7] is an indirect contact method between fiber optic with liquid.

The types of liquid that will be detected affect the selection of fiber optics and detection method. For gasoline, safe from risk of fire and explosion during operation is a major consideration in addition to accuracy and lifetime of the sensor. A sensor with these criteria was demonstrated has been able to detect the level of gasoline using a single output port plastic fiber coupler (fiber with a structure of 2 × 2). One of the output ports is paired with a reflector displacement device (RDD) and serves as a probe. RDD comprises a reflector Board that is attached to the

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membrane at the bottom of the tank. The sensing principle is to detect displacement of reflector, which is attached to the membrane, due to the change of gasoline hydrostatic pressure. The displacement of reflector can be detected using fiber coupler from the change of optical power light reflected by the reflector. The results obtained are dynamic range and sensors linear region, which are 180 cm and 40 cm respectively [7]. The linear region of the sensor, a working range of the sensor, are still far from industrial needs that require the detection of gasoline or fuel level.

In this paper, efforts to increase linear region of the sensor will be described by optimizing both the output port of fiber coupler with RDD (the probe) to detect the level of gasoline in multilevel way.

2. Sensors design and operating principle

Fig. 1 shows the design of gasoline level sensor using two probes. Fig. 1(a) shows the gasoline level detection mechanism using two probes. The first probe was formed

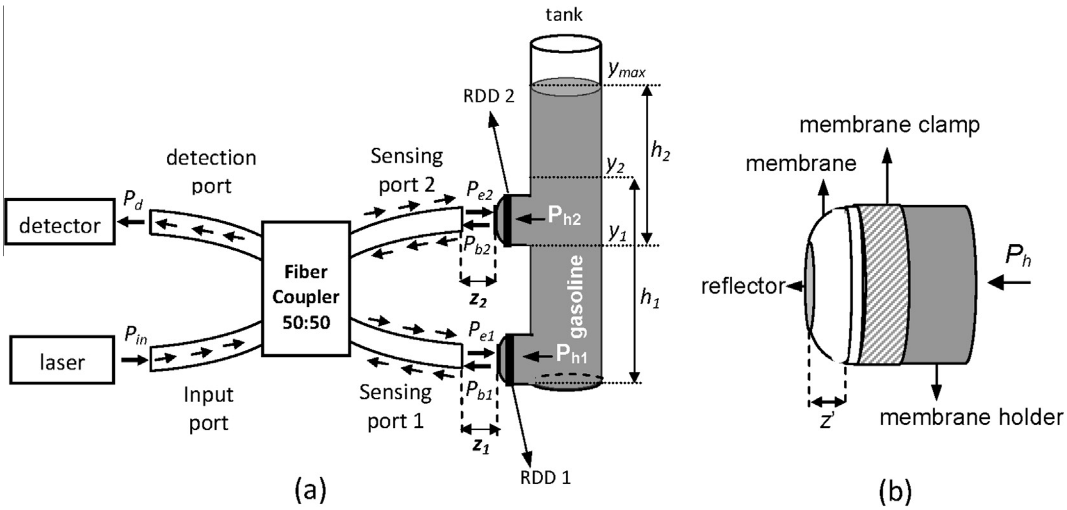

Fig. 1. (a) Sensor design and (b) reflector displacement device (RDD).

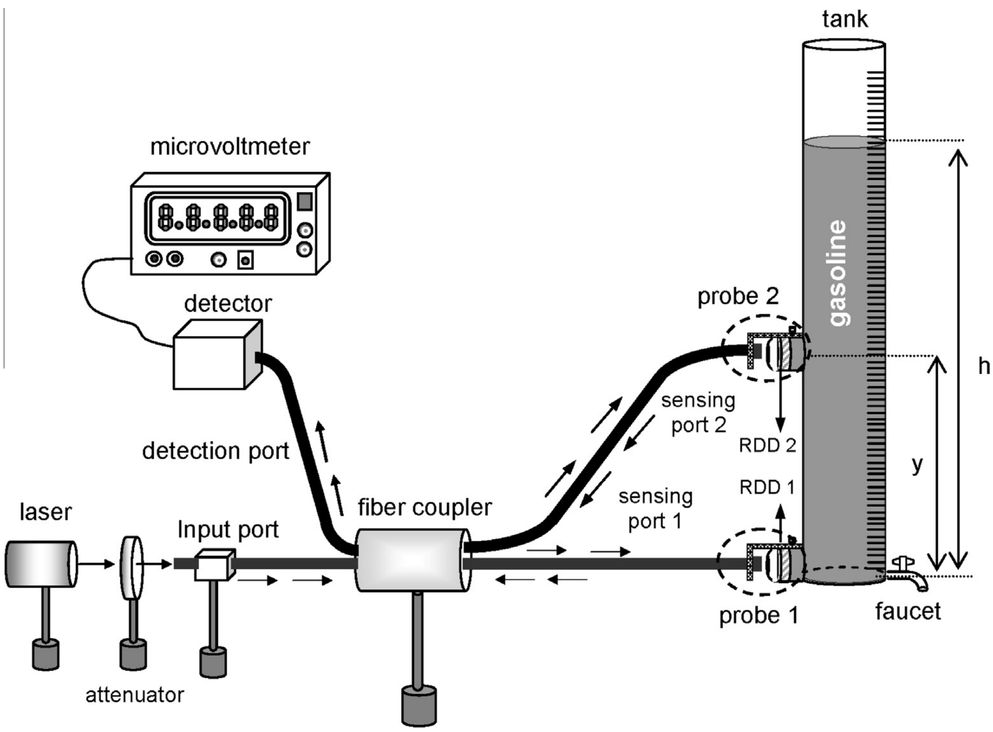

Fig. 2. Level sensor schematic diagram of gasoline using two probes.

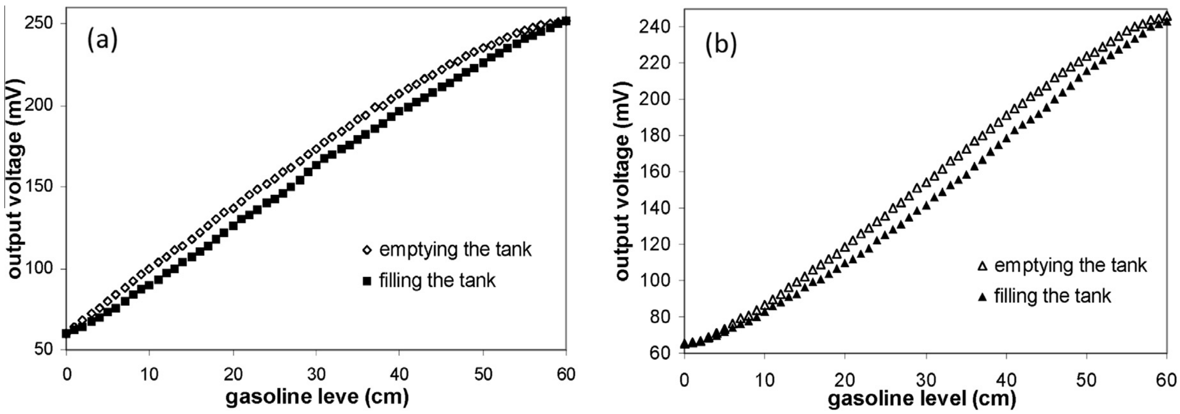

Fig. 3. Plot of output voltage detector to the gasoline level for (a) RDD A and (b) RDD B.

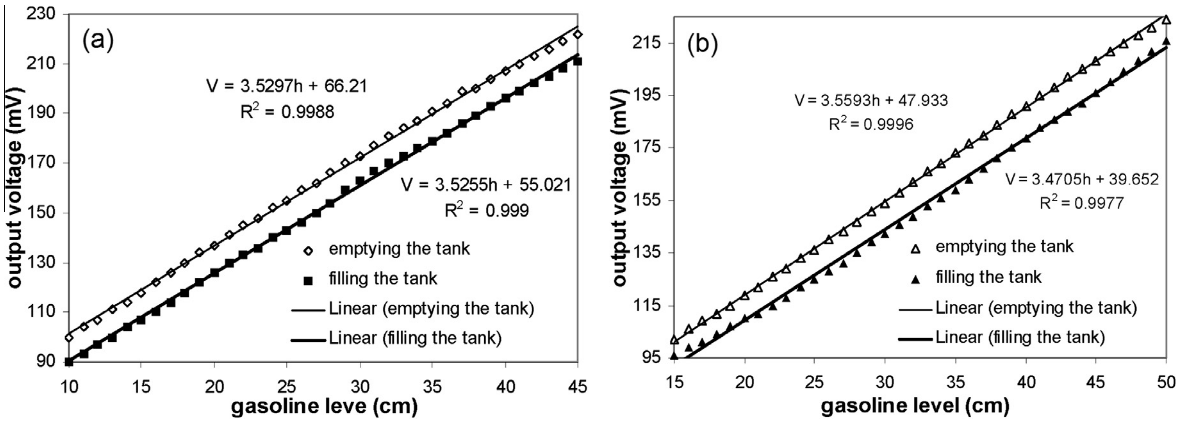

Fig. 4. The linear region of output voltage detector to gasoline level for (a) RDD A and (b) RDD B.

Table 1
The characteristics of gasoline using a single level sensor probe.

Parameters	Emptying the tank		Filling the tank	
	RDD A	RDD B	RDD A	RDD B
Dynamic range (cm)	60	60	60	60
Linear region (cm)	10–45	15–50	10–45	15–50
Sensitivity (mV/cm)	3.5	3.6	3.5	3.5
Resolution (cm)	0.3	0.3	0.3	0.3

by pairing the sensing port 1 with RDD 1 by face to face, while the second was formed by pairing the sensing port 2 with RDD 2 in face to face as well. Parameters P_{in}, P_d, P_{e1}, P_{e2} respectively are optical power of input light at the input port, output power at detection port, power emitted by the sensing port 1 and port 2. Parameter P_{b1} and P_{b2} are optical power of the reflected light from reflectors RDD1 and RDD 2, which reflected back to the sensing port 1, and sensing port 2. RDD is a reflector, which attached to the membrane. This reflector will shift (z') in case of hydrostatic pressure changes on the membrane as shown in Fig. 1(b).

The working principle of the sensor is detecting reflector shift against sensing port (z) due to hydrostatic pressure of gasoline in the RDD. The changes in hydrostatic pressure occur due to changes of gasoline level. The shift in reflector will cause optical power changes in the reflected light from the reflector, which goes into sensing port fiber coupler (P_b). The optical power changes will be observed through output voltage detector. Thus, the change in gasoline level will be detected through output voltage detector changes.

Probe 1 is used to detect the level of gasoline from the bottom of the tank to a certain level, for example y_2. This can be done by placing the sensing port 1 coincides with reflectors RDD 1 when gasoline reaches a level of y_2. Position of sensing port 1 is then made permanent. Change in gasoline level in 0–y_2 will cause shifts in reflector RDD 1 (z_1). As a result, the optical power of reflected light from the reflector RDD 1 to sensing port 1 (P_{b1}) is changed. Part of this change will be detected through the detection port. Optical power detected by probes 1 will be constant if the gasoline level exceeded y_2. Probe 2 is placed at a specific level above the position of the probe 1, for example y_1. With the same mechanism as the probe 1, probe 2 will detect the level of gasoline from y_1 to y_{max}. When gasoline level reaches y_{max}, sensing port 2 coincide with reflector RDD 2. Probe 2 will detect level of gasoline in term of

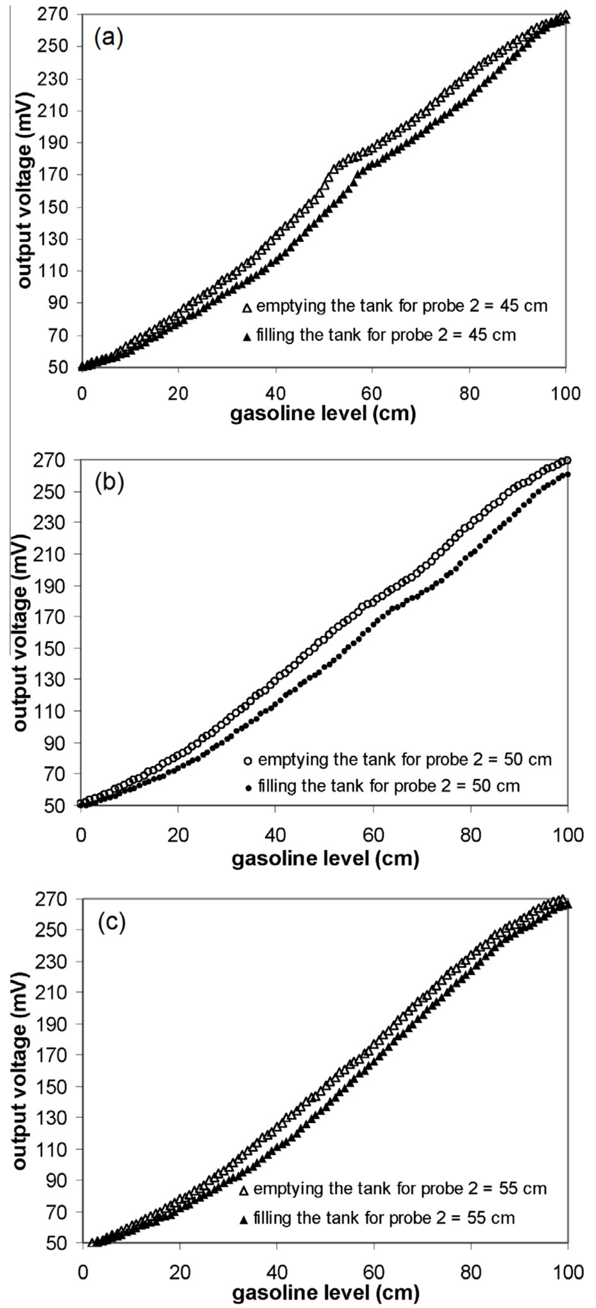

Fig. 5. Plot the data output voltage detector vs. gasoline level for emptying and filling process with position of probe 2 (a) 45 cm, 50 cm (b), (c) and 55 cm above probe 1.

optical power changes which coming into the sensing port 2 (P_{b2}), then part of it is passed on to detection port of fiber coupler. Thus the detection of gasoline level from the bottom of tank to y_{max} carried through summation of optical power generated by probes 1 and 2. Probe 2 can be placed on the detection upper limit of probe 1 i.e. y_2 or under y_2. If the location of the probe 2 is in y_2, the detection is done alternately by probe 1 (level: 0–y_2) and probe 2 (level: y_1–y_{max}). If probe 2 placed under y_2, then there is an area where the gasoline level (y_2–y_1) is detected simultaneously by both probes.

The detection mechanism as described, then shift of reflector on the probe 1 (z_1) occurred because of changes in the level of gasoline from 0 to y_2. If level range is denoted as h_1 then the pressure experienced by membrane in the RDD 1 can be written as:

$$P_{h1} = \rho g h_1, \tag{1}$$

where ρ and g are gasoline density and gravitation acceleration respectively. Shifting the reflector z_1 due to the pressure P_{h1} was detected through optical power of output light at detection port (P_{1d}) and is written:

$$P_{1d} = P_o\left[1 - exp\left(-\frac{2}{(cz_1(h_1)+1)^2}\right)\right]. \tag{2}$$

Relation between z_1 and h_1 in Eq. (2) has not been derived analytically [7]. Eq. (2) contains a provision $P_0 = 1.15cr(1-cr)(10^{-0.1Le} - 10^{-0.1D})^2 P_{in}$ and $c = (2 \tan \sin^{-1} NA)/a$. Parameter cr, Le, D, NA, and a are coupling ratio, excess loss, directivity, numerical aperture, and radius of fiber coupler respectively [8]. Eq. (2) emphasized that level detection in range h_1 is detected through P_{1d}. Then for level of gasoline on the range of y_1–y_{max} here in after denoted h_2, will result in pressure on the membrane of the RDD 2 as:

$$P_{h2} = \rho g h_2. \tag{3}$$

Pressure on the equation of (3) will result in a shift of the reflector on the probe 2 i.e. z_2. By the same mechanism, optical power output from detection port due to changes in the gasoline level h_2 (symbolized as P_{2d}) can be written:

$$P_{2d} = P_o\left[1 - exp\left(-\frac{2}{(cz_2(h_2)+1)^2}\right)\right]. \tag{4}$$

Detection of gasoline level in the range 0–y_{max} is the sum of optical power of light generated by probes 1 and 2 (P_d) and is written:

$$P_d = P_o\left[2 - exp\left(-\frac{2}{(cz_1(h_1)+1)^2}\right) - exp\left(-\frac{2}{(cz_2(h_2)+1)^2}\right)\right]. \tag{5}$$

Eq. (5) explains that the optical power output light at detection port is the sum of optical power of reflected light from reflector of probes 1 and 2. The reference point of reflector shift is the position of each sensing port. If total gasoline level (0–y_{max}) is denoted as h, then the detection zone is divided into three areas. For gasoline level at range of $0 \leqslant h < y_1$, then z_2 is constant and Eq. (5) can be written as:

$$P_d = P_o\left[2 - exp\left(-\frac{2}{(cz_1(h_1)+1)^2}\right) - exp\left(-\frac{2}{(cz_2+1)^2}\right)\right]. \tag{6}$$

Eq. (6) indicates that the third term is constant, it means that probe 2 has yet to detect the level of gasoline. For gasoline level at range of $y_1 \leqslant h < y_2$, Eq. (5) can be written as:

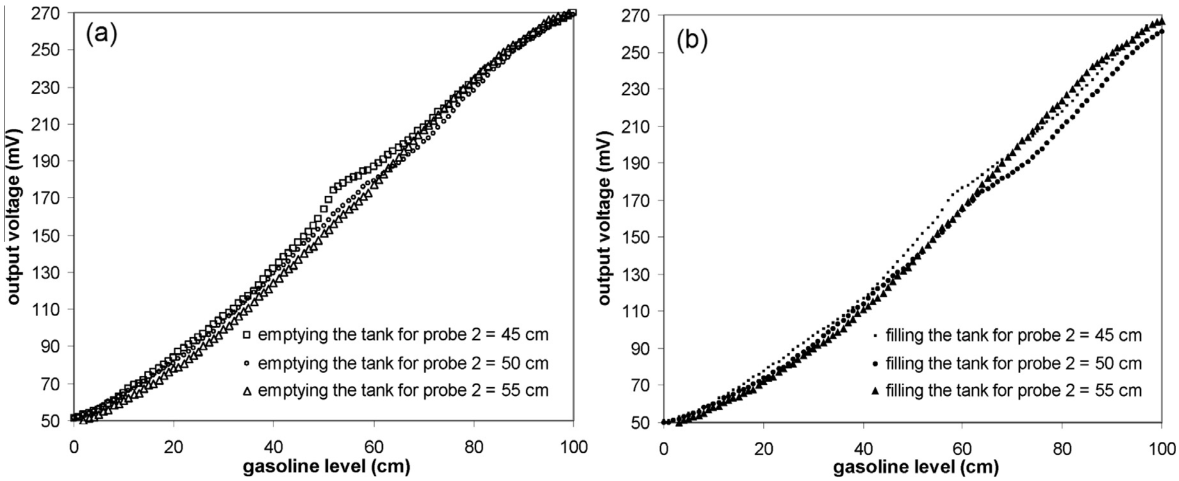

Fig. 6. Comparison chart data for probe 2 position of 45 cm, 50 cm, and 55 cm above probe 1 in process of (a) emptying and (b) filling.

$$P_d = P_o\left[2 - exp\left(-\frac{2}{(cz_1(h)+1)^2}\right) - exp\left(-\frac{2}{(cz_2(h-y_1)+1)^2}\right)\right]. \tag{7}$$

Eq. (7) shows that both of probes detect the gasoline level simultaneously. If gasoline level at range of $y_2 \leqslant h < h_{max}$, then $z_1 = 0$ and Eq. (5) can be written as:

$$P_d = P_o\left[2 - exp(-2) - exp\left(-\frac{2}{(cz_2(h-y_1)+1)^2}\right)\right]. \tag{8}$$

Eq. (8) indicates that the probe 2 stops detecting the level of gasoline.

In the case of the probe 2 is placed at position y_2 ($y_1 = y_2$), the detection zone is divided into two detection zones. For gasoline level is in the range of $0 \leqslant h < y_2$, Eq. (6) is applied and at a range of $y_2 \leqslant h < h_{max}$, Eq. (8) is applied instead with y_1 is replaced y_2. It means that both of the probe detect the level of gasoline interchangeably.

3. Experiment

Schematic diagram of the experiment is shown in Fig. 2. The experimental set-up consists of a laser semiconductor (with wavelength of 630 nm and output power of 10 mW), attenuator, silicon photo detector, multimode fiber coupler with structure of 2 × 2 made of plastic (with a diameter of 1 mm, 1 m length, 50/50 split ratio, 3.7–5.6 dB insertion loss, and 1.6 dB excess for loss), microvoltmeter, cylindrical scaled gasoline tank which is made of glass (with 6 cm diameter and 100 cm length) and filled with gasoline (715–780 kg/m^3 density at 15 °C). In the bottom of gasoline tank, a faucet is used to remove the gasoline. Two of the RDD each consists of reflector which is made of aluminum (with 10 mm in diameter and 0.20 mm in thickness), single ply membrane (nitrile polymer) with thickness of 0.08 mm (the elastic modulus is not known), and cylindrical membrane holder which is made of brass with 18 mm outer diameter and inner diameter of 15 mm. The reflector is attached to the membrane using epoxy glue and membrane itself behaves like a spring. Our RDD is handmade, because we made it manually using hand. An RDD is paired with a sensing port fiber coupler through holder form probe 1. Sensing ports can be moved closer to or away from the reflector RDD. RDD and other sensing port paired to form probe 2. Probe 1 is placed at the bottom of the tank. Probe 2 is connected through a pipe to the tank (the position of the probe 2 can be changed freely) and put on top of the probe 1.

The first step of experiment is to conduct characterization of both RDD (called RDD A and RDD B) as gasoline level sensor using one probe (second probe is not used). This characterization is necessary because both of RDD were handmade so that there is a possibility that both of RDD have different characteristics. The characterization is done by putting RDD A at the bottom of the tank. After all devices are activated, the tank is filled slowly with gasoline using a manual pump. Maximum gasoline level given is 60 cm. This is done because the range of the previous linear range of sensor is equal to 40 cm located in the maximum level, means that position of sensing port is close to the RDD. After gasoline reached levels of 60 cm, position of sensing port 1 is made to coincide with reflector RDD A. Data for the emptying gasoline tank was obtained by recording the output voltage detector every gasoline level decrease by 1 cm. Level of gasoline was lowered by removing the gasoline through the faucets. After the emptying process, RDD A was characterized for filling process. The recording of output voltage detector is done every level of gasoline increase by 1 cm. The same procedure was done for RDD B characterization.

The results of the characterization of both the RDD A and RDD B then used to determine the position and function of both the RDD as probe 1 or probe 2. Data on the range and sensitivity of sensors using a single probe from characterization is used to determine position of each RDD and the position of the probe 2. After the probe 1 and 2 probes as well as the position of the probe 2 is determined (e.g. y), then gasoline level sensor experiments carried out using two probes with probe placement refers to

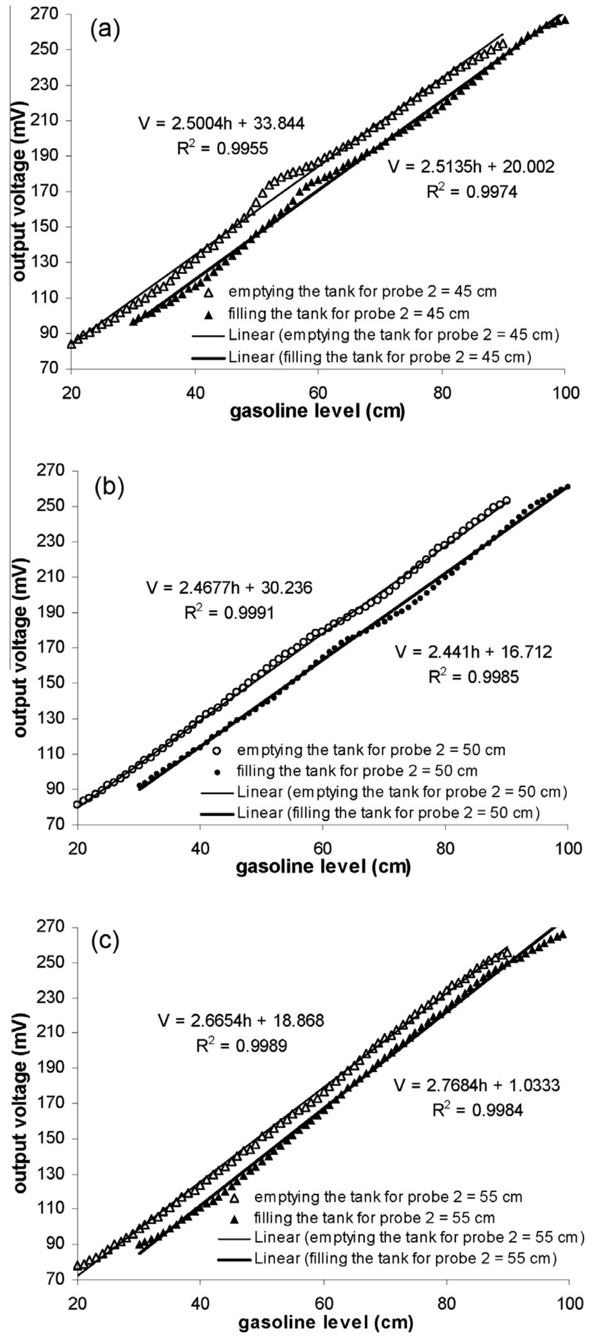

Fig. 7. Linear graph of the relationship between the output voltage detector to the level of gasoline for (a) position of the probe 2 = 45 cm, (b) position of the probe 2 = 50 cm, and (c) position of the probe 2 = 55 cm.

Fig. 2. The next step is filling up the tank with gasoline. When gasoline reaches a level of 60 cm, sensing ports 1 is placed coincide with reflector RDD 1. Filling of gasoline continued to reach maximum level (100 cm) and then sensing ports 2 is placed coincide with reflector RDD 2. Data retrieval for emptying gasoline tank was done by recording the output voltage detector every gasoline level decrease by 1 cm. In process of filling the tank, the recording of output voltage detector is done every level of gasoline increase by 1 cm. This procedure was done in the three different positions of the probe 2 (y).

4. Result and discussion

Characterization of RDD A and RDD B as gasoline level sensor using a single probe produces data output voltage detector as a function of gasoline level for filling and emptying process. The plot of this data is shown in Fig. 3. While linear region of relation between output voltage detector with gasoline level is shown in Fig. 4.

As described in section experiment, maximum level of gasoline supplied (dynamic range using a single sensor probe) of 60 cm is based on the results obtained previously. In previous research, linear area of 40 cm (for RDD using single-ply membrane) occurs when the distance between sensing ports with reflector RDD is not too far or the level of gasoline isn't too large [7]. Fig. 3 shows that there is a difference between emptying and filling process (hysteresis). This occurs on both RDD A and RDD B. The difference between emptying and filling process is 6.1% for RDD A and 5.3% in RDD B.

In this study, the main goal is to increase linear region (working range) of sensor by combining two sensors RDD and two sensing port fiber coupler as two probes. Both of these probes have function to detect the level of gasoline in multilevel way. Therefore, in RDD characterization as sensor using a single probe, wide dynamic range is not important. The range of linear region generated by RDD A and RDD B for emptying and filling process has an equivalent value of 35 cm (10–45 cm for RDD A and 15–50 cm for RDD B). For linear slope (sensor sensitivity), as shown in Fig. 4, RDD A and RDD B have small different for either filling or emptying process.

In this experiment, the devices only able to detect the smallest changes in gasoline level by 1 cm.

The detection was observed in the output voltage detector of 1 mV or $\Delta V = 1$ mV. If optical laser power is reduced, then the sensor is able to detect changes in gasoline level less than 1 cm or output voltage detector resulting in smaller than 1 mV, but the voltage is unstable. Conversely, if the laser power exceeds 10 mW, then the level of the smallest detectable gasoline level is larger than 1 cm. Value of ΔV produced divided by the value of the sensitivity of the sensor yields resolution of the sensor. Thus, the level sensor characteristics of gasoline using a probe with RDD A and B as probe are listed in Table 1. Table 1 indicates that there are differences between RDD A and RDD B in sensitivity and linear range. The differences are due to both of RDDs are handmade so it has unique characteristics.

To reconstruct gasoline level sensor using two probes, slope of linear graph (sensor sensitivity) both of RDD as probe is primary consideration. Because the value of RDD A and RDD B slope difference is not too large, then both of RDD are suitable for use as probe, which will be arranged in cascade. The second consideration is an area outside the linear region. Region 0–10 cm and 45–60 cm for RDD A and 0–15 cm and 50–60 cm for RDD B in Fig. 3 is taken into consideration in determining the RDD A or

Table 2
Characteristics of gasoline level sensor using two probes.

Parameters	Emptying the tank with position probe 2			Filling the tank with position probe 2		
	45 cm	50 cm	55 cm	45 cm	50 cm	55 cm
Dynamic range (cm)	100	100	100	100	100	100
Linear region (cm)	20–90	30–100	20–90	30–100	20–90	30–100
R^2 (goodness of fit)	0.9955	0.9991	0.9989	0.9947	0,9985	0.9984
Sensitivity (mV/cm)	2.5	2.5	2.7	2.5	2.4	2.8
Resolution (cm)	0.4	0.4	0.4	0.4	0.4	0.4

Table 3
The comparison of performance between optical level sensors.

Method	Dynamic range (m)	Linear region (m)	Resolution (cm)
Spiral side-emitting optical fiber	0.9	–	1
Long period fiber Bragg grating	1	–	10
Fiber Bragg grating	0.36	0.4	6
Fiber interferometer using PCF	0.05	0.05	–
One output port fiber coupler	1.8	0.4	0.6
Two output port fiber coupler (our paper)	1	0.7	0.4

RDD B as probe 1. Based on the data obtained, then RDD A was selected as RDD 1 paired with sensing port 1, which serves as the probe 1. While RDD B was selected as RDD 2 paired with sensing port 2 and serves as the probe 2 as shown in Fig. 2.

Gasoline level sensor experiments using two probes conducted by varying position of the probe 2 is as high as 45 cm, 50 cm, and 55 cm from the probe 1. Experimental results are in the form of output voltage detector as a function of gasoline level for emptying and filling the tank process. The results are shown in Fig. 5. In this experiment, the laser power used is scaled down using the attenuator as shown in Fig. 2. The use of two sensing port fiber coupler optical power increasing repercussions on the received light detector especially when the gasoline level reaches maximum level. Increasing the optical power caused the sensor does not detect changes in the gasoline level of 1 cm, but more than 1 cm. Hence, at maximum level (output voltage detector at the maximum state), maximum output voltage difference only ranges of 20 mV. When the tank is empty, the output voltage detectors made almost the same as when using a single sensor probe experiment. Data on the process of emptying the tank does not equal with the data on the process of filling the tank. The average difference is 6.5%, 8.1%, and 6.0% respectively for probe 2 position of 45 cm, 50 cm, and 55 cm. The comparative plot of the both data (emptying and filling process) for all positions of probe 2 is shown in Fig. 6. Fig. 6 (a) is for emptying process while filling process is shown in Fig. 6(b). For a graph of the linear relationship between the output voltage detectors to gasoline level for all positions of the probe 2, which is as high as 45 cm, 50 cm, and 55 cm from the probe 1, is shown in Fig. 7.

Comparison of gasoline level sensor characteristics using two probes with the position of probe 2 is at varying position is shown in Table 2. Table 2 shows the linear range of gasoline level sensor using two probes is 70 cm, which is twice in comparison with linear range of the sensor using a single probe (linear range at 35 cm). In other hand, sensitivity and resolution of the sensor using two probes are smaller than the sensor using a single probe. Smaller sensitivity occurs due to laser power reduction in experiment of gasoline level sensor using two probes.

Based on results of gasoline level sensor using two probes as shown in Table 2, almost no parameters showed significantly different values, except the value of sensitivity. From three positions of probe 2, gasoline level sensor with position of probe 2 at 55 cm showed the best performance because it had higher sensitivity value (an average of 2.75 mV/cm) than other positions. Thus the use of two sensing port fiber coupler as a component of two probes capable to increase linear range or working area of the gasoline level sensor. A study of the linear range of gasoline level sensor is very important because analytical formulation of gasoline level sensor transfer (Eq. (5)) is not complete yet. With linear range or working area of 70 cm, then gasoline level sensor prototype from this experiment is suitable as sensor level of gasoline or other fuels in industries that require fuel level sensor is secure from explosion or fire.

Table 3 shows the comparison of performance between our level sensors with other optical level sensor. The advantages of our sensor level compared to the other level sensor as shown in Table 3 is larger linear region and smaller resolution.

5. Conclusions

The use of two channel output fiber coupler structure of 2×2 as two probes to detect the level of gasoline are capable of producing a linear range or working area two times wider than the use of single probe. Gasoline level sensor using two probes with the position of the probe 2 at 55 cm above probe 1 is able to detect the level of gasoline with the dynamic range, the linear region, and resolution are 100 cm, 70 cm, and 0.4 cm respectively for emptying and filling the tank process. Sensor sensitivity value for filling and emptying of the tank process is 2.7 mV/cm and 2.8 mV/cm respectively.

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