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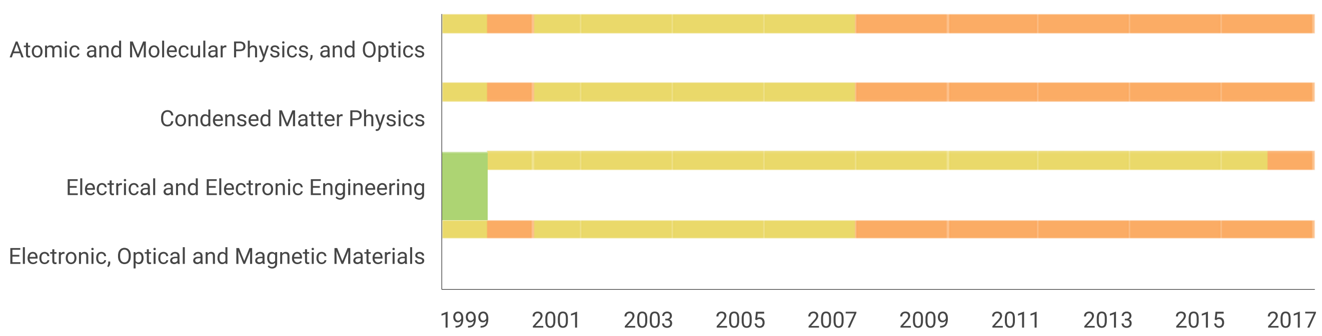

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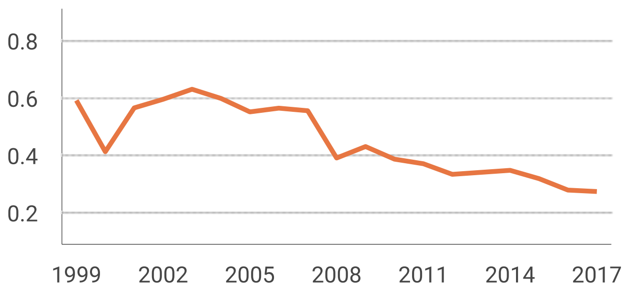

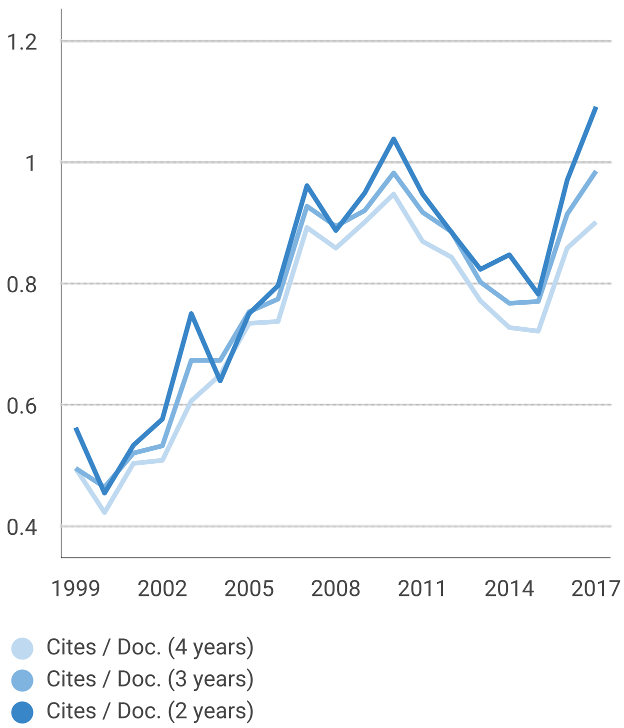

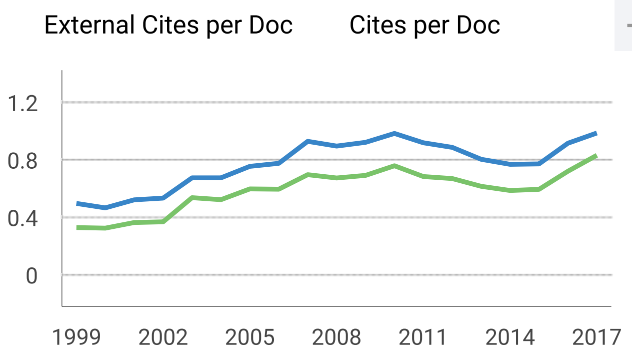

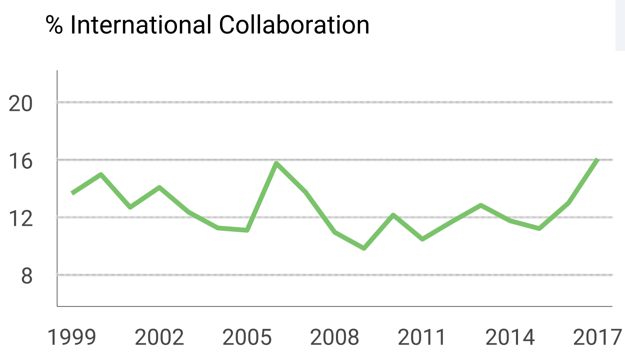

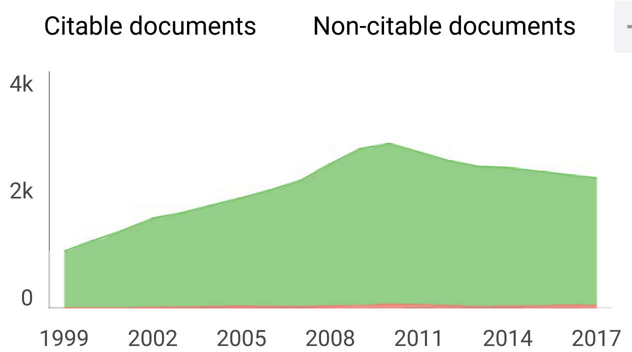

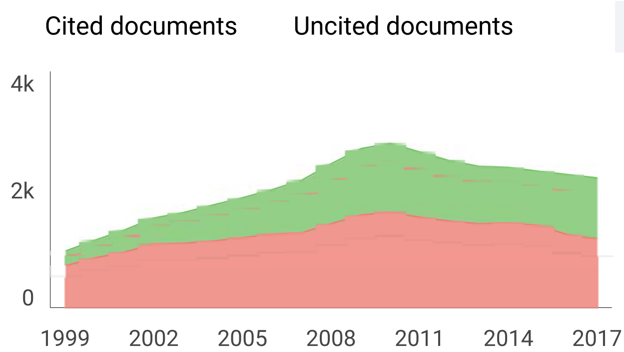

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Performance comparison of liquid level sensors using fiber coupler and fiber-bundled probe

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Abstract

Detection liquid level using fiber coupler, a pair, and concentric bundled probes has been demonstrated. The detection mechanism is based on displacement sensor and utilizing the principle of hydrostatic pressure. The results indicate that the concentric bundled probe has the best performance with a sensor range of 130 cm.

KEYWORDS

a pair-bundled probe, concentric bundled probe, displacement sensor, fiber coupler, hydrostatic pressure

1 | INTRODUCTION

The application of fiber optics to detect liquid level has been widely developed both based on wavelength modulation and intensity modulation. Wavelength-based modulation detection is performed using fiber Bragg gratings (FBGs),[1] tapered chirped,[2] and long period[3] connected with buoys. Movement of buoys due to change in liquid level will result in changes in lattice period of FBGs. The change of lattice period will change the Bragg reflection wavelength from the FBG.

Intensity-based modulation detection is done by several methods. Discontinuous detection has been done by making some sensors on the optical fiber section to detect the presence of liquids. The sensor is made by polishing the optical fiber cladding section like U curved (U-shaped). U-shaped interactions with liquids will change the intensity of guided light in optical fibers.[4] The use of transparent probe with shape of cone[5] and Prism[6] connected to the fiber bundle as liquid presence sensor has been also used to detect the level of liquid. The detection is performed by moving the probe to find the presence of liquid due to the probe interaction with the liquid will change the intensity of the reflected light received by the fiber bundle. Based on the displacement sensor and utilizing the principle of hydrostatic pressure, we have developed liquid (gasoline) level sensor using an output port[7] as well as two output ports fiber coupler.[8]

Research results have shown that fiber coupler,[9] a pair,[10] and concentric[11] bundled probe can be applied as a displacement sensor. Based on displacement sensor and using the principle of hydrostatic pressure, in this article, liquid level sensor is demonstrated using fiber coupler, a pair, and concentric bundled probes in the same experimental condition. Performance of the three sensors will be compared.

2 | SENSORS DESIGN AND OPERATING PRINCIPLE

The design of liquid level sensor using fiber coupler and fiber bundle (a pair or concentric bundled probe) is shown in Figure 1A,B. The mechanism of sensor in Figure 1A is as follow; the optical power of the laser output light (P_{in}) goes into the input port and is partially coupled to the sensing port that acts as the sensor probe. The output light from the sensing port (P_e) will go to the reflector. The reflected light from the reflector (P_b), some goes back to the sensing port. The light returning to the sensing port is partially coupled to the detection port and its intensity is read by the optical detector in the form of a detector's output voltage. For sensor design in Figure 1B, P_{in} will enter transmitter fiber (TF). The light output of the TF is reflected off by the reflector and some of the reflected light (P_b) is received by the receiver fiber (RF). A portion of P_b goes into an RF if it uses a pair-bundled probe and goes into some RF that surrounds TF when using a concentric bundled probe. The change in the intensity of light read by the optical detector, both in the sensor design of Figure 1A,B depends on the position of the reflector on the probe (z).

The working mechanism of the sensor can be explained as follows, change in the liquid level (h) will cause changes in the pressure on the membrane that is part of reflector displacement device (RDD), as shown in Figure 1C. Reflector attached to the membrane will shift (z') due to changes in hydrostatic pressure on the membrane. The reflector shift will be detected by changing the intensity of the light read in the form

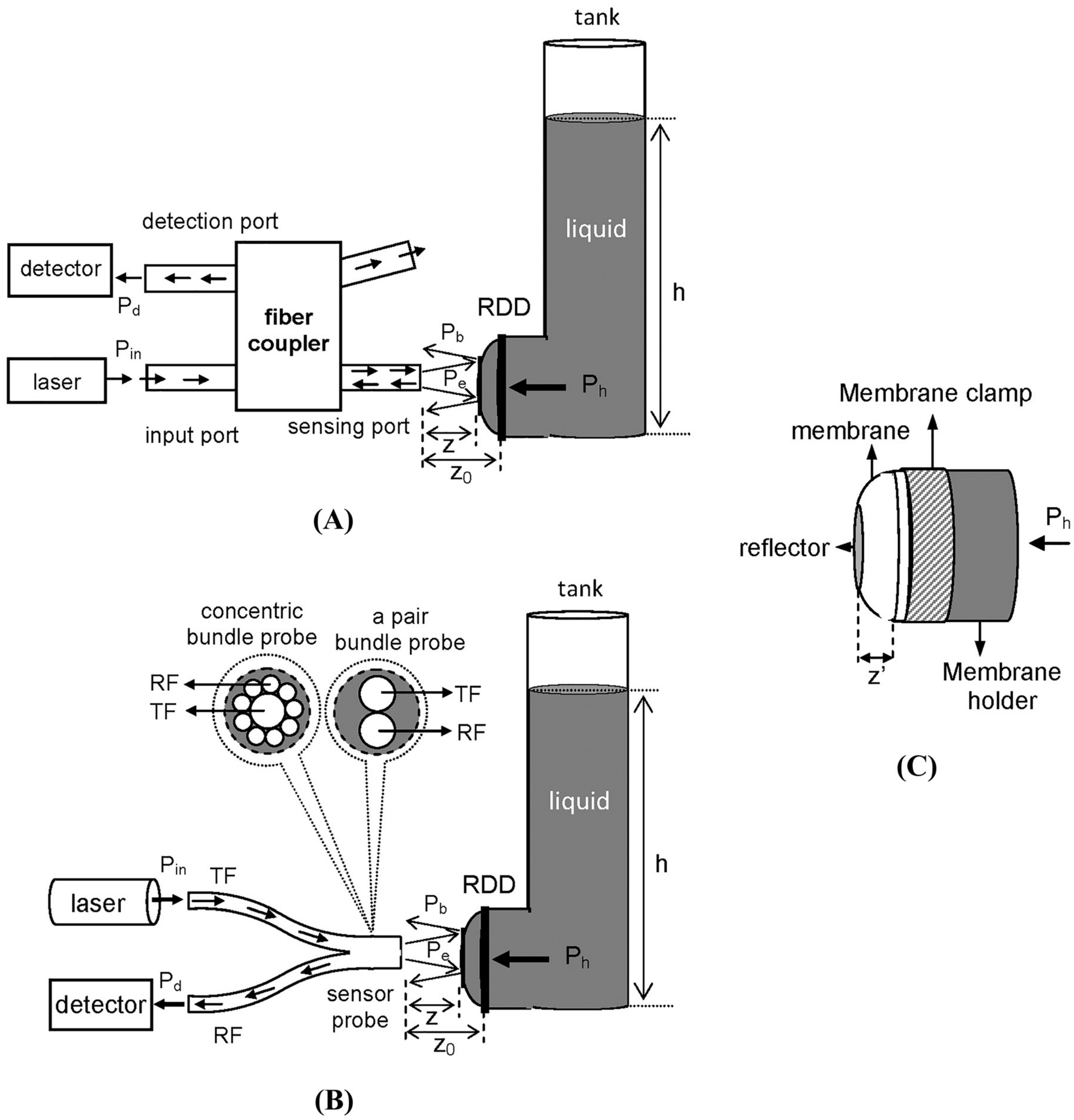

FIGURE 1 Design of the liquid level sensor using (A) fiber coupler, (B) a pair or concentric bundle probe, and (C) RDD

of a detector's output voltage. Thus, either using fiber coupler or fiber bundle, changes in the level of the liquid will be read through the detector's output voltage change. The farthest position of the reflector against the sensor probe (z_0) occurs when the tank is empty. The position $z = 0$ is the position when the reflector coincides with the probe. In such circumstances, the liquid level will be detected in the maximum state.

3 | EXPERIMENT AND DISCUSSION

The experimental schematic diagram is shown in Figure 2A for the case of fiber couplers and Figure 2B for the case of a pair or concentric bundled probe. The experimental set-up consists of a semiconductor laser (with 630-nm wavelength and 10-mW power output), silicon photodetector, 2 × 2 multimode fiber coupler made of plastic (with 1-mm diameter, 1-m length, 50/50 split ratio, 3.7–5.6 dB insertion loss, and 1.6 dB excess loss), a pair-bundled probe made of plastic (2-m long with TF and RF diameter of 1 mm each), concentric bundled probe made of plastic with length of 2 m (structure: a TF with diameter of 1 mm surrounded by 16 pieces of RF with diameter of 0.25 mm), voltmeter (digital multimeter), xyz translation stage is used to shift sensor probe, manual water pump is used to pump water into the tank, cylindrical scaled water tank which is made of glass (with 6-cm diameter and 200-cm length). In the bottom of water tanks, there are a faucet used to release water and a RDD consist of a reflector which is made of aluminum (with diameter of 10 mm and thickness of 0.20 mm), membrane (nitrile polymer) with thickness of 0.08 mm (the elastic modulus is not

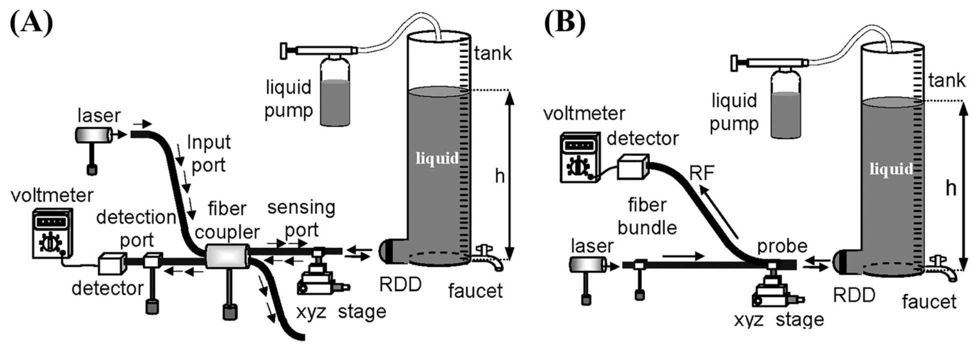

FIGURE 2 Experimental set-up of liquid level sensor using (A) fiber coupler and (B) a pair or concentric bundle probe

known), and cylindrical membrane holder which is made of brass with outer diameter of 18 mm and inner diameter of 15 mm. Reflector is attached to membrane using epoxy glue and membrane itself behaves like a spring. In this experiment, water is used as the liquid.

The first experiment was to characterize displacement of all probe sensors (fiber coupler, a pair-bundled probe, and concentric bundled probe) against the reflector. For the case of fiber coupler, sensing port of fiber coupler acts as a sensor probe. Characterization was done by placing the sensor probe in the middle and coinciding with the reflector of RDD when the tank is empty. The recording of the output voltage of the detector was carried out each when probe is shifted by 100 μm away from the reflector. Probe was shifted using xyz translation stage. The steps are carried out alternately for the three types of probe sensors with three times repetition of each probe.

The characterization result of the sensor probe displacement against reflector is shown in Figure 3. The sensor probe displacement against reflector for the case of the fiber coupler, resulting in only back slope (negative slope). For the case of a pair and concentric bundled probe, produced two slopes that is, front slope (positive slope) and back slope (negative slope). The front slope's steepness rate is greater than the back slope but the range is smaller.

The second experiment was to test the ability of the 3 types of sensor probes to detect maximum liquid level for the filling and emptying the tank. Regarding the ability of the RDD membrane to withstand the pressure of the liquid, we have tried is as high as 150 cm of liquid level in which the RDD membrane is still elastic. For liquid level higher than 150 cm, the membrane is deformed. After tank is filled with liquid up to level of 150 cm (maximum level limit), the experiment was done by placing the sensor probe coincide with the RDD reflector ($z \approx 0$) using the xyz translation stage. In this process, z_0 measured magnitude is 7.7 mm. For all probes, the detection liquid level for process of emptying the tank was done by recording the value of the detector's output voltage whenever the level of liquid is decreased by 1 cm. The reduction of liquid is done by opening the faucet. After the tank is empty, the experiment was continued with the detection of liquid level for the tank filling process. The process is carried out by recording the value of the detector's output voltage each 1 cm addition of liquid level to the maximum level of the liquid. The filling of the liquid into the tank was carried out using a manual pump. The data retrieval process for detection in tank emptying and filling process was conducted 3 times.

The results of the second experiment are shown in Figure 4. Data shows that the sensor output characteristics produce hysteresis. This is due to the use of membrane which has a relaxation property after getting pressure.[7] The result of the second experiment is in contrast with the data in Figure 3. The fiber coupler generates front slope and the bundled probes generate larger back slope's steepness than the front slope, while the range is much smaller. It can be understood that in the state of maximum liquid level, z value is minimal, and vice versa.

For emptying and filling process of the tank using a pair and concentric bundled probe, in the dynamic range of Figure 4, there is same value of detector's output voltage for different liquid level due to the presence of front slope and back slope at the same time in the dynamics range. It should not happen in the range of a sensor. Therefore, the maximum liquid level detected using a pair and the concentric bundled probe should be reduced. For that, a third experiment was

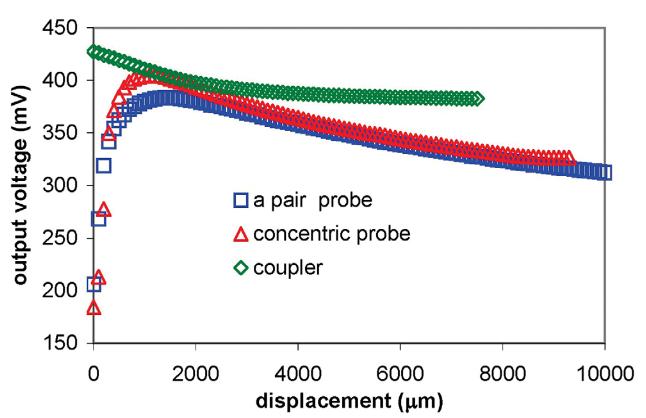

FIGURE 3 The graph of output sensor probe (mV) against displacement reflector (μm) [Color figure can be viewed at wileyonlinelibrary.com]

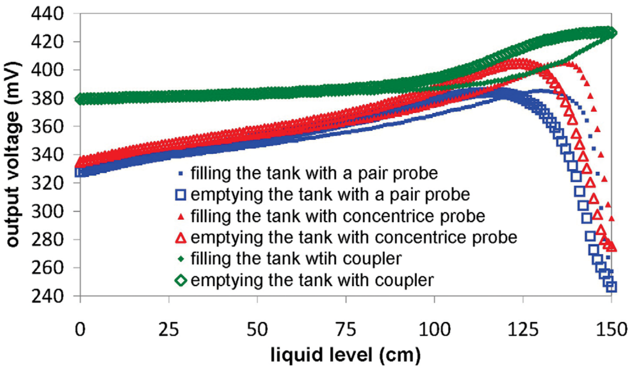

FIGURE 4 Second experimental results for emptying and filling process of the tank to a maximum liquid level of 150 cm [Color figure can be viewed at wileyonlinelibrary.com]

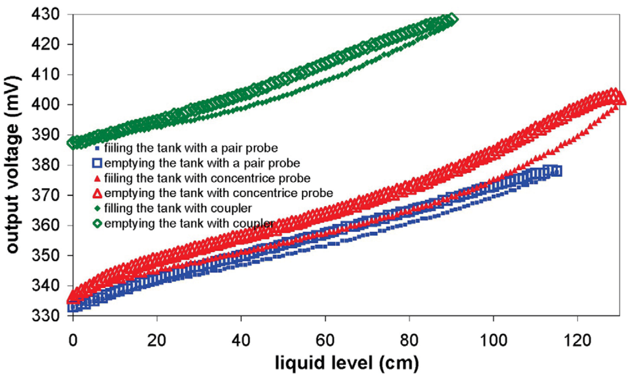

FIGURE 5 Result of detection of liquid level for emptying and filling process of the tank with restricted maximum level of liquid [Color figure can be viewed at wileyonlinelibrary.com]

conducted that is, the detection of the liquid level using the three types of probes with reduced maximum liquid level. For the case of a pair and concentric bundled probe, a reduction in the maximum liquid level is performed to produce the front slope area only, with the value of z_0 fixed as the second experiment. Maximum liquid level reduction refers to the front slope area range in Figure 3. The maximum range is from zero to the intersection point of the emptying and filling process of the tank. The front slope area ranges are 0–115 and 0–130 cm, respectively for a pair and concentric bundled probe. For fiber coupler, the data in Figure 3 shows a range of 0–60 cm having low slope's steepness. Therefore, the maximum liquid level is set to 90 cm. The third experiment procedure is similar to the second experiment. Except for the case of a pair and concentric bundled probe, when the liquid level reaches the specified maximum level, the probe position of the sensor does not coincide with the RDD reflector ($z \neq 0$). The position of the sensor probe against the reflector when the tank is empty (z_0) is 7.7 mm which is the same as the second experiment. The third experimental results are shown in Figure 5 with the largest measurement error for the case of fiber couplers, a pair, and concentric bundled probes, respectively is 1.7 mV (0.46%), 1.5 mV (0.38%), and 1.5 (0.37%). The value of z_0 for fiber coupler probe is 3.9 mm.

Reduction of the maximum liquid level on case of a pair and concentric bundled probes, resulting in sensor output profile that has front slope only. From Figure 5, the third experimental hysteresis curve shows different result from the second experiment. In the hysteresis curve, there is a maximum output of hysteresis (MOH) which is half of the maximum output voltage detector at the emptying and filling process for the same level of liquid. Another parameter is the dead space (DS), which is the range of liquid level that produces the same output voltage value in the emptying and filling process of the tank. MOH and DS calculation results of second and third experimental are shown in Table 1. From Table 1 data, it is known that MOH and DS of the third experiment are smaller than the second experiment, except the DS of the concentric bundled probe. The greater the reduction in the maximum level of liquid applied to the third experiment, the greater the decrease in the value of MOH and DS. The reduction of the maximum level of liquid in the third experiment using fiber coupler, a pair, and concentric bundled probe are 60, 35, and 20 cm, respectively. The data corresponds to the decrease in MOH and DS values in Table 1. Thus, it can be interpreted that the hysteresis profile of the sensor output is determined by the maximum hydrostatic pressure experienced by the membrane, meaning that the maximum level of liquid detected will determine the characteristics of the sensor.

The purpose of this study is to compare the performance of fiber coupler, a pair, and concentric bundled probe as a liquid level sensor component. Meanwhile, fiber coupler probe only produces front slope area; then the back slope produced by a pair and concentric bundled probes in the second experiment is not discussed further. The sensor range

TABLE 1 Hysteresis of the second and third experiments

	Fiber coupler		A pair-bundled probe		Concentric bundled probe	
Parameters	**Exp. II**	**Exp. III**	**Exp. II**	**Exp. III**	**Exp. II**	**Exp. III**
MOH (mV)	20	6	10	4	14	10
DS (cm)	21	12	16	11	16	16

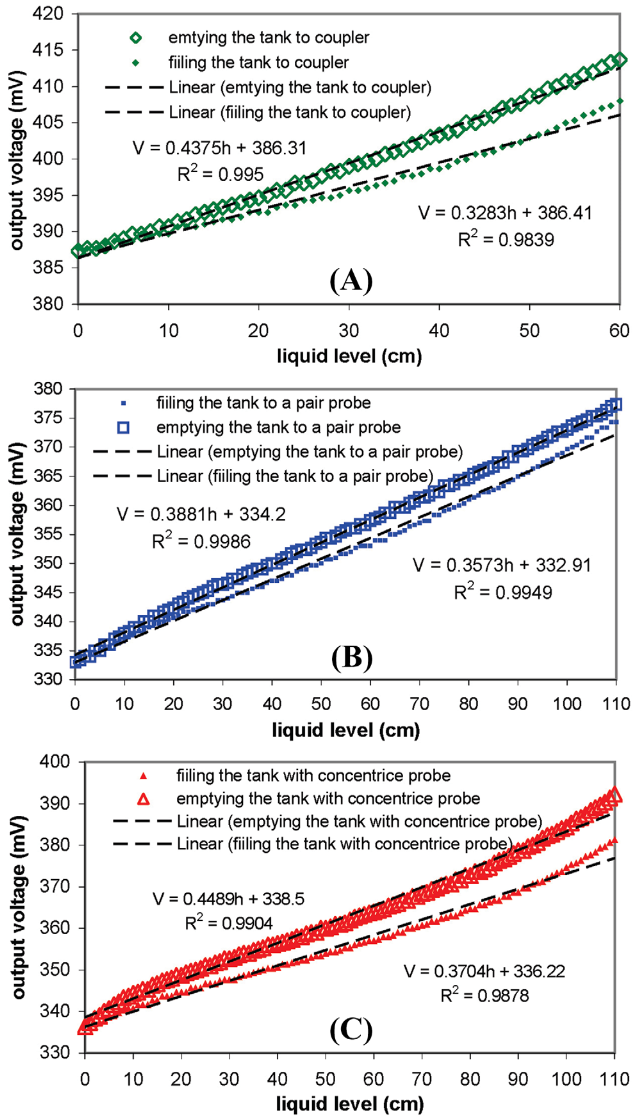

FIGURE 6 Linear test result of output voltage versus liquid level for case of (A) fiber coupler, (B) a pair, and (C) concentric bundle probe [Color figure can be viewed at wileyonlinelibrary.com]

measurement result for three sensor probe types is shown in Figure 5. The linear region of Figure 5 is shown in Figure 6. The linearity for all probes is >99%. The linear region is the working area of the sensor and the slope of the linear region is the sensor sensitivity.

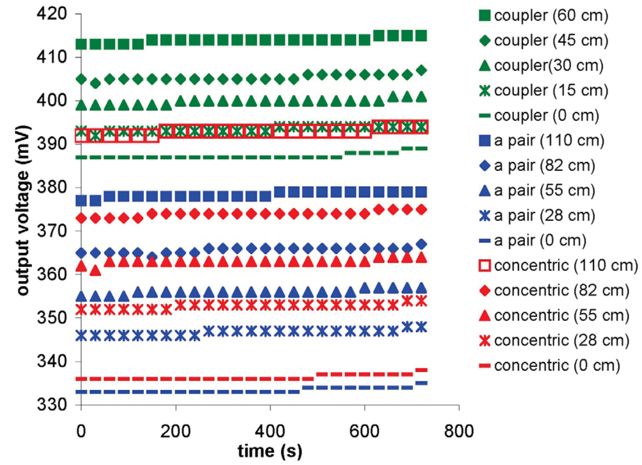

FIGURE 7 Results of sensor stability test [Color figure can be viewed at wileyonlinelibrary.com]

The fifth (final) experiment is to test the stability of the sensor. The sensor stability test was performed by measuring the voltage output at five level of liquid in the linear region range. Measurement of output voltage is conducted every 30 s for 720 s. The result of the sensor stability test is shown in Figure 7. From the graph in Figure 7, it is known that the sensor stability is quite good. The largest standard deviation for the use of fiber coupler, a pair, and concentric are same which is 0.7 mV. The sensor resolution can be determined using standard deviation and sensor sensitivity. The calculation result of sensor resolution at emptying and filling of the tank for the use of fiber coupler are 1.4 and 1.8 cm, for the use of a pair-bundled probe are 1.5 and 1.7 cm, and for the use of concentric bundled probes are 1.3 and 1.6 cm.

Overall, the performance of the fiber coupler, a pair, and concentric bundled probe to detect liquid level, in this study the sample is water, shown through the sensor characteristics in Table 2. The best range sensor is obtained on the use of the concentric bundled probe. The use of fiber coupler shows the lowest range and linear region sensors. For sensitivity of sensor resolution, the result is almost same for all probes.

From all data, it is known that liquid level sensor using fiber coupler, a pair and concentric bundled probe generally show good performance. The best result in the sensor range is obtained for concentric bundled probe. Performance of the

TABLE 2 Characteristics of the liquid level sensor using fiber coupler, a pair, and concentric bundled probe

	Coupler		A pair probe		Concentric probe	
Parameters	Emptying	Filling	Emptying	Filling	Emptying	Filling
Sensor range (cm)	0–90	0–90	0–115	0–115	0–130	0–130
Linear region (cm)	0–60	0–60	0–110	0–110	0–110	0–110
Sensitivity (mV/cm)	0.44	0.33	0.39	0.36	0.45	0.37
Resolution (cm)	1.4	1.8	1.5	1.7	1.3	1.6

sensors is strongly influenced by the maximum level of the liquid. This result can be explained due to elastic nature of the membrane used. In previous studies, the use of the same type of membrane (nitrile polymer) can be used to detect the gasoline level.[7] We can conclude that as long as the detected liquid does not damage the membrane used, the sensor system we have developed has a great potential to detect level of various types of liquids.

4 | CONCLUSIONS

Based on displacement sensors and using the principle of hydrostatic pressure, it has demonstrated the capability of a coupler, a pair and concentric bundled probe to detect liquid level. Performance of sensors is affected by the maximum level of detected liquids. The best performance of sensor range, shown by a concentric bundled probe capable of detecting up to 130 cm.

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UWB active antenna using dielectric resonator

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Abstract

This article presents the experimental study of a ultra-wideband (UWB) active antenna comprising of a chaotic oscillator coupled to a dielectric resonator antenna. Wide-band spectrum properties of chaotic signals are used to design an UWB active antenna. In contrast to classical active UWB antenna designed using patch, the proposed active antenna is capable of enhancing the bandwidth, easy to integrate with the oscillator and is small in size. The proposed UWB antenna using DR can be employed in UWB wireless communication systems.

KEYWORDS

active antenna, chaotic oscillator, Colpitt's oscillator, dielectric resonator, UWB antenna

1 | INTRODUCTION

Ultra-wideband (UWB) technology, occupying the band-width range of 3.1–10.6 GHz,[1] has emerged as the promising