Texas Instruments

Application Report

SNOA934–June 2015

Liquid Level Sensing with the Immersive Straw Approach

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ABSTRACT

The conventional and Out-of-Phase (OoP) liquid level sensing techniques are typically implemented for direct sensing or remote sensing applications. Sensors directly in contact with the liquid container maximize the performance of the system with minimizing sensor size, while remote sensing allows flexibility in system design. There are situations in which both of these sensor locations can exhibit false deviations in capacitance measurements from uncompensated environmental factors or the mechanical design does not allow direct/remote sensing. The immersive straw approach involves submerging the sensors directly in the liquid. The following application note describes the sensor design and compares the performance to direct and remote sensing applications.

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1 Direct and Remote Sensing Concept

Direct and remote sensing is widely used in liquid level sensing applications. As shown in Figure 1, direct sensing allows the sensors to be attached to the liquid container to minimize the spacing and dielectric constant variations to the liquid. This setup maximizes the performance and sensitivity of the system while minimizing the sensor size. Remote sensing enables the sensors to not be in contact with the container which allows flexibility in the system and mechanical design. Remote sensing is less desirable because larger sensors are typically required to keep the same performance compared to direct sensing.

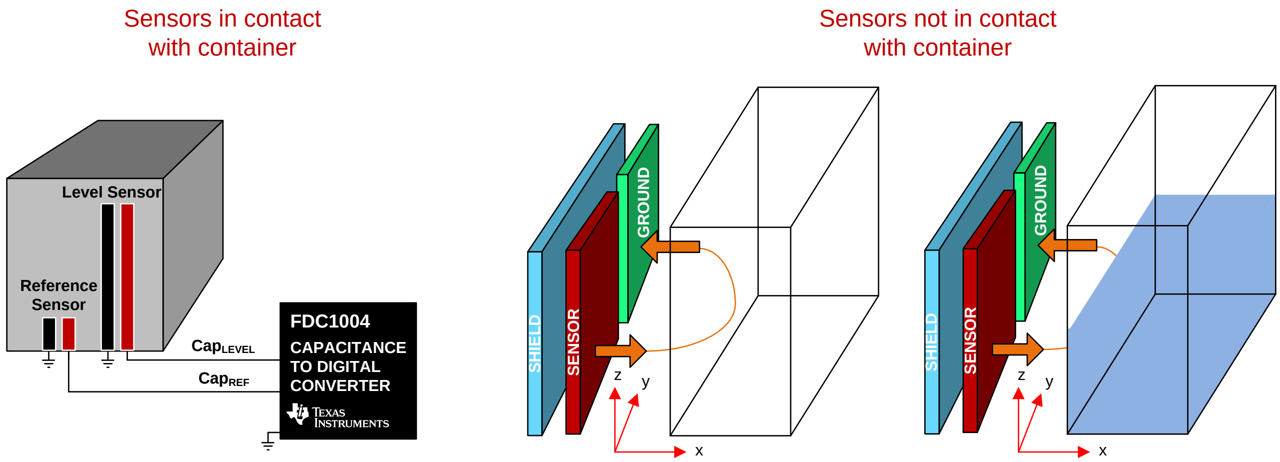

Figure 1. Direct and Remote Sensing Setups

One limitation with direct and remote sensing is that it may create compensation more difficult due to system conditions. For example, in liquid level sensing for gasoline tanks on automotive vehicles, the sensors are exposed to a variety of environmental conditions. If the sensors are directly attached to the side of the tanks and because the tanks are on the undercarriage of the vehicle, the sensors will be affected by all adverse weather conditions. It is possible to compensate for these conditions with an environmental reference sensor; however this may make the system design more complex due to the size of the sensors and the combinations of environmental factors to compensate for. This is a situation where the immersive straw approach, submerging the sensor system inside the liquid and container, becomes beneficial.

Another limitation with the conventional sensing setup is the mechanical design constraints. It is capable to do liquid level sensing with containers of different materials except for conductive materials. By using the immersive straw approach, liquid level sensing is possible.

2 Immersive Straw Sensing Concept

Immersive straw sensing allows the sensor system to be completely contained within the target liquid as shown in Figure 2. As the liquid level increases, the liquid flows through a tube with the sensors attached on the outside of the tube. The sensors cannot be directly exposed to the liquid so a larger tube is placed around the inner tube (as shown on the right side of Figure 2) with the gap between the tubes is sealed off from the liquid. This restricts the flow of the liquid to travel up the inner tube and through the generated electric fields.

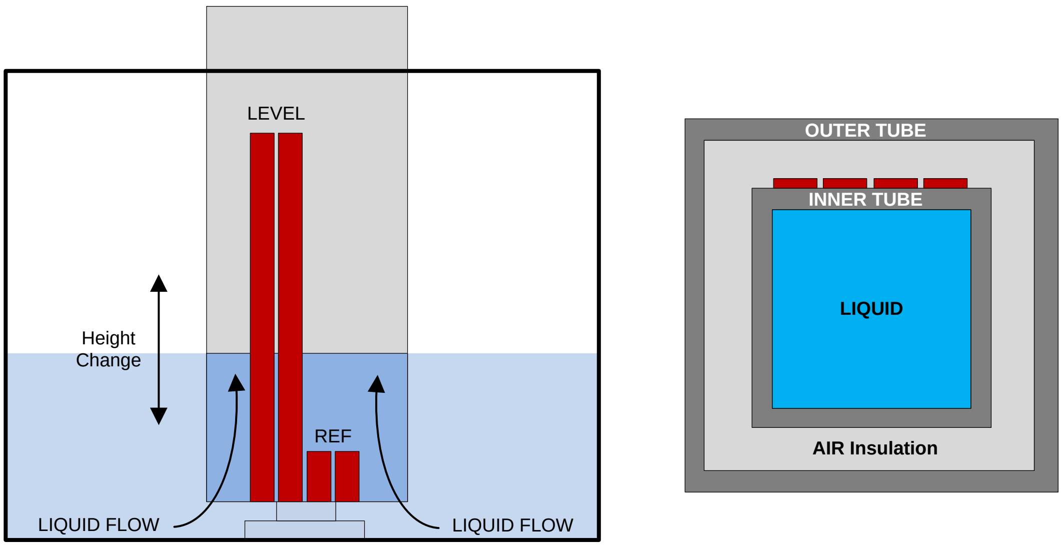

Figure 2. Immersive Straw Sensing Setup

The system will be extremely robust, reliable, and isolated from various environmental conditions and stray parasitic capacitance if the immersive straw approach is paired with the OoP technique.

3 Experiment Setup and Results

To verify the immersive straw sensing concept, a prototype was developed and measurements were collected. Figure 3 shows the prototype and test setup. Two acrylic square tubes of different dimensions were used so that the smaller tube (with the sensors attached to) fits directly in the larger tube, as described in the previous section. Water was used as the liquid target. The container was filled with water at different height intervals. Notches at the bottom of the outer tube allowed the water to flow through the inner tube.

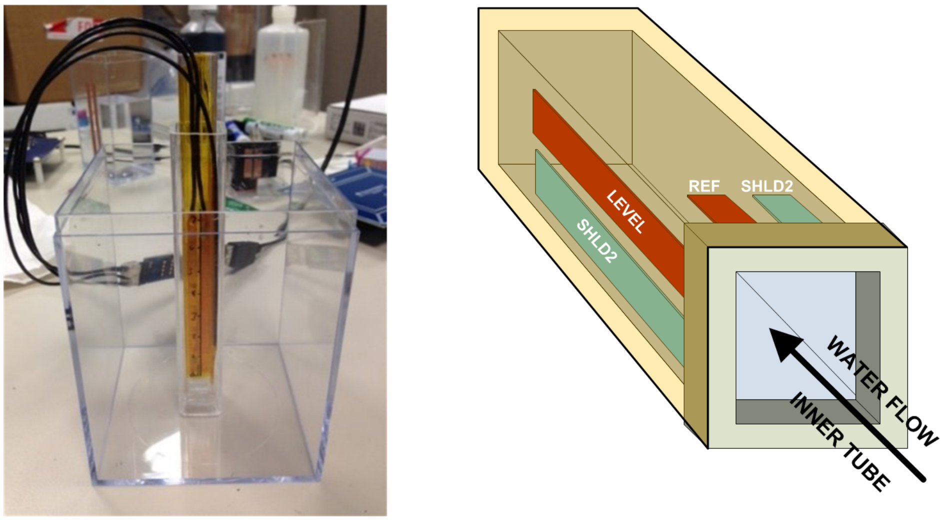

Figure 3. Immersive Straw Prototype and OoP Configuration Test Setup

The sensors were cut to a width of 0.3cm with 3M copper tape and configured with the OoP technique. The LEVEL sensor height was 7cm and the REF sensor height was 1cm. Due to the size constraints of the square tubes, the LEVEL and REF sections were attached to adjacent sides of the inner tube. Shielded cables were used and routed within the insulated air gap so the water surrounding the system does not affect the measurements as the water rises. Figure 4 shows the tube prototype design in detail.

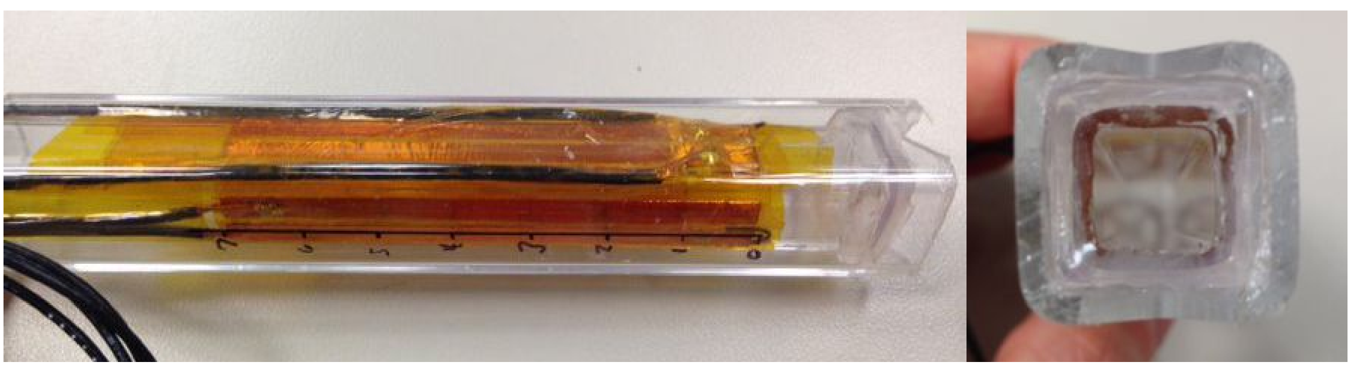

Figure 4. Straw Prototype Design

Table 1 shows the comparison between direct sensing for the conventional and OoP techniques versus the OoP technique with the immersive straw sensing at one water level height. The immersive straw sensing approach performs better than the conventional liquid level sensing, but slightly lags behinds the direct sensing with OoP based on the change in capacitance from the baseline measurement. The overall error for the immersive straw sensing was ~1.5% (shown in Table 3) compared to direct sensing using OoP and the conventional setup at ~0.7% and ~11% respectively.

Table 1. Comparison Between Direct and Indirect Sensing

	Hand Distance (cm)	Change in Cap From Baseline (fF) LEVEL MEASUREMENT			Calculated Level Error (%)		
		Direct Sensing (Conventional)	Direct Sensing (OoP)	Immersive Straw Sensing (OoP)	Direct Sensing (Conventional)	Direct Sensing (OoP)	Immersive Straw Sensing (OoP)
5cm Water Level	5	57.0	-4.4	8.4	1.83	-0.02	-0.11
	4	67.1	-5.4	10.0	2.13	0.05	-0.08
	3	80.9	-7.1	11.8	2.72	0.05	-0.07
	2	106.0	-9.2	15.2	3.38	0.06	-0.10
	1	135.9	-11.0	18.8	4.62	0.12	-0.09
	0	317.8	-15.0	32.3	8.98	0.18	-0.05

Even though the absolute change in capacitance for direct sensing (OoP) is smaller compared to immersive sensing, the calculated level error is larger. This discrepancy is based on both the change in the LEVEL measurement and REF measurement. The calculated level uses the ratiometric difference between the LEVEL and REF capacitance values to determine the appropriate level height. If the change in capacitance for the LEVEL and REF do not change at the same rate, then the error for the calculated level will not be minimized. The error from the hand interference based on change in water level value (examples shown in Table 2) can provide an estimate of how close the LEVEL and REF change as the hand interference approaches towards the container. The error from the hand interference based on the change in water level can be larger, but if both the LEVEL and REF change at the same rate, the calculated level will cancel it out.

Table 2. Comparison of LEVEL and REF Calculated Level Error

Error from Hand Based on Change in Water Level (%)		Calculated Level Error (%)
LEVEL	REF	
-2.6486	-1.9545	-0.71
-1.1171	-0.7517	-0.37
-0.9502	-1.0675	0.12
-1.5663	-1.5846	0.02
-0.5283	-0.5071	-0.02
-1.0751	-1.0775	0.00

4 Design Considerations

There are several factors that could have affected the performance of the immersive straw sensing compared to direct sensing even though both are using the OoP sensor configuration. One main factor is that since the sensors were cut out manually, each of the sensors could be slightly different in size. Symmetry is very important for the OoP technique and mismatched sensor sizes will cause an imbalance between the in-phase and out-of-phase excitation drive strength. This results in the system being more susceptible to stray parasitic capacitance. With the liquid surrounding the system now, the sensor mismatch would affect the performance more significantly compared to the direct sensing setup.

Another factor would be the size of the sensors, the direction of the interferer relative to the sensors, and dimensions of the container. If the container is small and the sensors are large, the electric fields could extend to the area where the hand is approaching and couple directly to the sensors. Performance will slightly vary if the direction of the interferer relative to the sensors is different. If the hand interference is approaching towards the backside of the shields, then the error performance will be slightly better compared to the hand approaching towards the front side of the LEVEL and REF sensors.

Minimizing the sensor size and maximizing the area from the sensors to the edge of the container will provide the most robust and consistent system.

Overall with a refined prototype, the immersive straw sensing approach offers designers more flexibility in where the sensors are located in the system and with similar performance results to direct sensing with the OoP technique.

5 Measurements

Table 3. Immersive Straw Sensing Approach Measurements

		LEVEL Measurement			REF Measurement				
Water Level (cm)	Hand Distance (cm)	Capacitance (pF)	Change in Cap from Baseline (fF)	Error from Hand based on change in water level (%)	Capacitance (pF)	Change in Cap from Baseline (fF)	Error from Hand based on change in water level (%)	Calculated Level (cm)	Error (%)
0	Baseline	3.5131			1.1332				
	3	3.5148	1.7000		1.1341	0.9000			
	2	3.5149	1.8000		1.1342	1.0000			
	1	3.5149	1.8000		1.1341	0.9000			
	0	3.5128	-0.3000		1.1319	-1.3000			
1	Baseline	3.8410			1.4241			1.1272	
	3	3.8453	4.3000	1.3114	1.4253	1.2000	0.4125	1.1373	0.90
	2	3.8458	4.8000	1.4639	1.4248	0.7000	0.2406	1.1409	1.22
	1	3.8455	4.5000	1.3724	1.4243	0.2000	0.0688	1.1419	1.30
	0	3.8409	-0.1000	-0.0305	1.4199	-4.2000	-1.4438	1.1434	1.43
2	Baseline	4.1808			1.4203			2.3257	
	3	4.1846	3.8000	0.5691	1.4222	1.9000	0.6618	2.3235	-0.09
	2	4.1848	4.0000	0.5991	1.4222	1.9000	0.6618	2.3242	-0.06
	1	4.1851	4.3000	0.6440	1.4222	1.9000	0.6618	2.3253	-0.02
	0	4.1839	3.1000	0.4643	1.4212	0.9000	0.3135	2.3292	0.15
3	Baseline	4.4628			1.4185			3.3288	
	3	4.4709	8.1000	0.8529	1.4203	1.8000	0.6309	3.3361	0.22
	2	4.4722	9.4000	0.9898	1.4205	2.0000	0.7010	3.3383	0.29
	1	4.4738	11.0000	1.1583	1.4207	2.2000	0.7711	3.3416	0.38
	0	4.4760	13.2000	1.3899	1.4207	2.2000	0.7711	3.3492	0.61
4	Baseline	4.7518			1.4153			4.3910	
	3	4.7624	10.6000	0.8557	1.4174	2.1000	0.7444	4.3958	0.11
	2	4.7647	12.9000	1.0414	1.4178	2.5000	0.8862	4.3978	0.15
	1	4.7677	15.9000	1.2836	1.4184	3.1000	1.0989	4.3990	0.18
	0	4.7761	24.3000	1.9617	1.4200	4.7000	1.6661	4.4038	0.29
5	Baseline	5.0835			1.4131			5.6106	
	3	5.0953	11.8000	0.7514	1.4154	2.3000	0.8217	5.6067	-0.07
	2	5.0987	15.2000	0.9679	1.4161	3.0000	1.0718	5.6048	-0.10
	1	5.1023	18.8000	1.1971	1.4167	3.6000	1.2862	5.6056	-0.09
	0	5.1158	32.3000	2.0568	1.4190	5.9000	2.1079	5.6078	-0.05
6	Baseline	5.3753			1.4109			6.7058	
	3	5.3904	15.1000	0.8109	1.4133	2.4000	0.8642	6.7022	-0.05
	2	5.3951	19.8000	1.0633	1.4139	3.0000	1.0803	6.7047	-0.02
	1	5.3998	24.5000	1.3156	1.4146	3.7000	1.3324	6.7047	-0.02
	0	5.4224	47.1000	2.5293	1.4183	7.4000	2.6647	6.6969	-0.13
7	Baseline	5.6348			1.4051			7.8032	
	3	5.6516	16.8000	0.7918	1.4078	2.7000	0.9930	7.7877	-0.20
	2	5.6573	22.5000	1.0605	1.4086	3.5000	1.2872	7.7858	-0.22
	1	5.6641	29.3000	1.3810	1.4097	4.6000	1.6918	7.7794	-0.31
	0	5.6979	63.1000	2.9740	1.4147	9.6000	3.5307	7.7613	-0.54

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