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A self-calibration water level measurement using an interdigital capacitive sensor

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ABSTRACT

A water level measurement using an interdigital capacitive sensor with low-cost, low-energy, good repeatability, high linearity, and ease of installation is proposed with a support of experimental results. This sensor comprises a printed circuit board (PCB) with configuration of two interpenetrating comb electrodes. The comb electrode is 70–80 mm width, 300 mm height with 1–2 mm spacing between each comb. This configuration of electrode causes the capacitance between comb electrodes to vary by the water level. Microcontroller is used to calculate the capacitance between comb electrodes in terms of a discharge time correlated to the water level. A practical water level measurement technique using two comb electrodes designated as level and reference sensors is presented. This technique can directly be applied to water with different conditions without recalibration. This sensor is able to measure absolute levels of water with 0.2 cm resolution over 30 cm range. In addition, it is also sensitive enough to trace the variability of water level. A flood monitoring simulation is carried out in wave flume where this sensor is used to detect the rising wave.

1. Introduction

There are many requirements of liquid level measurement in an industrial application, such as in food, chemical, pharmaceutical and power generation industries. Monitoring of liquid level is also required for recharged areas and leachate in landfill. In addition, the measurement is applied for early warning of coming dry season in agriculture. In 2011 various regions in Thailand were ravaged by flood. The liquid level monitoring could provide early warning of flood and the devastation should be reduced [1].

There are various methods of measuring liquid level in tank, vessel, container, and water resource. The methods can be divided into two main categories: continuous level measurement for process monitoring and point level measurement to activate alarm or trip. The level measuring devices in both classes can be intrusive or non-intrusive. Many traditional techniques for liquid level measurement are based upon visual inspections, hydrostatic pressure, mechanical float system or displacer, bubblers, load cell, electrical property, thermal conductivity, capacitance, radiation-based level measurement, microwave, ultrasonic, optical, etc. [2–8]. There are both strengths and weaknesses in each technique discussed by many studies.

There have been many new techniques in liquid level measurement developed to improve performance, like linearity, accuracy, reliability, repeatability, retrofit, recalibration, versatility, lifetime, simplicity, robustness and cost. A non-contact method using single digital camera and circular float with simple setup was proposed [9]. However, there was measuring error if the floating object was out of range from the field of view. In addition, the color of the floating object should be different from the color of liquid. The time domain reflectometry (TDR) was specially designed for ability to measure multiple levels of different stratified liquid [10–12], but this method might be not suitable for high agitated waters as well as flood monitoring and farm level monitoring where many level sensors were used.

The development of optical fiber sensors have progressed significantly during the last few years. For optical fiber sensors in liquid level measurement, they were served mostly to point level switch. Fiber-optic sensors can be designed in many different forms to exploit reflection and transmission of light to measure liquid levels. Most of them are based on the effects of the indices of refraction of liquid on the waveguide properties of optical fibers [13–18]. In a typical case, there is a loss of internal reflection of guided electromagnetic modes as a result of contact between the outer surface of optical fiber and a liquid. An optical fiber sensor known as fiber Bragg grating (FBG) was usually used for continuous liquid level measurement. A liquid-level sensor based on the bending of fiber Bragg grating embedded in a cantilever could provide

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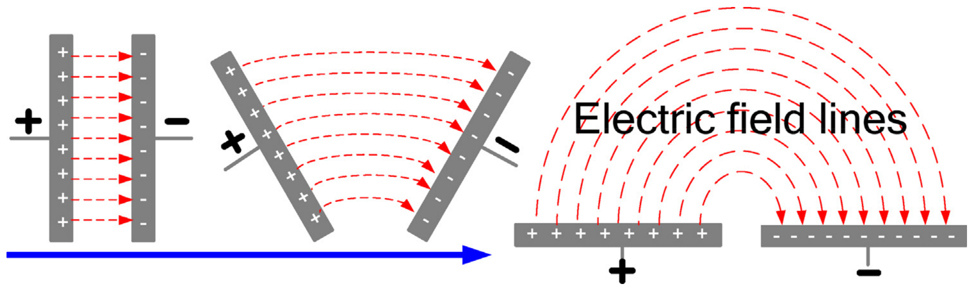

Fig. 1. Operating principle of an interdigital sensor [29].

the consistent results with good linearity, reproducibility, and hysteresis [19]. It required a certain amount of mechanical equipment, especially in pressure vessels. In addition, this technique was dependent on the specific gravity of the water and only used for relatively clean fluids otherwise the movement of installed roller will affect the measurement value. Recently, both of the novel liquid level measurements using a dual-pressure-sensor system comprising a FBG pressure sensor and a Fabry–Pérot (FP) pressure sensor [20] and using a dual-optical-fiber system comprising a FBG level sensor and a FP pressure sensor [21] were developed to obtain the unknown level and specific gravity of liquid simultaneously. Nevertheless, the capabilities of these sensors enhanced when the sensitivity and repeatability of the FBG pressure sensor, FP pressure sensor, and FBG level sensor improved. An intensity-based fiber-optic liquid-level gauge could continuously measure the levels of all kinds of liquids with recalibration [22].

To overcome the problem of practical use, the capacitive sensors for water-level measurement were presented in many research papers [23–28]. The main advantages of these capacitive sensors were low cost, low power consumption, linearity, easy adjustability to the aspect of application, and suitable for use in extreme condition. This paper describes the design and implementation of a water-level measurement system based on an interdigital capacitive sensor comprises a printed circuit board (PCB) with configuration of two interpenetrating fingers electrodes. The capacitance between parallel fingers electrode varies according to the water level. A signal conditioning circuit has been designed and fabricated to measure the change in capacitance of the interdigital electrode in form of a discharge time. The experimental results demonstrate that the proposed sensor has good repeatability, reliability, linearity, resolution, non-recalibration, cost effective, easy to use, portable and low power consumption. In addition, this proposed sensor is suitable to display a waveform of varied level in real time with a flood simulated experiment. This sensor can also be appropriate for flood level monitoring in an open channel or a river.

2. Design of an interdigital capacitive sensor

An interdigital capacitive sensor is a coplanar structure comprising multiple interpenetrating comb electrodes. The operating principle of the interdigital capacitive sensor is similar to that of two parallel plate capacitor. Fig. 1 shows the transformation of parallel plate capacitor to an interdigital capacitive sensor. By applying different potentials on each comb electrodes, the fringing fields is generated between the positive and negative electrodes. These fields travel from positive electrode to negative electrode passing the material under testing (MUT) contacting on the comb electrode. Thus, electrode and material geometry as well as material dielectric properties affect the capacitance and conductance between electrodes. The fringing capacitance measured between the comb electrode varies with the dielectric constants of material. Therefore, applications of interdigital capacitive sensor [29,30] were widely used in chemical sensor [31], strain gauge[32], food inspection [33], humidity sensors [34], biosensor applications [35–38], concrete moisture content measurement [39], etc.

For the proposed water level measurement technique, the interdigital capacitive sensor is based on the capacitance measurement attached with water and air. The schematic drawing of this water level interdigital capacitive sensor is shown in Fig. 2. The sensor

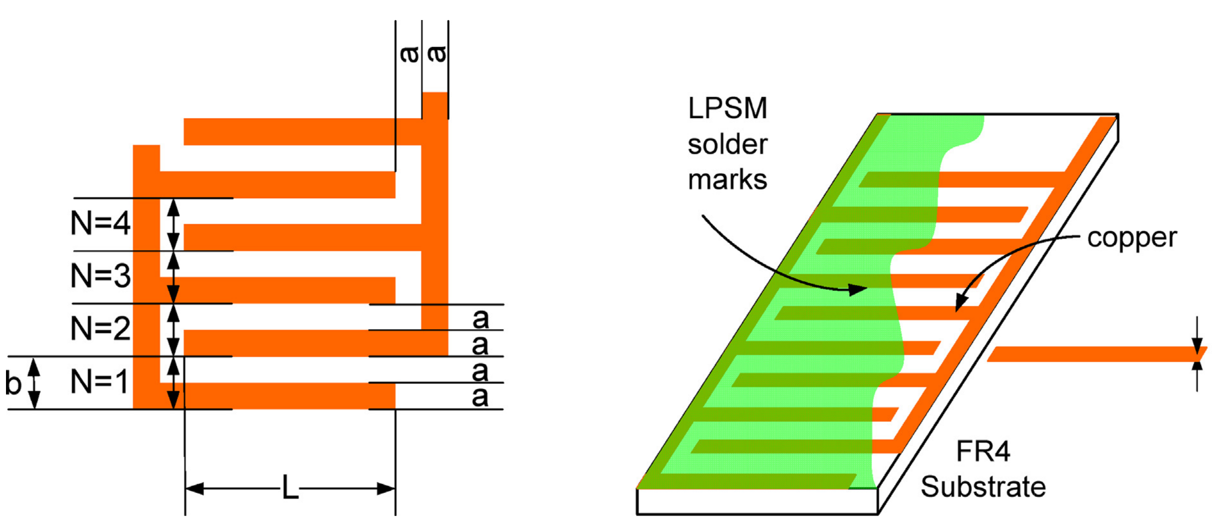

Fig. 2. Schematic drawing of the interdigital capacitive sensor.