NON-CONTACT DETECTION OF FREE FLYING NANOLITER DROPLETS

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Abstract: In this paper we present a non-contact droplet sensor that allows for the detection of free flying liquid droplets with diameters in the range of 200-400 µm. The working principle is based on capacitive detection. The detector was fabricated cost-effectively in standard PCB-technology (printed circuit board) and characterized by experiments. Due to its small dimensions (18 x 56 x 1.6 mm) it can easily be placed into the flight-path of the liquid droplet when the distance between the dispenser and the target is at least 3 mm. The proposed sensor is able to detect any irregularity such as velocity, shape or volume variations in the droplet dispensing process by comparing the actual sensor signal with an average liquid specific "fingerprint". Therefore it is especially suited for online process monitoring in its present form.

Keywords: contact less, capacitive sensor, dispensed liquid

1. INTRODUCTION:

Dosing small amounts of liquids in the nano litre range has gained more and more importance in the past years. Especially in the biomedicine, pharmacy and mechanical engineering field, the demand for the use of controlled small droplet application has enormously increased. In these applications expensive chemical reagents are typically used to perform hundreds and thousands of bio-chemical experiments (e.g. for combinatory chemistry or pharma research) [1]. In this context an extensively media independent, contact less and inline droplet monitoring is desired to optimize the dispensing process and to improve the control on the dispensing process. Gravimetric and optical techniques routinely applied for droplet detection and measurement are often unsuitable for compact integration and parallelization, which is required in liquid handling robots. The sensor concept presented here can contribute to an improvement in the field of liquid handling, since it enables inline low-cost and non-contact detection of liquid droplets.

Non-contact droplet detection sensors can be applied to any dispensing system that produces free flying droplets like for example the PipeJet^{TM} dispenser (see figure 4), which was used for this work exclusively [2]. This dispensing system is based on the high dynamic extension of a piezo electric actuator, which squeezes a polymer tube at a defined position to eject a droplet. The refill process of the system occurs from the backside of the tube and is based on capillary forces.

2. CAPACITVE DROPLET DETECTION PRINCIPLE

The working principle of the proposed transducers is based on detection of the change an electric field undergoes when a liquid droplet passes through it. In particular the change of the capacitance of an open plate capacitor, while a droplet passes the electric field, can used to extract an utilisable signal [3]. The change of capacity arises from the change of the average permittivity ε_r caused by the droplet's presence. Since many liquids belong to the group of paraelectric materials, their permittivity ε_r will be larger than 1, resulting in an increase of the overall capacitance while they pass the electric field [4]. To estimate the attainable field change the well known formula for the capacity of an open plate capacitor is applied:

$$C = \varepsilon_0 \cdot \varepsilon_r \cdot \frac{A}{s} \qquad (1)$$

While a droplet with a permittivity ε_r in the range of water (water ε_r = ~81 for frequencies < 1 GHz [4]) passes the open plate capacitors field, the capacitance of the transducer increases. Since the droplet does not occupy the whole space between the capacitor plates equation (1) provides an upper estimate only. The measurable

capacity change is in fact much smaller. A more significant change could be reached if the measured liquid touches one of the capacitors electrodes [3]. However, this would lead to contamination and loss droplets and is therefore not permissible in the present context.
A change in capacity can be measured by two basically different techniques. 1.) by using the capacitor as part of a resonant LC circuit and measuring the change in frequency or 2.) by charging the capacitor and measuring the change in voltage [3]. In this work the second approach is used to generate the output signal like sketched in figure 1 a).

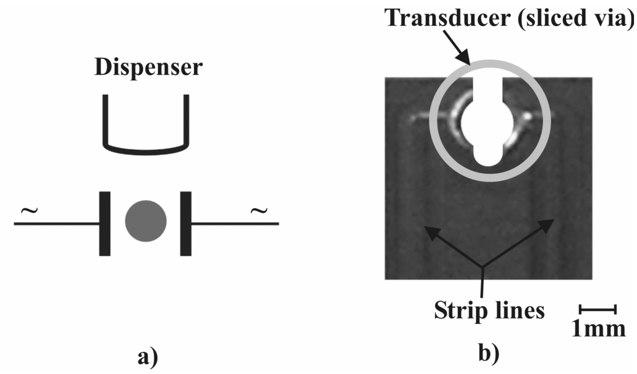

Fig. 1: a) Capacitive working principle; b) sliced standard through connection (via) serves as transducer.

3. FABRICATION TECHNOLOGY

The transducer as well as the readout electronics was realized by the use of standard PCB (printed circuit board) technology on a 1.6 mm FR4 material board. The use of this technology enables a very rugged design and a cost efficient fabrication.
A standard round PCB through connection (via) with a diameter of 1.5 mm was set on the PCB to serve as the measurement capacitor. This via was sliced by a 0.8 mm milling tool to create the two opposite capacitor plates as displayed in figure 1 b). The reason for using round vias to create the transducer is their enhanced mechanical stability in the FR 4 material compared to other shapes. The use of rectangular shaped through connections for example resulted in delamination of the copper layers while milling the slit with conventional techniques.

The whole signal conditioning circuit was integrated on the same PCB (sensor board) with a footprint of 18x56 mm, which was adapted to the footprint of the PipeJet^{TM} dispenser used for droplet generation. On a second external PCB a further rectification, RC smoothing and the voltage sources were implemented. The sensor board used for experiments is shown in figure 2.
The shape of the sensor board was designed to enable easy integration with the dispenser module. The precise concentrical alignment of the dispenser nozzle to the transducing capacitor is realized by a simple mechanical plastic holder which was mounted underneath the PipeJet^{TM}, see figure 3. This setup allows for a minimum distance from the nozzle to the target of 3 mm.

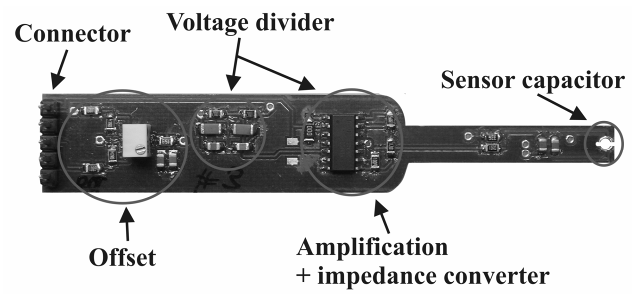

Fig. 2: Populated PCB sensor board as used for the experiments.

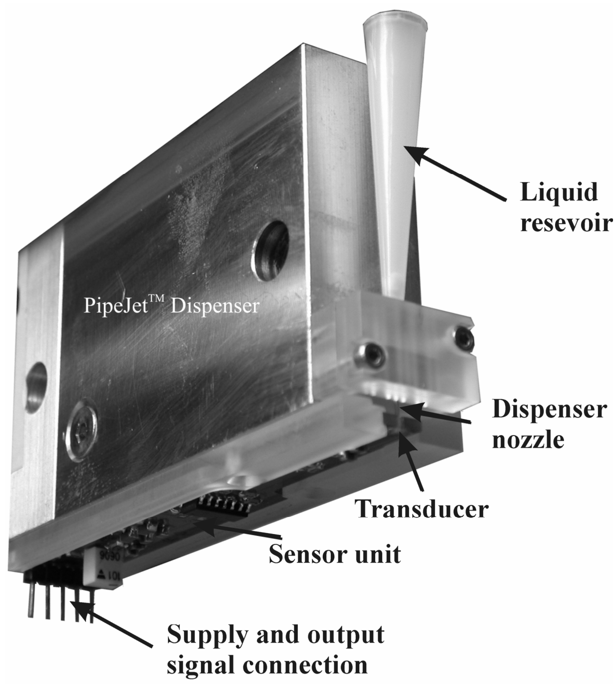

Fig. 3: Picture of the setup used including PipeJet-dispenser and sensor board.

The change in capacity by a water droplet with a volume of v=50 nL being positioned between the electrodes of the described transducing capacitor was estimated to be 0.8 fF according to the model published in [3]. Since the capacitor plates are circumflex, like displayed in figure 1b, the resulting electrical field is inhomogeneous. Therefore the theoretical approach of [3] should only be used as a first estimate. However, a simulation of the electric field (see figure 5) shows that if the droplet is small relative to the diameter of the transducing capacitor and placed in its centre, the field can still be considered to be homogeneous and the estimate should be correct.

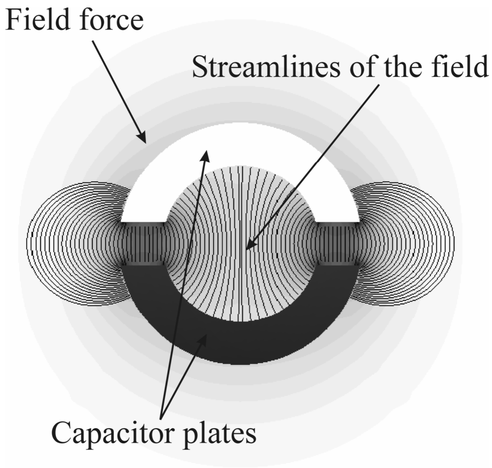

Fig. 5: Simulated electrical field of a capacitor with circumflexed plates.

4. ELECTRONICAL CONDITIONS

The transducing capacitor is supplied with an alternating voltage of U_{pp}= 20 V. Using this voltage the resonance frequency was determined to be about f_{Res}= 297 kHz (cf. figure 4). Driving the system at its resonant frequency provides a further enlargement of the change that can be achieved in the output amplitude.
The required +/- voltage supply for the sensors signal-processing-part is created by a voltage divider on board which is realised by an operational amplifier (OPA 3540) that serves as virtual ground. The same four-channel OPA also accomplishes the amplification of the signal in two steps to avoid exceeding its gain bandwidth product.

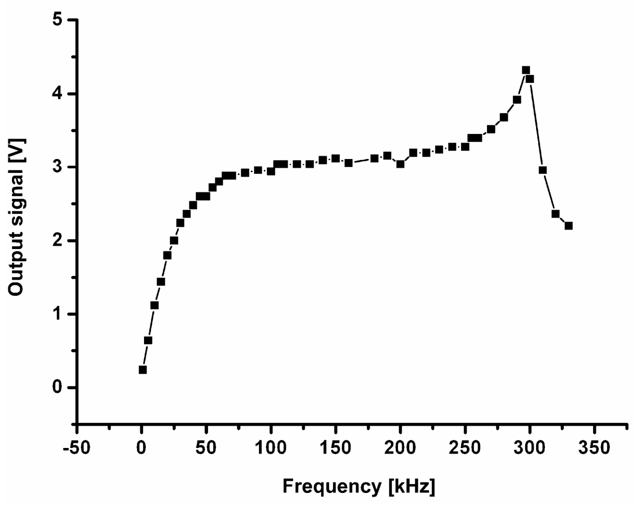

Fig. 4: Frequency measurement.

To avoid the influence of leakage currents on the signal, which can be of the same order of magnitude as the expected exchange current, a ground area covers the whole PCB to act as guard ring. The electrical circuit diagram of the whole sensor board is shown in figure 6.

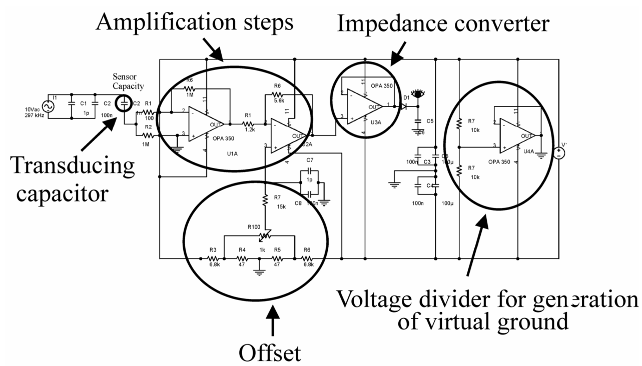

Fig. 6: AC driven sensor circuit.

5. EXPERIMENTS AND RESULTS

As a first test the sensor signal was recorded while an insulated 0.3 mm steel plate was introduced between the capacitor plates. Figure 7 shows the output sine wave of the sensor in an empty state (black) compared to the state being filled by the steel plate (grey).
Using the sensor board as before and applying rectification and RC smoothing, capacity changes could be observed while droplets with about 50 nL volume were passing through the transducers field.

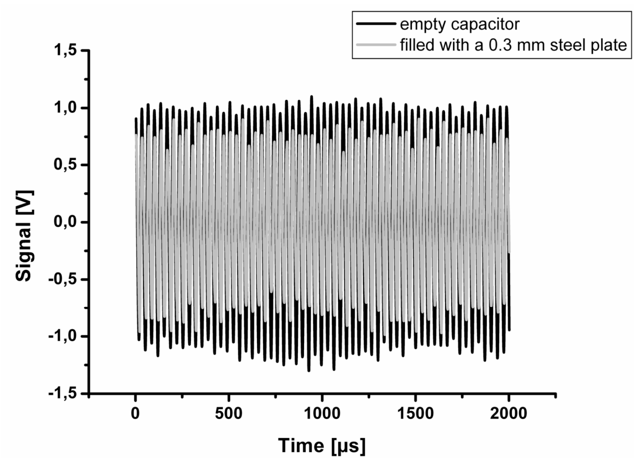

Fig. 7: Typical sensors output sine wave before rectification and RC smoothing.

The resulting typical output signals are shown in table 1. The correlation of these signals with stroboscopic images display also in table 1 is clearly visible. Besides a droplet presence detection the sensor can also distinguish between "large and small" as well as "fast and slow" droplets on basis of the signal shape (i.e. characteristic "fingerprint"). It can be clearly seen from table 1 that the time which the droplet needs to pass the capacitor correlates to the signal length.

6. CONCLUSUON AND OUTLOOK

A non-contact nano litre droplet sensor based on a low-cost PCB-board with integrated transducing capacitor was presented. It was shown that changes in the droplet volume and velocity can be detected. The modular approach of the setup allows for the easy integration into the PipeJet™ dispenser as well as other existing nanoliter dispensers. The performance demonstrated could already have a considerable impact on the online process control in nano litre dispensing equipment. The quantitative evaluation of the signal towards droplet volume, velocity and liquid type is subject of future research.

7. ACKNOLEDGEMENTS

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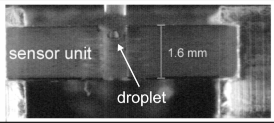
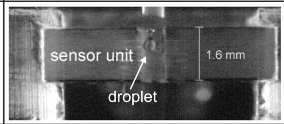
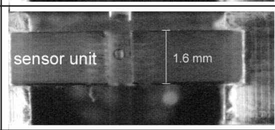
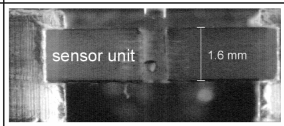
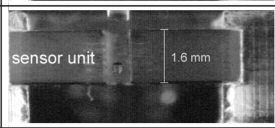
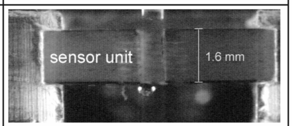
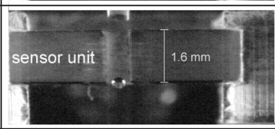
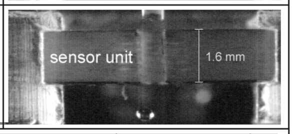
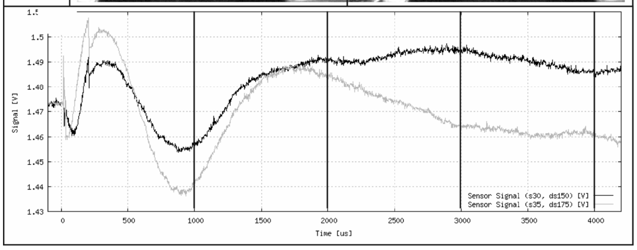
Table 1: Stroboscopic images of the droplet flight through the sensor and corresponding output signals for two different droplet sizes and speeds.

	volume: 45 nl speed: 0,46 m/s	volume: 68 nl speed: 0,74 m/s
1 ms		
2 ms		
3 ms		
4 ms		



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