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3D Printed Capacitive Fluid Level Sensor †

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Abstract: A three dimensional, additively manufactured interdigital capacitive sensor for fluid level measurement applications is introduced. The device was fabricated using the fused filament fabrication (FFF) additive manufacturing (AM) process and an off the shelf conductive filament with a volume resistivity ϱ = 0.6 Ω cm. The 3D fabrication process allows great flexibility in terms of sensor ˙ design and an increase of the surface area between the electrodes, compensating the relatively large plate separation and yielding a high sensitivity to increasing fluid levels. The measurements presented in this abstract show the average increase of capacitance in response to an incrementally increasing volume of de-ionized water (DI-water) filled between the separate digits.

Keywords: capacitive sensor; interdigital capacitor; fluid sensing; 3D printed sensor; fused filament fabrication; conductive filament; fluid level sensing

1. Introduction

Fused filament fabrication (FFF), is an additive manufacturing (AM) process in which a thermoplastic filament is driven through a heated nozzle (between 0.2 and 0.8 mm in diameter), usually very closely above its melting temperature [1]. The melted filament is then deposited by the moving nozzle on predetermined paths, forming single layers that, when added above each other, lead to a complete three dimensional (3D) object [2]. The use of thermoplastics allows for a wide variety of filaments, and more importantly the used of the thermoplastic as a matrix where various particles and fibers can and have been integrated as fillers of various degrees. This leads to functionalization possibilities such as making FFF filaments conductive using for e.g., graphene or carbon black filling [3–5]. This opens the door for a wide area of sensor applications that are designed for AM processes (as opposed to traditional electronics fabrication processes), and the integration of sensors and electronic components in functionalized additively manufactured parts.

The use of the FFF technology for the production of capacitive and other sensing elements has already been investigated in works such [6] using incorporated copper meshes in FFF parts, or using custom designed polypropylene (PP) based filaments with carbon black filler [4]. Works like [5] investigate the use of polylactic acid (PLA) based conductive filaments with graphene filler for energy storage applications. Other AM technologies, such as material jetting, have also been used for the production of electric components and sensor elements using a method involving metal paste filling [7].

In this contribution, we introduce an interdigital 3D-printed capacitive sensor built for fluid level measurement using commercially available, PLA based, conductive FFF filament with graphene filler and the results of measurements made with DI-water are presented and discussed.

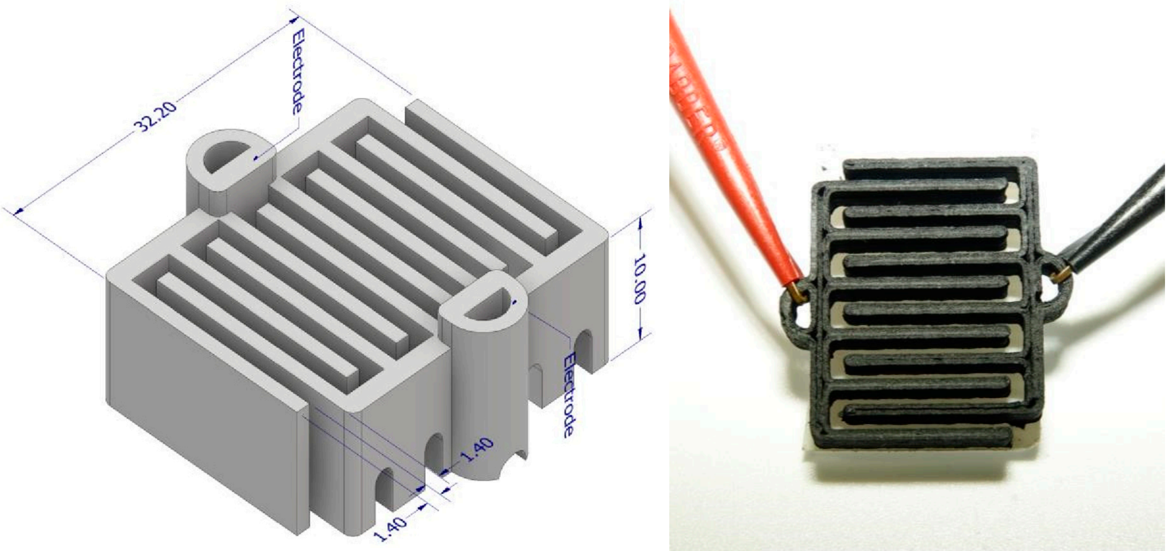
2. Motivation

The main motivation behind this work is the investigation of off the shelf polylactic acid (PLA) conductive filament for the production of fluid measurement capacitive sensors. This is a novel application area and promises a wide range of interesting applications. The integrability of 3Dprinted devices and the reduction of geometrical restrictions, enable flexible design and incorporation of capacitive, as well as other, sensing elements in highly complex geometries. In addition, the 3D sensor design allows for a great increase in the sensing surface area, which is of great advantage for capacitive sensors.

3. Sensor Fabrication

The capacitive sensors were fabricated using conductive graphene PLA filament from the company BLACKMAGIC3D. The filament has a volume resistivity of ϱ = 0.6 Ω cm according to the manufacturer [8]. The filament was extruded through an abrasion-resistant 0.6mm nozzle at temperatures varying between 185 and 195 °C, as per manufacturer recommendations. The abrasion resistance of the nozzle is necessary due to the graphene filling of the filament. The high graphene filling of the filament makes it also necessary to use a 0.6 mm (0.5 mm was recommended by manufacturer but is not very common) or wider nozzle diameter, which strongly limits both vertical and horizontal build resolutions.

The CAD drawing of the fabricated sensor is seen in Figure 1 along with the characteristic dimensions in mm. The 3D interdigital structure was chosen due to its high surface area, and channels were integrated in the geometry. This sacrifices some of the sensitive area in favor of a uniform fluid distribution between the electrodes. The great increase in surface area, made possible by a 3D-fabrication, compensates for the relatively large electrode separation of approx. 1.4 mm.



(**a**) (**b**)

Figure 1. (**a**) CAD drawing of the tested interdigital capacitor with given dimensions in mm. The channels at the bottom were introduced to ensure a uniform fluid distribution between the digits/plates; (**b**) Photo of the tested sensor with connected electrodes.

4. Experimental Results

The capacitance (C) of the device was measured, using an HP4278A capacitance meter, with respect to an increasing filling volume (V) of DI-water from 0 to 3 mL in 0.5 mL steps. The liquid was filled with a pipette between the electrodes, allowing enough time for homogenous fluid distribution before the measurements were carried on.

The measurements were made at a temperature between 24 and 25 °C. The initial tests show a strong dependence of the average capacitance on the increasing volume, with C varying between

0.052 nF for an empty sensor (air-gap) and 13.270 nF for a filled sensor. The initial results are very promising and next steps will include extensive tests with various geometries and fluids. Figure 2 shows the averaged results of three measurements made with the fabricated prototype and the resulting standard deviation represented by the shown error bars. The observed deviation could be due to absorbed moisture by the PLA filament and has to be further investigated.

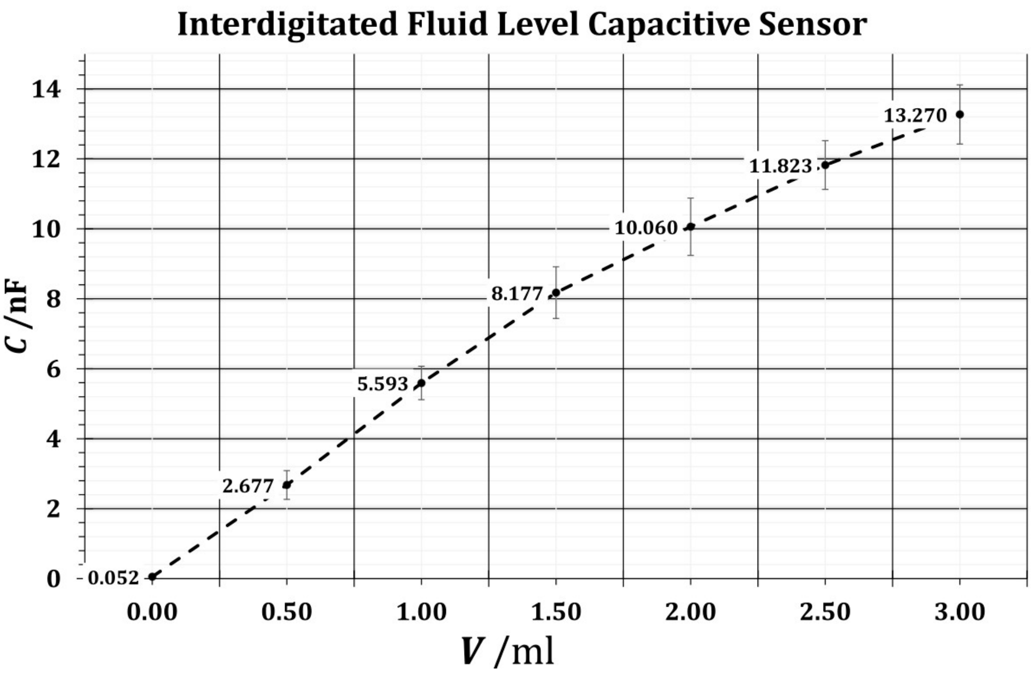


Figure 2. Graph showing the dependence of the interdigital sensors capacitance C on increasing filling volume V of DI-water. The measurements were made at room temperature between 24 and 25 °C using an HP4278A capacitance meter. The initial tests show a strong dependence of the capacitance on the increasing volume. The plotted curve is the average of three measurements with the error bars being the standard deviation. The sensor has an average capacitance of C = 0.052 nF while empty (air gap) and 13.27 nF while completely filled.

5. Conclusions and Outlook

In this work a 3D-printed capacitive sensor for fluid level measurement has been introduced. The sensor was realized using existing off the shelf FFF filaments with a high grade of graphene filler integrated in a PLA matrix, proving the usability of these filaments for capacitive sensing applications.

The design and fabrication of the sensor element are introduced and the increase of capacitance to increasing DI-water level has been measured and discussed.

The increase of surface area made possible by the 3D design of the sensor is a great advantage that can also open the way for other applications such as for e.g., integrated capacitive pressure sensors.

This work, along with others introduced in this contribution, show the potential of the FFF and other processes for the manufacturing of various sensor elements which are designed with AM in mind, and due to the high flexibility of AM processes, could be easily integrated in additively manufactured parts, allowing for a greater functionalization potential.

Conflicts of Interest: The authors declare no conflicts of interest.

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