Inkjet-Printed Capacitive Sensors and Electronic Structures

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Annotation:
The paper summarizes activities of the research company PROFACTOR in the field of functional inkjet printing of capacitive sensors and their usage as a human to robot interface and as a fluid level sensor directly printed on a 3D object. Printing processes and techniques are discussed and sensor functionality is proven on several demonstrators, namely the robotic arm equipped with printed capacitive touch buttons and a glass vase with printed capacitive level sensors on one side and LED signalization of the water level on the other side.

Anotace:
Příspěvek shrnuje aktivity výzkumné společnosti PROFACTOR v oblasti inkoustového tisku kapacitních senzorů a jejich využití při ovládání robota člověkem či jako senzor hladiny tekutiny vytištěný přímo na 3D objektu. Diskutovány jsou procesy a techniky tisku a funkčnost senzorů je prokázána na několika demonstrátorech, zejména na robotickém rameni vybaveném tištěnými kapacitními dotykovými tlačítky a na skleněné váze s tištěnými kapacitními senzory na jedné straně a signalizací hladiny vody pomocí LED na druhé straně.

INTRODUCTION

Printed organic electronics are currently forming a new basis for low-cost microelectronic technology on typically thin, light-weight, and mechanically flexible substrates. Low-cost printed sensors and structures are highly demanded, especially especially due to emerging concepts of Industrie 4.0 and Internet of Things. The future in sensing technology partly lies in additive technologies of material printing using low-cost additive processes like screen, ink-jet or roll-to-roll printing on substrates such as plastic foils, paper or freeform surfaces of additively manufactured parts [1]. This paper gives an overview of research performed at PROFACTOR GmbH [2], which aims are related to ink-jet printing of capacitive sensitive structures for touch, proximity, and level measurement and combines additive manufacturing technologies, robot-based printing and robot safety technologies.
A multi-layer and multi-material printing process is being developed by PROFACTOR, to realize sensors and electronic circuits on a variety of different substrate including flexible and textile substrates

INKJET PRINTED SENSORS

Inkjet-Printed Capacitive Touch Sensors for Direct Human-Robot Interaction

Capacitive sensing for touch detection has gained popularity due to the achievable sensitivity, accuracy, and easy processing directly with capacitance measurement enabled integrated circuits or microcontrollers [3]. Inkjet printing allows fast and efficient deposition of conductive materials on a wide range of substrates digitally and allows customizable design of sensitive structures for different robots and applications. Printed structures are compatible with SMT processing, passive and active components can be integrated directly on printed structures [4].
Four rectangular touch electrodes (each 15 mm x 15 mm) in size, were designed printed on flexible substrates of Novele™ using Meyer Burger LP50 equipped with an industrial Dimatix Spectra-128 piezoelectric printing head.
A silver nanoparticle conductive ink I50TM-119, supplied by PV nanocell LTD [5] was used for printing. Optimization of printing parameters and jetting waveform were performed before printing at high resolution up to 1500 DPI (Fig. 1). Individual droplets deposited on the substrate are down to 35 μm in diameter (see Fig. 2, left).

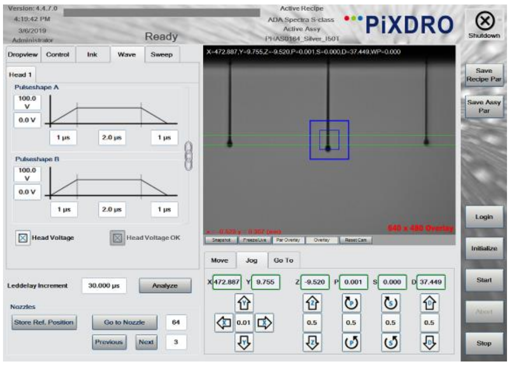

Fig. 1. Drop watching and waveform optimization window of LP50 printer

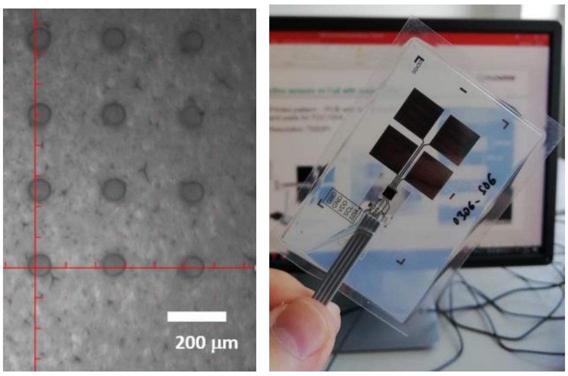

Fig. 2. Individual dops of conductive ink printed on foil substrate (left); Printed, assembled and a laminated sample of capacitive touch buttons with readout chip integrated (right)

The structures were thermally cured in a convection oven for 30 min @ 125°C. Printed structures were characterized using optical imaging and profilometry. An integrated capacitive readout chip (FDC1004 from Texas Instruments **Chyba! Nenalezen zdroj odkazů.** as SMT part in VSSOP package) was directly embedded in the printed flexible element. Printed lines of width down to 80mil were realized on the flexible substrate in order to connect electrodes and the readout chip (Fig. 2, right) The printed structure was contacted using a silver adhesive (Henkel PF050) and thin copper flat cable and then thermally laminated (120 °C) with covering PET foil with 80 μm in thickness (see Fig. 3). The lamination of electrodes serves both as a protection of electrodes and a dielectric layer for touch sensing.

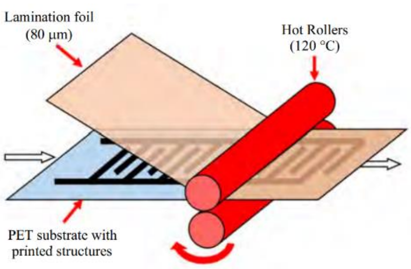

Fig. 3. Description of the lamination process

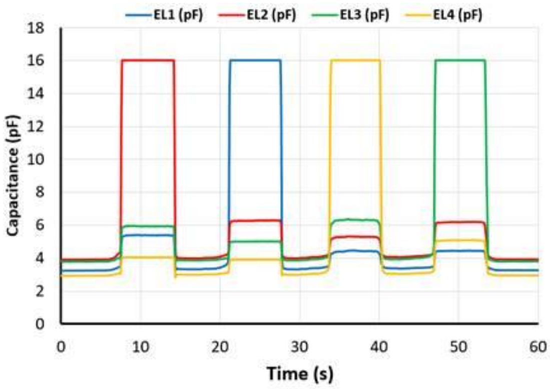

Fig. 4. Capacitance response of individual electrodes

The fabricated sensor was placed on a UR10 robot arm and characterized in touch detection mode (Fig. 4). The digital output (I2C) allows direct interfacing with a microcontroller. After interfacing the sensitive part with UR10 robot using a UART/USB interface, capacitive sensors were configured such that a user interacts with a robot by touching buttons to change modes of operation, for example, hand guidance, program change or re-start of an application (see Fig. 5.). System design and extensive characterization are presented in [7].

Fig. 5. Example of integration of the printed sensor on UR10 robot arm.

Robot-based Inkjet Printing of Capacitive Sensors on a Freeform Surface.

Robot-based inkjet printing offers the possibility to print digitally onto curved surfaces ("direct-to-shape printing") over a large area and with high throughput. The application of graphical or functional elements to curved surfaces excludes conventional methods like screenprinting. Individual printing on objects and components with curved surfaces has so far is usually done via transfer printing on foils or non-digital pad printing. New approaches use robotic guidance of the print head or the substrate.

PROFACTOR developed a process of functional printing of conductive nanoparticle ink with robotic guidance of the print head [8][9]to print a single layer circuit board on a curved surface. The 3D object is

represented by a glass vase, which offers direct capacitive level measurement on one side and signalization of the water level on the other side.
The printing on the vase demonstrator were performed with the Stäubli robot (Industrial Robot series TX90L [10]) and an industrial print head (Ricoh Gen 4/MH 2420 [11]). This robot shows very high accuracy and repeatability (0.035 mm), which is suitable for inkjet printing. The path planning was done in PROFACTOR-internal software framework. In this software, a model of the Stäubli TX90L is used for the simulation of the robotic movements during printing. A 3D model of the substrate is loaded into the simulation (see Fig. 6).

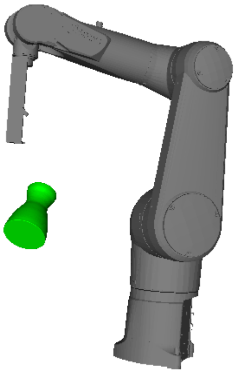

Fig. 6. Model of UR10 robot (grey) and model of the substrate (glass vase, green) used for path planning

After printing of the conductive layer, a protection layer was printed to prevent the silver layer from oxidation (non-conductive, transparent UV ink, Heavy Duty Varnish 140/11000, Tiger Coatings [12]). This protection layer also serves as a solder stop mask for further assembly of SMT LEDs as is depicted in Fig. 7

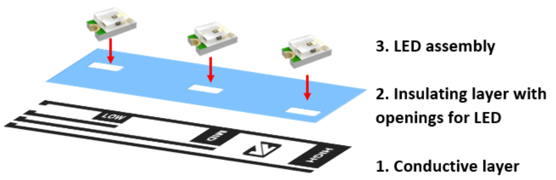

Fig. 7. Design of conductive paths and mask for LED assembly

A custom capacitance readout circuitry based on STM microcontroller with Touch Sense capability [13] was designed to measure the change in capacitance and to control indication LEDs accordingly (using a calibration curve depicted in Fig. 9). A custom-designed and 3D printed part with spring contacts provides a reliable electrical connection from readout electronics to the contacts on the bottom of the glass vase. The vase demonstrator is depicted in Fig. 8.

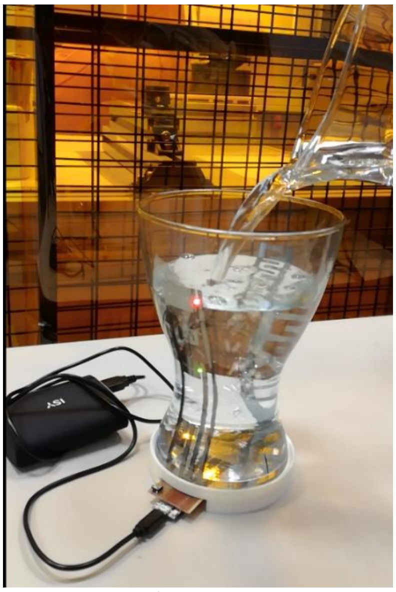

Fig. 8. Demonstrator of the glass vase with direct capacitive level sensing and signalization of the water level

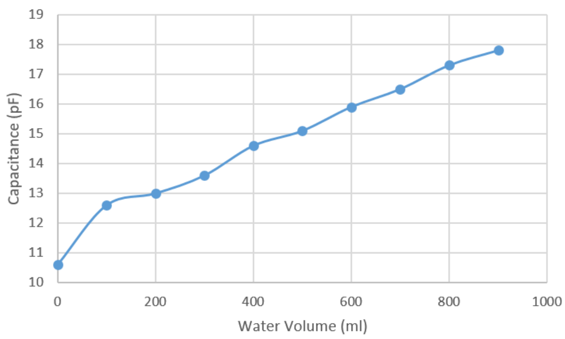

Fig. 9. Capacitance calibration curve

CONCLUSIONS

PROFACTOR is a research company (located in Steyr, Austria) and provides solutions and systems for industrial assistance and additive micro/nano manufacturing with a focus on inkjet printing. Both support the “Factory of the Future” realizing efficient, effective production processes ranging from nano scale processes over collaborative robotic systems to complex adaptive production systems. In both research areas PROFACTOR builds on years of expertise and over 1,600 national and international research projects.

ACKNOWLEDGMENT

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