

Developing printed sensors for the Internet of Things & Materials

InnovationLab GmbH (Heidelberg, Germany) has built a comprehensive eco-system for printed electronics. In OPE journal, the company showcases some of its latest activities related to printed sensors

The concept of printed electronics is linked to new opportunities in the electronics sector due to the capability of producing devices on thin and especially flexible substrates. Using printing technologies inherently implicates that large production volumes and cost efficiency are core features of the approach. Being able to provide cost-competitive printed sensors in industrially relevant quantities is thus an enabler for Internet of Things (IoT) applications.

To realise the full potential of printed electronics two requirements must be fulfilled: first, as a prerequisite the technical capabilities and a reliable eco-system from first prototypes to mass-production must be available. Second, suitable use-cases with significant market potential must be identified.

With respect to technical capabilities InnovationLab GmbH (iL) has developed into a one-stop-shop for printed electronics. Being a hub both for academia as well as industry, iL has established an extensive eco-system for printed electronics spanning all the way from first product concepts to mass production (Figure 1 (a)). Novel sensor technologies, systems, and applications are developed both based on an established technology as well as new concepts arising out of R&D work with academic and industrial partners. To support further steps in the design cycle, a strong team of engineers is available to design, plan, prototype, and finally realise suitable hardware and software including the integration of, e.g., sensor applications into an IoT environment. Due to a highly modified 17m Gallus RCS 330 roll-to-roll printing press the production process can be taken directly from lab to fab. The pilot line allows to print on up to 2km of 330mm wide substrates of 1.5 – 300µm thickness per run. The modular nature of the Gallus makes it a perfect tool for process



Fig. 1: Production capacity of iL: (a) Lab-to-Fab concept for printed electronics, (b) industrial production capacities at iL

development and initial pilot production. Mass production can then be realised through iL's collaboration with Heidelberger Druckmaschinen AG, world market leader in the manufacturing of printing presses, who have established mass-printing capabilities in their new centre for printed electronics production in Wiesloch (Figure 1 (b)). The additive manufacturing process along with iL's worldwide unique partnership enables the development and production of customised sensors on an industrial scale and at low costs.

To probe into the second prerequisite for success in printed electronics – the identification of use-cases and market opportunities – in collaboration with BASF SE, iL recently embarked on a journey to study the

use of printed sensors to enhance and/or digitise existing products and applications. For a material producer adding additional features to products can be an interesting option to offer customers additional benefits. Test cases for enhanced materials were for example the outfitting of thermal insulation materials with sensors for physical damage control and the combination of foam and coating materials with force sensors to generate "smart" surfaces. In the area of digitising, an existing application, i.e., contact-less fill-level monitoring in glass and plastic containers, was studied. Within this project, the company developed capacitive and resistive sensors for pressure, touch, proximity, fill level monitoring, and damage detection. Sensors were

implemented in connected prototypes towards the “Internet of Materials” combining BASF materials, sensors, data collecting hardware, wireless transmission systems and software. Three of these use cases are presented in this article: a solution for weight monitoring on a smart pallet, a solution for measuring fill levels in plastic containers, and a large-scale damage detection system for thermal insulation systems.

Capacitive technology

In a first series of use-cases, printed sensors were developed to detect and measure changes in capacitance. Changes in capacitance occur for example by approaching two metallic electrodes in a dielectric medium, or by placing a conducting electrode in a different dielectric environment. Both mechanisms can be used in printed sensors, the first one to measure forces, the second one to measure presence, approach, or touch. Two examples of prototypes using the patent-pending printed capacitive sensors are shown in Figure 2.

Figure 2 (a) shows a smart pallet equipped with four universal sensing blocks designed for monitoring quantitatively the weight and weight distribution applied to it. The pallet relies on four capacitive pressure sensors printed and mounted in a rigid housing allowing to protect and transmit vertical forces to the sensors. Such pressure sensors employ the change of the capacitance of an arrangement of parallel electrodes

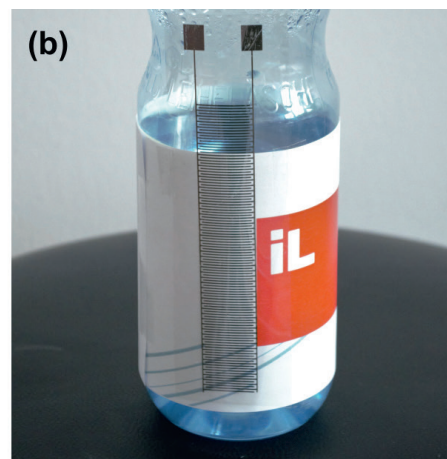


Fig. 2: Prototypes using capacitive sensors. (a) Smart pallet for weight monitoring using four capacitive sensing blocks; (b) printed capacitive stripe system to measure the fill level in a plastic container

sandwiching an elastic deformable foam. Under pressure, the dielectric foam is compressed, and the two electrodes get closer to each-other, increasing the total capacitance. One main issue of capacitive sensing is the unwanted detection of environmental charges leading to a false response of the sensor and complicated calibration. This issue could be eliminated by the development of an improved sensor design which guarantees highly reliable measurements without external interference.

From the hardware point of view, the capacitance data from the four sensing blocks is collected simultaneously and transmitted to a main electronic board, powered by a battery which communicates via Bluetooth

with external devices. A readout software and a graphical interface were programmed at iL for this prototype.

This system allowed iL to quantitatively measure weight and weight distributions on a pallet using printed capacitive sensors and a BASF foam as compressible dielectric material. Due to the optimal properties of this dielectric foam, high measurement range (some 100g to over 1 tonne), high temperature stability, and very low drift under constant load were observed making this system suitable for many industrial applications. The costs for such a solution offer a very competitive alternative to existing weighing systems. The rigid housing developed to protect the sensors offers the



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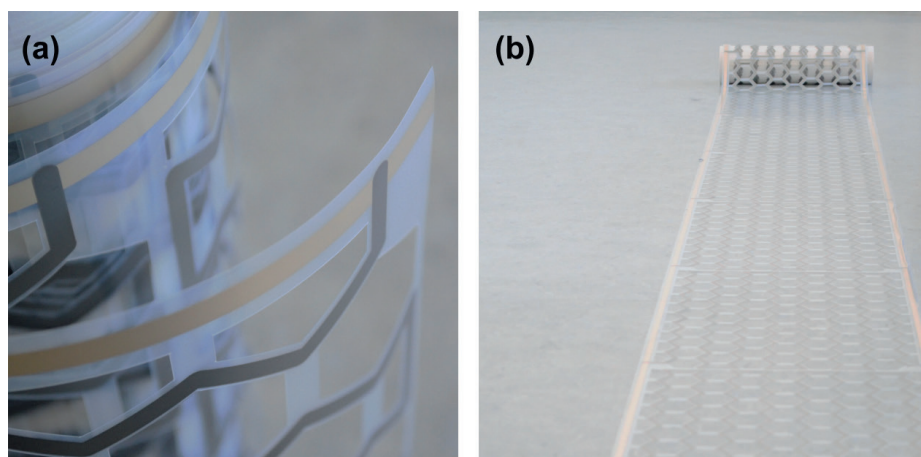


Fig. 3: Printed large-scale damage and temperature sensor foils. (a) Detail image of the printed sensor; (b) image of a 4-metre-long sensing element with only two connectors

possibility to retrofit these sensors in any wooden pallet as well as in other industrial systems e.g. in the field of logistics or retail. Figure 2 (b) shows a capacitive liquid or solid level monitoring system allowing to measure from the outside the fill level of a plastic container. The proposed prototype consists of a printed continuous stripe or a series of distinct capacitive pads mounted on the outside of a container. Using the proper readout electronics, the iL team was able to detect the fill level or the presence of different liquids through the plastic container. Examples of fluids include water, organic solvent, or motor oil. The achieved resolution in liquid height was of the order of 1mm for water in a plastic bottle. This approach may prove useful when considering non-invasive methods to determine the fill level of plastic containers, such as IBCs.

Resistive technology

The second use-case is based on conductive traces printed on flexible substrate foils, used for both damage detection and temperature monitoring on a very large scale in composite materials using a resistive technology. In this case, variations in the electrical resistance are used for sensing. These foils were developed specifically for monitoring damage and temperature changes occurring in insulation systems used in logistics, e.g. in a refrigerated trailer. In this context, damage often occurs due to fork-lift assisted loading and unloading of merchandise. The damage is usually detected too late because of an increase in the inner room temperature. The consequences of such damages are

important (i) because refrigerated consumer goods may not be suitable for retail any more after rise in temperature; and (ii) for the trailer owner who must usually replace the whole insulation after damage.

Many insulating materials are protected by a composite material (polymer reinforced, e.g., by fibre glass) including some refrigerated trailers. Detecting the exact location and timing of damage to the large area composite structure is challenging. The two problems faced to achieve a solution for this problem are therefore: (i) the integration of a large-scale sensor array inside the composite structure; and (ii) to be able to determine the position and time of damage with a spatial resolution of a few centimetres on a surface of a few hundred square meters. Solutions are not trivial because of the tremendous number of connectors required to reach such a resolution using standard existing solutions, e.g. wiring, and manufacturing processes.

The patent-pending solution which was developed on a real-size prototype is shown in Figure 3. Spatial resolution was achieved based on a special, newly developed sensor topology. All physical preconditioning steps necessary to enable an easy integration of the sensor into the composite material were also realised on the roll-to-roll printing machine thus making the whole sensor production process fast and economical (Figure 3 (a)).

Proof-of-concept experiments showed that it is possible to use these printed patterns as temperature sensors. A linear dependence of the resistance with the temperature was observed between -20°C and $+55^{\circ}\text{C}$ and a

resolution of temperature measurement of about 1°C was estimated from this measurement. This result is important because it shows that the printed large-scale damage detection system can be used as a temperature sensor without any modification of the electronic readout to indirectly detect temperature changes in the insulation material.

Conclusion

Within this joint project, the team implemented printed sensors in existing materials to enhance their function through integrated data gathering. Capacitive and resistive printed sensors were embedded in several materials to detect and measure for example damage, temperature, pressure, approach, or the presence of a fluid.

Taking advantage of printed sensors, they could solve several issues inherent to both capacitive and resistive sensors. For instance, via their the freedom of design, printed sensors allow, (i) to cover large surfaces such as the walls of refrigerated trailers, (ii) to solve the major issue related to the number of connectors necessary to cover such a large area with a sufficiently high resolution, (iii) to develop quantitative and stable pressure sensors, and (iv) to print all necessary printed layers onto one foil, offering a very compact and robust solution. The team has shown that these printed sensors could be implemented in networks of sensors embedded in materials and systems such as a smart pallet, an intermediate bulk container (IBC) or a glass fibre composite material. But these are only first use-cases for the development of connected materials from prototype to commercial products and many further applications based on the developed sensors are possible. These achievements constitute an important step towards the Internet of Things and Materials and in this scope, iL would like to encourage collaborations using the developed technologies for other products and ideas.

Image sources: InnovationLab