A Survey on Organic Smart Labels for the Internet-of-Things

Leonardo Weiss Ferreira Chaves, Christian Decker

Abstract—**Organic Electronics refer to electronic components that are created from polymers. With this technology, novel RFID and sensor devices, so-called organic smart labels, will be printed like today's newspaper at high speed and in large amounts. This approach promises a dramatically cost reduction while providing on-label sensors. Because of that, organic smart labels are expected to find a broad adoption where current passive and active RFID technologies have failed. For instance, in the context of the Internet-of-Things (IoT), organic smart labels enable item-level tracking and in-depth sensory monitoring of real-world objects over the Internet. In this article, we set a business related perspective in correspondence with a technological roadmap of the organic smart label development. Furthermore, we discuss technical problems that will arise when processing the huge amount of data expected from the usage of organic smart labels.**

Keywords-**Emerging technologies, RFID, Printed organic electronics, Internet of Things**

I. Introduction

The Internet-of-Things (IoT) aims at connecting information systems with real-world objects. It enables to automatically acquire, process and react to real-world data in real-time. One of the promising technologies enabling IoT is Radio Frequency Identification (RFID) [1]. RFID labels that are attached to physical objects provide a unique identification and other object information directly acquired from those objects. RFID technology provides an accurate real-time representation of 'things' to the information systems. As a consequence, labeling the world with RFID is business relevant. It enables enterprises to measure and manage real-world objects in real-time.

Currently, different market players label palettes with RFID. The next step is to label every single object. As a result, every item on a pallet can be identified. Additionally, objects will become smarter by the use of smart labels, i.e., devices that combine identification with sensors. For instance, smart labels with temperature sensors that are attached to every item of perishable goods can measure their storage quality. A direct implication is an increase of the information load. From a small heap of information from a single RFID label on a pallet, it scales up two or three magnitudes when 100s or 1000s of items on a pallet are interrogated for their information. And it takes two or three magnitudes more time to interrogate so many RFID labels. The situation even intensifies in the context of multi-tagging, whereas multiple RFID labels are attached to a single object.

In this paper, we investigate and discuss the technical implications of such a combination of multi-tagging and item-level tagging when using novel organic smart labels. We study it from the perspective of the identification and sensing technology as well as from the perspective of data integration.

The paper is organized as follows: We first analyze the business relevant aspects of RFID and introduce under this motivation organic smart labels. Under the same premise we then classify the gap that will be closed by organic smart labels within the IoT. A roadmap shows how organic electronics will evolve technically. Finally, we investigate the challenges that will arise when utilizing organic smart labels in the IoT.

II. What is wrong with RFID

RFID labels consist of a tiny computer processor accompanied by a memory and connected to an antenna. They transmit a unique identification number and other information stored within their memory when interrogated by a reader device through radio waves. Passive RFID labels are powered wirelessly by the reader device and do not require a battery for their operation.

On average, current RFID labels cost between 0.20 US$ and 1.00 US$ [2]. In the cost-sensitive supply chain of a retailer the cost of an RFID label is too high. It seems that traditional RFID will not reach the ultra-low costs required for applying the technology in many product segments or even on item-level basis. This is mainly because the production of RFID labels requires many expensive steps that cannot be eliminated today: first the RFID chip is produced, and then it is typically attached to a strap providing contact plates for the further assembling. Also, the RFID antenna has to be produced, laminated, and finally assembled to the RFID chip. Solely, 50% of the costs are determined by that interconnection [3]. Finally, the resulting label has to be attached to an object. All these different steps are conducted separately.

Smart labels extend the functionality beyond the identification. A smart label is able to detect and react to its environment through sensors. For instance, an RFID label equipped with a temperature sensor detects when a temperature range is exceeded and starts recording these data for reporting. Batteries often support the sensing process or even the communication with the reader device. For this reason, these RFID labels are referred to as active RFID. Integrating additional components, such as sensors, adds dramatically to the costs (see Figure 1). As a result, RFID labels equipped with sensors are only

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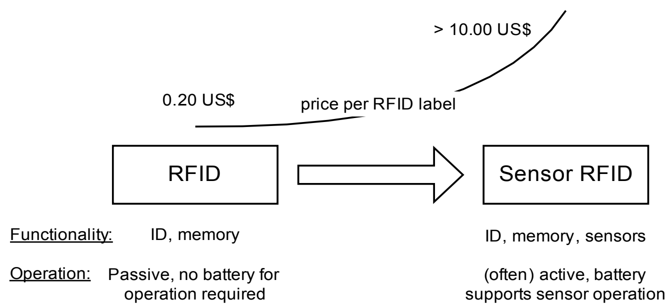

Fig. 1. Smartness by the use of sensors is exceptionally expensive. (Prices taken from [2]).

used sporadically, on a coarse-grained scale, e.g., for palettes carrying 100s or 1000s of objects, or on single very high valued goods and objects.

The benefit of using RFID labels in large quantities, e.g., on every single item within a supply chain, has to outweigh the costs to be feasible from an economic point of view. The dilemma is that costs and benefits are asymmetrically distributed in a supply chain. For instance, the manufacturer makes the investment to attach RFID labels and the retailer may have the benefit. The costs of item-level RFID deployments could be shared among supply chain partners such that the overall supply chain profit is optimized. Doing so requires knowledge about the complete supply chain. However, supply chain partners are unwilling to share such information, e.g., because third-party business relationships might be inferred. Thus it is more attractive to generate the benefit for each partner separately. As a consequence, the costs for RFID labels have to be cut down and new features have to be provided.

III. Organic Smart Labels within the IoT

Numerous IoT applications using RFID labels have been proposed and are already implemented. It is important to understand where organic smart labels could find their use. We will cite business research studies in order to demonstrate that costs of labels and the demand for on-label sensor information span a gap for regular RFID labels. Organic smart labels will close this gap.

Sensory monitoring becomes crucially important in both supply chain processes and inventory management, in particular for perishable food products. The authors in [4] list several IoT solutions for implementing temperature managed traceability systems using RFID labels with embedded temperature sensors. In another example, the research project GoodFood (http://www.goodfood-project.org) evaluates the use of RFID labels with onboard chemical sensors in order to monitor food products, for instance by measuring the gases generated by deterioration.

Today, these approaches utilize active RFID sensor systems where batteries support the sensing process or even the communication with the reader device. Industry sources estimate that about 50% of all loss in grocery stores is attributed to perishable goods [5]. That is why enabling smartness through smart sensor labels is necessary. Although smart sensor RFID technology for the IoT is available, it has not pervaded supply chains, because this sector is extremely cost-sensitive.

Definitely, supply chain processes are one of the key drivers for developments and implementation of the smart label technology. IDTechEx's recent worldwide study on active RFID from 2009 [6] finds the largest number of projects in the logistics sector. The study predicts that in the next 10 years one of the largest sectors with more than 20% of all smart label applications will be related to supply chain processes. The same study forecasts that although prices for active RFID labels will drop, they will still hardly drop below 1 US$ at the end of the next decade. This is still higher than today's available ID-only labels. It is already anticipated that part of this price erosion will be due to the upcoming use of printed electronics.

Summing up, the smartness that is enabled through sensing is a vital demand. However, it is prohibited by its high costs. Smartness and costs span a gap for regular active RFID sensor systems within the IoT. Organic smart labels aim to close this gap. They will open-up cost sensitive sectors for the IoT by providing a low-cost holistic sensory monitoring.

IV. The Vision of Organic Electronics

Organic Electronics [7], [8], [9] is a collective term that refers to electronic circuits that are made of organic materials, e.g., plastics and polymers in general. Such materials are printed using standard industrial printers, e.g., printers that are also used to print newspapers and that can print several square meters per second. This results in ultra low-cost electronic components, and thus allows the use of electronic components like smart labels in scenarios where it was not possible before.

Most of the traditional electronic components used today are based on silicon. These electronic components show a high performance, they are highly miniaturized and integrated, and their price per transistors is very low. However, they are complicated to manufacture, i.e., they require creating several masks and etching a silicon wafer (subtractive process). And they require costly clean room facilities, taking the costs of a microchip factory to several hundred millions of dollars.

With Organic Electronics several layers of different materials are printed onto each other to form electronic components (additive process). This reduces the overall number of steps in manufacturing, it reduces the material costs and the overall tooling costs, i.e., its production is very simple, fast and cheap. However, Organic Electronics show a worse performance. And even though the price per transistor for Organic Electronics is higher than the one of traditional electronics, the price per area is very low. Therefore, Organic Electronics are expected to replace traditional silicon-based electronics in scenarios where electronics do not need to be very small or fast, and where the price of the electronic components has to be very low. This is the case with smart labels. Note that inorganic materials can also be used to print electronics. However, we focus on organic materials because they show a better processability.

The basic system design of an organic smart label is virtually not different from a regular silicon-based RFID label. However, organic smart labels can contain a multitude of

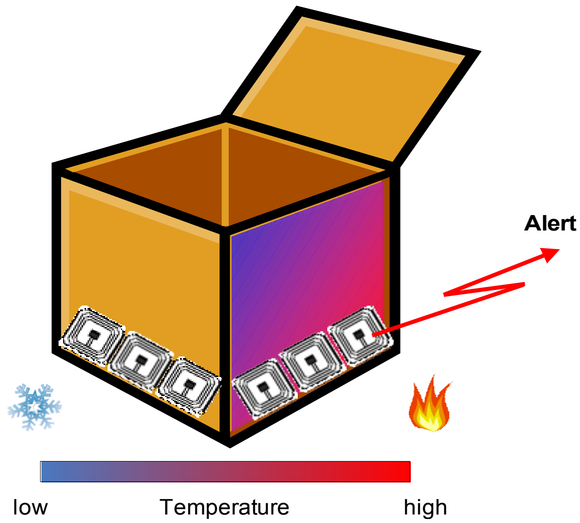

Fig. 2. Multi-tagging: example of one smart label that reports a high temperature spot, which was not discovered by other smart labels.

TABLE I
COMPARISON OF RFID WITH ORGANIC SMART LABELS

	Passive RFID	*Active RFID*	*Organic Smart Label*
Labels per Object	1	1	Many
Sensors	–	Yes	Many
Battery	–	Yes	Yes
Price	0.20 - 1.00 US$	10.00 - 30.00 US$	Expected to be more than 10 times lower than passive RFID [1]
Range	< 1 m	< 100m	not known yet
Frequency	LF, HF, UHF, GHz	LF, HF, UHF, GHz	HF (UHF by 2024)
Memory capacity	Up to 64KByte	Up to 1MByte	1 Bit (96 Bit by 2014)
Memory type	ROM, WORM, RW	ROM, WORM, RW	ROM, (WORM by 2014, RW by 2016)

sensors, like temperature, light, pressure and strain sensors. And because of its ultra low-costs, several organic smart labels can be printed onto a single object (multi-tag). On the one hand, this increases the communication reliability of organic smart labels (cf. [10] for similar experiments with RFID). On the other hand, it provides many sensor values for a single object and therewith it enables a holistic sensory coverage of that object. For instance, the temperature within a palette of objects may be distributed unevenly and may display different dynamics [11]. Therefore, a single smart label on an object captures only an incomplete view. As a result, suspect spots may remain undiscovered, because there was no smart label to detect it. Multiple smart labels holistically acquire sensor information from the entire packaged object and therefore report previously undiscovered suspect spots. This is illustrated in Figure 2.

To conclude this section Table I compares organic smart labels to standard ones.

V. Roadmap for printed Organic Smart Labels

The main concepts required for building organic smart labels have been researched, and demonstrators exist that show the proof-of-concept [12]. However, production parameters like yield have to be optimized for successful market introduction. Today, only simple organic smart labels exist, which only have 1 - 4 Bits of Read only Memory (ROM) and that contain no sensors and no battery.

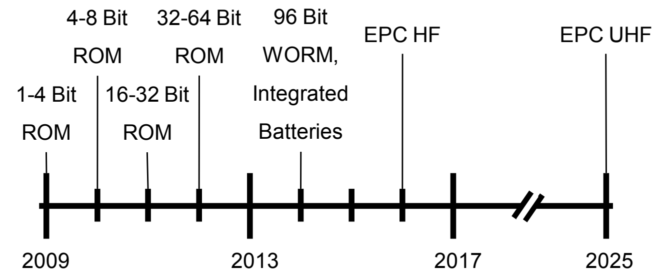

Fig. 3. Roadmap for printed Organic Electronics (with data from [8]).

Figure 3 shows a roadmap for the general availability of printed organic smart labels. It is based on the data in [8]. As already mentioned, today only simple organic sensor exist. Over the years, the memory capacity of the smart labels will increase until reaching the milestone of 96 Bits in 2014. Furthermore, memory of the type Write once Read many (WORM) will be introduced. This is a milestone in the development of organic smart labels, since they will be able to store an Electronic Product Code (EPC) [13], which is an important standard for coding the identification number of an object. In the same year, the first fully integrated printed batteries will appear, allowing the organic smart label to be equipped with more complex sensors that can continuously monitor their environment, even in the absence of a reading device. On a long term, organic smart labels are expected to implement the full EPC communication protocol. First for High Frequency (13.56MHz), and later for Ultra High Frequency (850 - 950MHz).

Sensors are not shown in the figure to avoid clutter. Today, a large variety of sensors exist, like temperature, light, pressure and strain sensors. And a plethora of other sensor types is being developed.

VI. Challenges when Utilizing Organic Smart Labels in the IoT

The IoT consists of large-scale information systems, which encompass resource planning systems, database management systems, application servers and others. The IoT utilizes smart label technologies to couple real-world objects with business processes. The information systems within the IoT obtain data from an infrastructure network of reader devices, e.g., all reader devices from all stores of a retail chain. The main tasks are then to (1) process the acquired data, e.g., the identification information and additional sensor data, (2) perform actions accordingly, e.g., initiate an order process for replenishment. And (3) store the acquired data, often for several years, e.g., for the purpose of compliance in the food industry. However, the massive deployment of organic smart labels will result in data which cannot be efficiently processed by current systems. This is because the data volume will be orders of magnitude larger than the one that results from equivalent

RFID installations, since each object will carry many smart labels. And therefore each object will contain many more sensors that may return conflicting data. Both aspects are discussed in the following [9].

Huge Amounts of Data: With the massive usage of organic smart labels the central challenge for information systems within the IoT is the processing and management of the vast amount of data. Identification information is always associated with metadata, such as location of an item or status within a business process. For instance, if Wal-Mart operates RFID on item level, it is expected to generate 7 terabytes (TB) of data every day [14]. When applying 10s or 100s of organic smart labels to each item, the data volume vastly increases. At peak load situations, e.g., when palettes of items arrive at a reader device, metadata changes dramatically as a flood of update operations propagate through the information systems, e.g., updating the items' locations metadata. Information systems must operate at high data rate to process the data fast enough. The massive data explosion will impose higher loads for middleware software frameworks throughout the entire supply chain. Data from different sources will be combined to enable complex event processing along the supply chain. Simultaneously, the information systems are requested to provide real-time processing.

Data Quality: Data quality becomes a crucial aspect when multiple organic smart labels and their sensors are attached to an object. With 100s or 1000s of sensors per object, the data from a single smart label may move into the background. On the one hand, redundancy is provided. A failed smart label is not fatal and data from neighboring smart labels can be used for compensation. On the other hand, it is more complex to filter out inconsistent or conflicting readings. Erroneous sensors may trigger unnecessary or even costly processes and actions. The manifold relationships between information systems in the IoT make it hard to isolate the original cause.

The integration of organic smart labels into the IoT presents challenges for additional research efforts. Information systems are requested to scale up with the vastly growing amount of data while simultaneously allowing real-time queries. The high load on middleware systems, the event processing throughout the supply chain and the use of multiple organic smart labels per object require a flexible distribution of the processing. It may be distributed among the organic smart labels, the reader device, middleware computer systems and data base management systems. It also means that one needs to partly reconsider some established ways in order to accomplish these challenges. For instance, novel communication protocols for organic smart labels can be designed to fuse and to combine data online. This could be applied for palettes completion checks: Instead of collecting the information of 1000s of single smart labels one-by-one, a palette communicates only its completion status. This speeds up the process and significantly reduces the data stream within the IoT.

VII. Conclusion

Organic smart labels integrate RFID and sensor functionality as printed electronic components. They can be printed in large amounts at high speed and therefore facilitate the approach of item-level tagging for the Internet-of-Things (IoT). In this article, we set a business related perspective in correspondence with a technological road map of the organic smart label development.

Organic smart labels enable a holistic sensory coverage of goods and objects in cost-sensitive domains such as supply chain processes. Within the next 10 years this will open-up a huge market where such a technology could pervade one of the largest sectors with more than 20% of all applications that are related to supply chain processes. As a direct consequence of this development, data integration challenges arise: Information systems within the IoT are required to organize a huge volume of item-level data and a peak loads while providing real-time processing.

We believe that organic smart labels will have the potential to influence the market strongly. Finally, investigations from [15] attest organic smart labels a better environmental sustainability than silicon-based RFIDs when deployed in high numbers what we expect in the future.

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