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Low-cost extension of information transparency throughout the product life-cycle via optical identification and quality indication

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Abstract

Growing needs for data transparency are experienced in production networks, calling for individual product traceability and accurate information on actual state, quality or history of the individual product. Special challenges arise when "low-tech" network members, retailers or customers are likewise to be served during the product life-cycle, or in case low unit prices or tight profit margins require highly cost-efficient solutions. In line with the latter, the paper examines the integration of optical identifiers with optically perceptible quality indicators as an alternative to sensor-equipped RFID, including new designs not yet covered by implemented solutions. Following a separate survey of the two combined technological domains, possibilities of synthesis are examined from the point of view of optical codes, as their (semi)automatic acquisition and subsequent processing presents the key value added to most present-day indicator-only labels. As different targeted application ranges, e.g., supply chain members of different size, may require different pre-implementation surveys, the paper includes a collection of acceptance aspects for all of the identified user groups.

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1. Introduction

Production networks have spread and evolved much in recent decades, as did services become more important that stretch beyond strictly production-related stages of the product life-cycle (e.g., guarantees and customer care, or product feedback for future design upgrades). These trends all require improved transparency on one hand, and may imply more data "travelling with the product" on the other hand. As services and operations stretch across further life-cycle stages, it becomes more and more likely that the individual product will meet network members, retailers or users who represent a "low-tech" group and have very limited possibilities at hand to access and interpret data attached to the product. In parallel with this trend, improved transparency and provision of product data gradually begins to penetrate product ranges that are characterised by lower per-unit value or low profit margin. The latter raises the need for low-cost technologies that can carry data unique to the individual product—often in relation to its individual state—remain suitable for inclusion in data sharing, but also being interpretable with low-tech equipment or no reading devices at all. While various problems of this kind exist, the paper focuses on data supplied with perishable goods in particular, with an emphasis on the low-end problems of small retailers and consumers.

Providing item-level information about de-facto quality or integrity of sensitive or perishable products is now being offered commercially, often as part of intelligent packaging solutions. Labels equipped with sensors or indicators play a substantial role in these, as they provide the required degree of observability on the level of individual items or packaging units [3, 4] (remarkably, this trend runs hand-in-hand with a redesign of material handling practices [5] and supply chain structures [6, 7]). This is especially present in areas where demands for efficient and safe operation of supply chains are becoming more and more pressing, as in the food sector [8]. It

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can be observed that this process, as it frequently occurs in adopting new technologies, is mostly initiated by large members of the supply chain who take a pioneering role but also shape the mainstream of application demands in accordance with their own typical needs, i.e., solutions that efficiently support large-throughput operation but may require the high initial investment and technical expertise only a major player can afford. In this context, RFID is generally regarded as the most promising technology providing the required transparency and efficiency of reliable and automated use with minimal labour costs [9]—also this technology started out as an expensive adventure of isolated pioneering solutions, gradually spreading from supervision of durable assets [10] to scenarios with massive material throughput. RFID tags can easily be coupled with sensors [11, 12, 13] that provide information about actual ambient conditions or material status, opening up a new vista of accurate traceability. The adoption threshold for RFID is decreasing and affordable reading devices are becoming available even to consumers (e.g., near-field communication or NFC phones), with associated traceability practices now beginning to penetrate the small-business domain, too [10, 14]. Still, the cost and further aspects of RFID (e.g., not even partial information being accessible without a reader) suggest that optically readable labels are likely to persevere for a longer time in certain areas. This is especially true for "low-end" application or cases extremely sensitive to overhead costs. These previous findings are the key motivation for this paper proposing the integration of optically readable binary code and optically perceptible indicators displaying the freshness or estimated remaining shelf life of individual items.

While some examples of the above synthesis have already been commercially implemented, like CoolVu [15], the complete range of possibilities is far from exploited. The goal of this paper is i) to show that optical alternatives to sensor-equipped RFID are a feasible bridging solution, and ii) to present a map of possibilities with corresponding requirements and limits. It is not purpose of this article to judge which of the technically possible solutions would be preferable in a given application scenario, rather, it is meant to present a catalogue of possible integration principles and implementations along with their key characteristics, so that making a specific choice for a targeted user community is facilitated.

To this end, we first present preliminaries of available optically readable codes (technically suitable to convey digital information as unique identifiers and auxiliary data) and optically perceptible indicators (capable of displaying measured or estimated freshness of perishable items). Hereafter, as the main contribution of the paper, a framework of integration possibilities is presented, with applicability and expected acceptance in selected user groups receiving special attention.

2. Identification with optical symbologies

Commonly used optical identifiers are, in essence, images consisting of regular fields of different colour that can be reliably recognized and mapped onto an interpreted message by a reading device (see Palmer [16], or LaMoreaux [17]). The concept of optically perceptible patterns conveying information was proposed as early as the 1950s by [18], however, practicable implementation of the concept had to wait for 2–3 decades until adequate equipment became available for acquiring and processing the information carried by optical labels. Widespread use, especially of bar codes, began in the 1980s, and since then, the most common type of bar code, EAN13, became a symbol of commerce. Nowadays, the vast majority of optical codes uses two distinct colours only (i.e., reflecting vs. non-reflecting), even though multicolour codes did occur in history [19] and are currently in occasional use with devices (typically camera-equipped phones) that can compensate their low image resolution with good multicolour sensing capabilities, as described by Zhou and Rong [20]. In the paper, we assume a general preference for pure black-and-white codes, however, classification principles of the presented solutions do apply likewise to colour codes as well.

Optically readable codes offer the advantage of automatic data acquisition, i.e., the process of entering data into a computer system is performed automatically, even if some human assistance of positioning or motion may be required for the scanning procedure. This considerably reduces the probability of human error and the need for (skilled) human labour—often, to the degree that identifier acquisition would not be worthwhile at all without such automation. In most cases, the optical codes themselves contain a mere identifier, classifying them as a type of automatic identification (AutoID). The degree of identifier uniqueness (e.g., item-by-item, batch-by-batch, article-byarticle) depends on the nature of the given application: EAN13, for example, only makes a distinction between articles, however, perishable goods exposed to different conditions or belonging to different production batches are likely to require a finer granularity of unique distinction. Optical codes, as many other AutoID technologies, may offer the option of carrying additional data as well—these could be key data of the item, or instructions regarding the interpretation of readings. Nowadays, a wide variety of standards is available for optical codes: various symbologies (i.e., specifications for expressing information as optical patterns of a given kind) allow different levels of unique distinction, different amounts of data stored, different levels of correcting reading errors, etc. As a complete review would transcend the limits of this paper by several orders of magnitude, we only list the most important characteristics of optical codes that must be assessed when implementation and application decisions are made.

- Shape of optical code: 1D or 2D? In the most simple case, optical codes consist of bars of varying thickness or length aligned in a one-dimensional row—these are referred to as 1D code, and can be read in a single scan by any linear reader (wand moved by hand, oscillating scanner moving point of sensing automatically, or line sensor acquiring the code in a single pass). Stacked codes are basically several 1D codes printed above each other—in this case, a linear reader needs multiple passes, while a full two-dimensional imager (essentially a camera) can acquire the entire code in a single pass. Any other form (such as the most widespread