Journal of Manufacturing Systems 40 (2016) 76–86

Contents lists available at ScienceDirect

Journal of Manufacturing Systems

journal homepage: www.elsevier.com/locate/jmansys

A fully yarn integrated tag for tracking the international textile supply chain

Vijay Kumar[a,b,c,*], Ludovic Koehl[a,b,c], Xianyi Zeng[a,b,c]

[a] GEMTEX, France
[b] ENSAIT, France
[c] Université Lille 1 Sciences et Technologies, France

ARTICLE INFO

Article history:
Received 30 July 2015
Received in revised form 19 April 2016
Accepted 12 June 2016
Available online 5 July 2016

Keywords:
Traceability
Textile supply chain
Tracking tags
Yarn coding
Decision support system

ABSTRACT

Textile and clothing industry is one of the classical manufacturing industries which have recently undergone major transformations due to delocalization and high market volatility. In this context, one solution to guarantee the control and optimization of globalized supply chain is the implementation of a traceability system to follow-up the activities of different actors of the supply chain, improve brand value by countering pirate and enhance value creation in reverse supply chain. Therefore, in this paper, we first introduce the idea of fully integrated tracking tags for casting traceability in the textile. Then, as one stage of the traceability system development, we describe a yarn coding scheme to transform a textile structure into a tracking tag. Here, a number of special yarns were coded according to various combinations of optical characteristics. Further, a recognition system was developed for identifying the unique identification yarn code by using different image analysis techniques.

1. Introduction

Globalization has opened possible ways for enterprises to manufacture products, especially textiles, in developing countries due to cheap labor and relaxed environment policies/working regulations, and ship all around the World [1–3]. However, with this spectacular increase in distance between manufacturers and customers, distribution systems have become more complex and keeping track of every product has placed a great demand for right and on-time delivery [4–6]. In today's global competitive and volatile market, offshore suppliers are also required to respond faster to the manufacturers' demands in order to be competitive in the market and reduce the possible production lead-time. Therefore, globalization has led to an open market to undercut the competition with optimized global supply chain and maintaining a rapid communication between suppliers and buyers. Development of various manufacturing processes has realized a fast production with reduced liability on labor for increasing textile and fashion products' demand but at the same time opened possible ways for easy cloning by opponents and counterfeiters. On the other side, exposition of counterfeit products and various unethical practices in production, poor labor conditions in manufacturing countries and consciousness for the environment, consumers are demanding transparency and sustainable products [7–9]. Therefore, the conventional business models standing on the pillars of product cost or quality are not sufficient to compete in today's globally changing business environment. New ways are being explored to satisfy the customers' needs and technologies are being developed for optimizing supply chain, bringing transparency to customers and protection against counterfeits [10].

The adoption of traceability system is a good proposition to handle above-mentioned issues. A good traceability has a significant importance for manufacturers, distributors and consumers in terms of quality control, supply chain organization, warehouse management, market forecast, and product security. It reinforces the communication between different industrial partners, especially when the communication is hindered by geographical separation. Therefore, it can bring more transparency and control over production and distribution systems. The traceability works on tracking unique identifiers assigned to each traceable resource unit [11,12]. Universal product code (UPC), 2-D barcodes and radio frequency identification (RFID) tags are the common unique identifiers. This system relies on enterprise's credibility which ensures the authentic information management, maintenance and delivery of an authentic product to its counterpart or the buyer. Easy replication of above-mentioned identifiers, however, makes an easy break-in to integrate counterfeit products in the supply chain or

* Corresponding author. Present address: University of Borås, Skaraborgsvägen 3, 501 90 Borås, Sweden. Tel.: +46 33 435 45 72.
E-mail addresses: vijay.kumar@ensait.fr, vijay856@gmail.com (V. Kumar).

http://dx.doi.org/10.1016/j.jmsy.2016.06.007
0278-6125/

directly in the market [13,14]. Therefore, identifying counterfeit textile products has become increasingly difficult. Detachability of identification tags is another issue which opens possible ways for losing the product in supply chain and a breach in well-managed traceability system. The covert identifiers integrated into textiles such as integrated RFID tags minimize the separation possibility from the textiles but their disposal cause severe impacts on the environment [15]. Therefore, development of cost-effective, easy to manufacture, reliable, electronic chip less and secure marking or tag in the integrated form for textiles has become the interest of many researchers.

Securing product based upon product's inherent features is a good proposition to fight against counterfeit and other earlier-mentioned threats since it does not add extra cost and accessories to the product [13]. In the similar way, the structure of woven fabrics has been utilized by many researchers to transform them into traceable label [16–18]. A textile consists of yarns as a basic building block; therefore, optical features based yarn in a textile structure opens possible ways for generating yarn based integrated tags [19]. Further it opens the scope for casting traceability in the product itself, which is a common practice in many fields (for example [20]). Yarns in woven textiles appear in two sets of perpendicularly interlaced yarns, known as warp and weft. Yarns in a set appear nearly parallel to each other. Whereas, (weft) knitted textile structures are made by interlooping of yarns with each other, and the loops for a yarn appears linearly along the wales or fabric width. The use of yarns with foreknown optical features can be used as a traceable marking, where the optical/visual stamp generated by optical-featured yarns can be used as traceability code for the textile. Therefore, in this paper, we propose a methodology for yarn coding based fully integrated tracking tag for textiles. Here, yarns are coded based on multiple optical features and it is anticipated that weaving or knitting in a particular sequence can create a numeric token for traceability system which can be used as an original product identifier and information recalling signature in the supply chain and on the consumer end.

2. Literature review

GS1 global traceability system [21] defines traceability as "*the ability to track forward the movement through specified stage(s) of the extended supply chain and trace backward the history, application or location of that which is under consideration*." In sectors like agri-food, government regulations have pushed various organizations to adopt traceability system for providing guaranteed healthy product. Whereas, sectors such as textile and fashion, implementation of traceability is motivated by customers' expectations and economic incentives associated with lower cost distribution systems, reduced recall expenses and brand protection [22,23]. A traceability system is a management system permitting to identify and track the unique identification code assigned to each product. The unique identification code acts as a token for storing or retrieving data from a product data management system which is accessible to manufacturers/distributors and consumers. The widely used tags for traceability applications are as follows.

2.1. Barcodes

Barcodes are the printed machine-readable patterns used for the data representation. Due to the low manufacturing cost, and easy and robust readability, they are widely used in many commercial applications including in-house production management, supply chain management and in supermarkets. Since the unearth of first barcode developed by IBM named 'Universal Product Code' (UPC) which is, in general, capable of encoding 95 bits [24] with unidirectional data representation, bidirectional or 2D high data encoding capacity barcodes [25] have been developed and widely used in many commercial applications. However, owing the possibility of easy cloning and implementation [14], these codes are problematic in counterfeit detection and brand protection for textile products [13]. Nevertheless, barcodes have been proven very useful in production management, warehousing and logistic applications.

2.2. Radio frequency identification tags (RFIDs)

An RFID tag contains electronic microchip and antenna coil. Electronic chip holds the memory of the tag and the antenna coil powers the chip by electromagnetic mutual induction coupled with the receiver or decoder and transmits back the identity encoded in the memory. Delivering non-contact and covert read and write capability with large data capacity, RFID tags find applications in textile production and supply chain. Recently, integrated RFIDs have been explored with the direct encapsulation on fabric surface [26]. Similarly, RFIDs have been incorporated inside the seam so that they could stay with fabric for post selling 'intelligent' applications [27,28]. However, the requirement of dedicated devices for decoding hinders its reach to the wider public. Cloning and easy implementation make them questionable to use in anti-counterfeit and brand protection. Data encryption techniques have improved the RFID protection at the cost of increased size and implementation cost [29,30].

2.3. Magnetic barcodes

Magnetic barcodes are similar to the printed barcodes (or UPC) except the variant width printed lines are replaced with spaced magnetic elements. For decoding, the position of each magnetic element is identified remotely for precise location and response using magnetic sensing technology [31,32]. Thin size and resistance to heat and pressure make magnetic barcodes suitable to use with products and packaging during manufacturing [32].

2.4. Miscellaneous techniques

Microtaggant® developed by 3M is another tagging technique, initially designed for explosive testing, finds popularity in counterfeit medicine detection (www.microtaggant.com). In this technique, the arrangement of highly cross-linked melamine plastic particles with multiple stratified layers of different colors are translated into a numeric code for counterfeit detection. Cloning is deterred by highly complex replication manufacturing process. More recently, anisotropic optical characteristics of highly oriented polymers have also been explored to form a tracer fiber or pattern under polarized light [33,34]. Organic chemical marking of fibers is another proposition for anti-counterfeiting at the cost of sophisticated testing instruments. Covert and invisible taggants or inks responsive in a specific wavelength of light or heat or other conditions are another class of signature developed to fight counterfeit [35].

3. The proposed textile fully integrated tracking system

Textile and clothing industry is organized by a number of worldwide spread supply-chains, each comprising diverse partners such as fiber as raw material manufactures, yarn spinning mills, weaving and knitting mills, dyeing and finishing factories, apparel manufacturers and retailers. For a meaningful information exchange between different partners, a unified information sharing scheme is required which is hindered by lack of explicit semantics and contexts in knowledge sharing through product data management