Identification of Fibre Composition of Apparel for Recycling

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Abstract

We present the results of a recent review of fibre identification technologies for apparel recycling. The review focuses on tagging and labelling approaches that can help apparel recyclers identify the material composition of the recycling grades of apparel, in preparation for the introduction of more material-specific recycling technologies. We conclude that the adoption of the 2D barcode linked to an external database will both contain sufficient bits to encode useful information, and that such an approach could also give consumer (and hence brand) benefits that would help make the business case for their introduction.

Introduction

Increasing knowledge about the environmental impact of apparel has driven a desire by societies and policies by governments to collect and recycle or reuse a greater proportion of discarded apparel. Greater collection is likely to lead to a higher proportion of lower quality grades only suitable for materials recycling. In addition, brands and retailers would like to offer closed loop products or more materially circular business models in contrast to the existing recycling approaches. These two trends are driving development of fibre-specific recycling technologies for materials such as polyester and cotton. In order to implement these, improved methods of identifying the composition of apparel are required. In addition, virtually all textile sorting is carried out by hand, and it is useful to assess whether technology is able to reduce this cost. The study on which this paper is based was commissioned by the UK Waste and Resources Action Programme to support the UK Sustainable Clothing Action Plan. It comprised a desk-based review of existing techniques and also those under development, supplemented by interviews with practitioners, researchers and technology providers.

The existing sorting and recycling system has been described for example by Hawley (2006a, 2006b, 2009). A review of commercial textile fibre recycling technologies is by Thompson et al. (2012). Further overviews from the perspective of fashion companies are by Caniato et al. (2012) and Hvass (2014).

Scope of Technologies Examined

We investigated tagging and sorting techniques which are available on the global market. Whilst the four main types evaluated are described in greater detail below, these were considered the most viable of a range of chemical identification methods (Table 1) and machine-readable marker technologies (Table 2).

Attribute	Technology
Enthalpy	Differential scanning calorimetry (DSC)
Pyrolysis (evolved gas)	Thermogravimetric analysis (TGA) Gas chromatography / mass spectrometry (GCMS)
Reflection spectrometry	Infra-red (FTIR) spectrometry Visible-ultra violet (UV-Vis) spectrometry X-ray fluorescent (XRF) spectrometry Hyper-spectral imaging
Solubility	Acids and alkalis Organic solvents

Table 1 Chemical identification methods

Domain	Technology
Physical	Present (e.g. dummy button) Absent (e.g. punch card)
Electronic	Contact (aka chip-and-pin) Contactless (radio frequency identification, RFID) Contactless (RFID chip-less)
Magnetic	Magnetostrictive (e.g. security tag) Stripe (e.g. airline boarding card) Electrostrictive Magnetic ink character recognition (MICR)
Optical	Character/symbol recognition (label reading) Bar code / matrix code Optical mark reader (OMR)
Chemical	UV/fluorescent stain (e.g. envelopes)
Nano	Engineered DNA Smart water Quantum dots Nano particle signature

Table 2 Machine-readable marker technologies

We also evaluated their cost-effectiveness and minimum economic scale for the additional purpose of reducing the cost of sorting discarded textiles. This involved analysing existing information on the commercial use of these techniques in the textiles sector, and extending the analysis to the specific application of textiles reprocessing. Where necessary, consultation with textiles reprocessors, technology providers, logistics experts, retailers, academics and other industry stakeholders was undertaken.

The economic analysis required many estimates and assumptions to be made; in particular, that technology can be used to sort all textiles in the waste stream. In practice, this level of utilisation will take many years to achieve. The approach taken was as consistent as possible so the technologies could be compared relative to each other.

Technologies to identify textiles

A number of technologies exist that can be used to identify textiles as they pass through a reprocessing facility. There were four candidates:

Manual sorting. This is the incumbent technology. Using this method it is only possible to separate textiles by parameters that humans can detect by sight and touch. Consequently the description of the output bins is limited in colour, comprising a subjectively-assessed spectral range and not necessarily the original dye colour; in fabric, with broad categories, such as leather, wool, cotton, denim; in quality, for example whether the textile is worn, damaged, repaired, soiled etc.; in style, such as shirt, dress, socks, child etc.; in brand, particularly for denim; in complexity of textiles, because of the use of various fabrics and materials in different areas of the garment; and finally in the more unusual nature of the garment, such as vintage, or wedding dress.

Fourier transform infra-red spectroscopy (FTIR). FTIR is one of a family of hyper-spectral imaging techniques. It is potentially able to determine the colour and fibre content of a textile. However, it has not yet been developed to the point where, under real operating conditions, it discriminates significantly better than a skilled manual sorter. Unless this technical ability is enhanced, FTIR is best viewed as a useful augmentation to manual sorting, since it can refine some of the steps of sorting by fibre type and colour, and hence add value to those output streams.

Radio Frequency Identification (RFID) Tags. An RFID tag can be thought of as a "wireless memory stick" that can carry data and which can be remotely read. The tag is attached by the manufacturer and travels with the textile throughout its life. The tag contains a precise description of a textile, which can include items of complex construction. On arrival at the reprocessor the tag can be read, permitting sorting of the textile to an appropriate bin. The very high specificity of sorting possible means that the waste stream can be processed dynamically to achieve best value. Low cost and non-intrusive RFID tags that can survive multiple laundry cycles do not yet exist, and tag readers will require modification - which may or may not be possible - to guarantee association of one tag with one textile during interrogation of the tag.

Bar codes. A two dimensional (2D) bar code label can also carry information about the textile to instruct a sorting process. In this instance, the black and white pattern of the label is read by camera and decoded by computer. Work is required to identify the most appropriate data format for the bar code and to verify that labels will remain machine-readable at the end of the use phase of the textile. Where the bar code directs the consumer or reprocessor to an external link, the associated databases, mobile phone applications (Apps) and web landing pages all need to be written and managed.

Sorting method and equipment

Each of the candidate sorting technologies is based on a different sorting method as shown graphically in Figure 1. Manual sorting uses a multi-stage tree sort (1: M: N), where each stage has between five and eight parallel outputs. FTIR and RFID use a 1: N topology where each item is interrogated in turn and directed to the desired output bin in a single step. Bar codes also operate on a 1: N topology, except that, due to the slowness of interrogation, multiple stations feed single sorting equipment. Thus the topology is better described as M:N. This means a bar code sort can be combined with a manual sort, but FTIR and RFID require the process flow to be configured differently to accommodate these identification technologies.

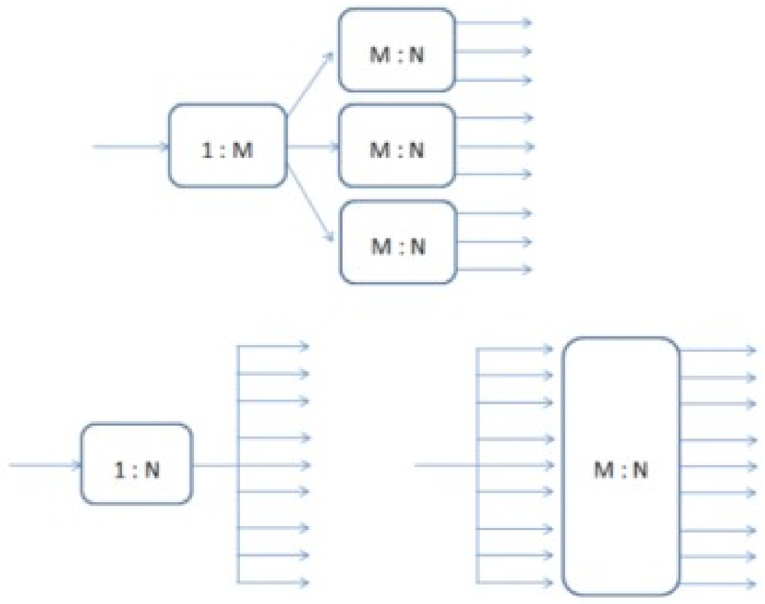

Figure 1 Textile sorting topologies

In manual sorting, the operators place or throw items into the appropriate bin or chute. The most widely used automated equivalent is by ‘blowing’ using a jet of compressed air. To be effective it is essential that the textiles are ‘singulated’ (separated into single items). Because textiles can easily become tangled, any singulation by machine is always supplemented by a human operator.

Another sorting criterion only humans can undertake is determination of quality; this step, together with removal of non-textile items from the waste stream, must be conducted manually.

Economic evaluation

Manual sorting was used as the base line for comparison. For a facility with a capacity for 16,500 tonnes per annum, operating on feedstock that has been 100% converted to the technology being utilised, the findings are summarised in Table 3, using UK market values current in early 2014.

For completeness, also included in Table 3 is the cost of the marker (applies to RFID tags and 2D bar codes) and the cost of attaching the tag or label to the textile.

Manual sorting is the most expensive, least accurate and lowest resolution option. However, only manual sorting is able to remove non-textiles, to separate the textiles as single items and to ascertain their quality. Manual sorting is the only method that is able to assess quickly whether a garment is likely to be suitable for reuse rather than for material recycling, and is therefore likely to remain important in textile sorting, given the much higher prices obtainable for reused compared to recycled garments. Therefore these steps must still be done manually as part of any automated sorting process and are included in the cost models. An important assumption of using RFID and bar codes is how much labour can be displaced and if information such as the age of a garment can be used as a proxy in order to replace human judgement in the reuse/recycle decision.

The ability of FTIR to sort only by fibre type and colour limits the range of textiles to which it can usefully be applied. The main application is likely to be sorting wiper and recycling grade material, potentially securing higher value for this stream owing to the greater precision and accuracy of output. This restricts the economic benefit, since only around 20% of the textile stream passing through reprocessing facilities is of these grades.

Parameter	**Technology**			
	Manual	**Manual + FTIR**	**RFID**	**Bar code**
Labour, £/tonne	200	160	70	70
Capital requirement, £k	Inc.in 'Labour'	424	645	1120
Running cost, £/tonne	Inc.in 'Labour'	5	7	6
Feedstock, £/tonne	550	550	550	550
Sales price, £/tonne	780	785	785	785
Profit, £/tonne	**30**	**70**	**155**	**150**
Margin, % of sales price	**4**	**9**	**20**	**19**
Marker cost, £	0	0	0.50 – 0.75	0.01
Marker attachment cost, £	0	0	0.02	0.02

Table 3 Economics of sorting technologies for full adoption of technology

Economic evaluation of the business case for RFID tags and bar codes is more uncertain since neither technology has been developed to operate in this environment, necessitating a number of assumptions to be made over important variables like capital cost and throughput. The high capital cost of 2D bar codes stems from the slowness of the associated manual handling to find and present the bar code label to the reader. Thus a large parallel operation is required to achieve the same throughput as the other options. Despite this, both RFID tags and 2D bar codes are economically favourable compared with manual sorting and manual sorting supported by FTIR in a case of full adoption of this technology. Since a mixed scenario of part-barcode or RFID/part-uncoded is the most optimistic scenario, the capability for manual sorting needs to be retained alongside automation. This favours either the FTIR or bar code solution.

Stakeholder perspectives

Using knowledge of the capabilities of the technologies, we have described the expected perspectives of the five key stakeholders, the manufacturer, logistics chain, retailer, consumer and reprocessor towards each technology may be summarised in the flag chart given in Table 4.

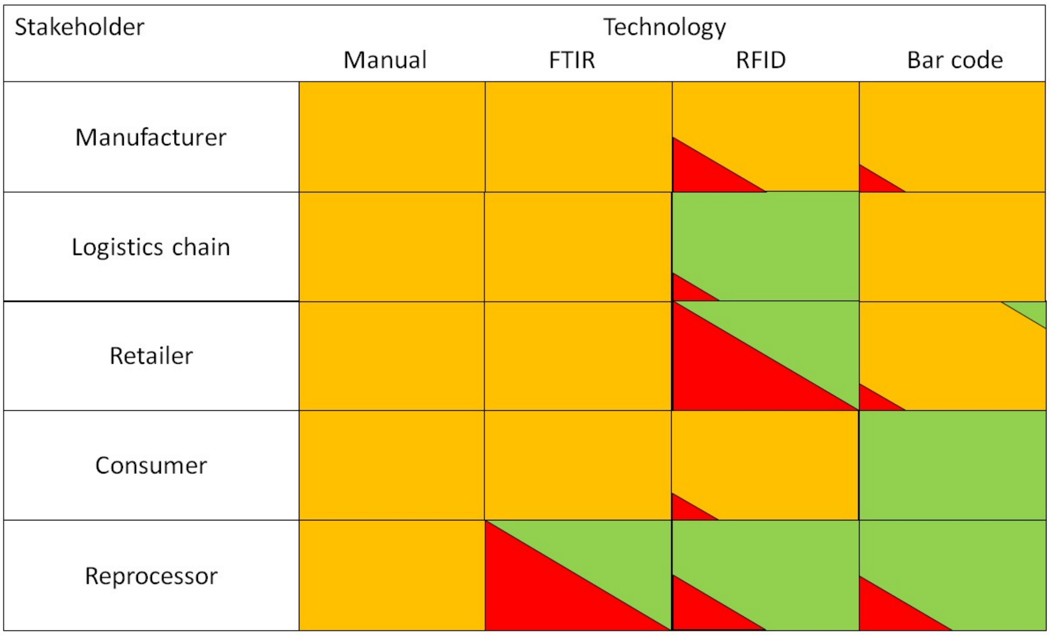

Table 4 Traffic-light viewpoint of stakeholders towards each technology

Green = positive, Amber = neutral, Red = negative

Manufacturer: **o**nly the two technologies, RFID tags and bar codes, should be of concern to the manufacturer. Both have negative consequences since they require marrying a tag or label to an item. This means a control system will be required to ensure textiles are correctly marked, plus a quality system and corrective action process to detect and rectify errors. Managing the supply of markers to the factory represents an addition cost and an additional cause of delay and reason for holding work in progress. RFID tags have potentially greater negative impact since they are more likely to be used for item-specific tagging, and therefore require more detailed management than 2D bar codes that will probably be used for batch-level marking.

Logistics chain: the only technology that should benefit the logistics chain is RFID tags. Because textiles are uniquely tagged, item-level tracking from the manufacturer to the point of sale is rendered possible. RFID tags can be remotely interrogated *en masse* and this makes it possible to determine the contents of a volume, such as a carton, without opening it. The supply chain will need to invest in hand-held RFID tag readers and suitably equipped gantries and doorways to make full use of the technology. Although the use of RFID is increasing for manufacturing and supply chain reasons, the tags are not designed to last the lifetime of the garments. To extend the life and to manage the data past the retail stage requires major reductions in the cost of washable RFID tags, as well as further developments in technology to reduce size and intrusiveness.

Retailer: the retailer should be essentially ambivalent to manual sorting, and manual sorting supplemented by FTIR, since they provide no direct benefit. But, neither do they involve any cost. RFID has high cost but potentially high benefit since it permits item-level tracking through the supply chain to the point of sale, and potentially to the textile's end of life at the reprocessor. Bar codes incur a smaller cost that might be offset by intangible benefits including corporate social responsibility and the intriguing potential of a new marketing conduit to consumers.

Consumer: there is an expected issue with RFID tags over privacy of information. Consequently a small flag in Table 4 is set to red for this technology. Bar codes are the only technology where there is scope for interaction with the consumer. Many styles of 2D bar codes can be read by smart phones, so, when combined with an App, it should be possible to provide the consumer with local information on how to dispose of a textile when it is no longer wanted. This may include retailer take-back schemes and other incentivised options and marketing opportunities. The 2D bar code also could carry a link to a web page managed by the retailer, facilitating targeted marketing.

Reprocessor: all the identification technologies will involve the reprocessor in some capital and set-up cost. To a first approximation these are similar for all cases, but RFID tags and bar codes deliver faster return by being applicable to all (marked) textiles in the waste stream.

A key difference between RFID tags and bar code labels is that a sorting facility based on reading bar codes could also be operated manually, with the operator entering a short code on a keypad based on his/her assessment of the textile[1]. This would be beneficial in the transitional phase while technology is introduced over several years and the proportion of textiles marked by bar codes slowly rises.

Recycling organisations, such as charity shops, would also benefit from the availability of RFID tags or bar codes on textiles, since the presence of an in-built identification number and

[1] http://www.youtube.com/watch?v=Pl7H7JAtnl4

product description would assist both the sorting process and store management (inventory management, pricing, and gift aid reclamation). Charity shops already use the ISBN code on books for this purpose.

There is a general concern of the recycling industry about possible future contamination of apparel received by it with wearable electronics, and RFID tags would form part of this concern unless they can be shown to have a benefit to the recycler.

Conclusions

Manual sorting of textiles operates successfully, but at a small profit margin. FTIR can only sort by fibre type and colour, limiting its applicability, but can be implemented by a textile sorter without involvement of the manufacturer or retailer. RFID tags and 2D bar codes can sort by any level of description that can be encoded. Economic models suggest the capital and running costs of sorting by RFID and 2D bar codes could be easily recouped through reduced operating costs and by targeting higher value markets for recyclates once the proportion of marked textiles in the waste stream is very high.

None of the technologies is yet developed to the point of being usable for this application. FTIR works to date only for a restricted range of colours and fibre types, and has proved difficult to implement commercially, while low cost RFID tags will not survive the laundry cycle and tag readers able to interrogate tags on single items in a batch have not yet been developed. Bar code labels that remain readable at the textile's end of life are currently unproven, but can probably be developed without major investment.

Machines capable of handling the sort stage of textile recycling are available commercially. Generally they comprise a linear conveyor with perpendicular diverters operated by compressed air. The sort command is currently derived from a code manually input onto a keypad, but this could be easily changed to an RFID tag or bar code reader. Because this approach to sorting could be enhanced simply by changing one part of the process, the existing operational textile sorting systems could easily be rendered capable of sorting simultaneously into hundreds of output bins.

Further Opportunities

FTIR identification can be developed further in order to make identification more robust and with greater sensitivity and speed[2].

Laboratory trials for the durability of bar code labels and their subsequent readability at the projected end of life would be a first step towards testing this approach. The additional benefits to the consumer of a 2D bar code on the packaging or on the product in order to provide additional consumer information could be tested to determine how attractive these are. Above all, implementation of a common approach has to be considered by a group of brands and retailers representing a significant proportion of a country's sales, in order to make investment by textile sorters an attractive alternative to manual sorting of recycling grades.

[2] For example, the IDENTITEX project funded by the EU Horizon 2020 research and innovation programme http://www.2020-horizon.com/IDENTITEX-Innovative-technologies-for-the-economically-sound-identification-and-sorting-of-post-consumer-textile%28IDENTITEX%29-s56036.html

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