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Digitalization in the sorting process for garment recycling

BY

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Abstract

Textile recycling becomes increasingly important to address the sustainability transformation of the garment sector. It holds the promise to reduce negative ecological impact by reducing waste incineration, land use and resource extraction for new fibers for garments. Within the European Union, an official directive requires all member states to collect textile waste – including worn garments – as a separate waste stream starting in 2025. As the aim is to increase recycling and reduce incineration of textile waste, research and technology development aims to improve the whole recycling processes. One step to increase the economic feasibility of fiber recycling is improving the sorting process of worn garments. Automation and digitalization technologies, such as near infrared (NIR) spectroscopy for analyzing the raw material compositions, fiber markers, QR codes, and radio frequency identification (RFID) chips to store information of raw materials and finishing agents are currently discussed and analyzed. We tested the potential of an automated sorting process using NIR-spectroscopy by sorting postconsumer garments according to their fiber compositions with a manual NIR-spectroscopy device. The yield rate in terms of sorting to correct fiber composition categories depends on the fiber composition library, which is built. We compared single-layer garments and multi-layer garments, such as coats with linings and provide suggestions in terms of how to increase the yield rate.

Keywords: Textile recycling, RFID, digitalization, near infrared spectroscopy, automated sorting, circular textiles

Introduction

The transition towards sustainability of the fashion and garment industry requires each step of the value chain to transform from raw materials over processing fibers into fabrics and apparel, including dyeing and finishing, but also design, logistics and sales, as well as the end-of-lifetime treatment. A popular approach to address sustainability issues are circular economy concepts (Korhonen, et.al, 2018). Textile recycling is one of the circular approaches to process postconsumer waste into new resources and by this reduce extraction of new raw materials.

A large number of fashion brands, such as the Swedish Corporation H&M have committed to increase their use of recycled fibers (Textile Exchange, 2023). This led to a major increase in recycled polyester fibers originating from recycled beverage bottles, as recycling of postconsumer waste polyester garments into high quality grade fibers is still challenging (Radhakrishnan, et.al, 2023). So far, recycled polyester fibers based on textile waste are only available on small pilot scales (d'Ambrières, 2019). However, the packaging industry as a source of recycled polyester does not address the issue of garment waste.

Within the European Union, an official directive requires all member states to collect textile waste as a separate waste stream – equivalent to paper and glass – starting in 2025 (EC., 2018). Hence, policies aim to increase recycling and reduce incineration of textile waste. So far, for garments virgin (new) fibers are in general cheaper than recycled fibers. Garments consists often of fiber combinations and may include further dyeing and finishing auxiliaries as well as accessories and haberdasheries, such as zippers and buttons, which makes recycling challenging. At private businesses and at public research institutes, research and technology development aims to improve the whole recycling processes, to provide cost-efficient solutions. A promising approach is to improve the sorting process, as the fiber composition are important information to recycle them adequately, especially for chemical and biological recycling.

Recycling of worn garments still includes high amounts of manual labor for sorting. Automation and digitalization technologies bear the promise to radically improve and speed up sorting, hence, make recycled fibers economically competitive with virgin fibers (Eppinger, 2022). One technology that is already successfully applied in plastic waste sorting is near infrared (NIR) spectroscopy.

In the following, we provide in the short review current technology solutions for improving sorting of worn garments. The benefits of NIR spectroscopy in sorting are explained. The method section describes our test materials and the NIR spectroscopy device. The discussion highlights the advantages of automated NIR sorting, namely it reduces labor and sorts of garments according to fiber material at higher speed. On the other hand, only partially automation with the manual device increases the precision of sorting, especially for processing multi-layer garments and garments with extraneous materials such as prints, beads, finishing agents, and accessories. Accordingly, fully automated NIR sorting requires careful preparation of the input streams or several NIR sorting lines to enable high yield rates.

Review of technologies for postconsumer textile waste sorting

The fiber blends of worn garments can be recycled into mechanically or chemically bonded non-wovens for insulation and damping matting, for applications in construction. Mechanical recycling is rather nonsensitive to fiber blends. However, in cases where textile recycling targets fiber processing for new garments, it is obligatory in some countries to know the fiber compositions and declare them in the garment. Besides, for dyeing and finishing it is important to know the fiber composition.

Besides mechanical recycling, chemical and biological textile recycling methods become popular. These methods promise to extract dyestuff and other auxiliaries and process textile waste into new fibers with properties comparable to new fibers (Yuksekkaya, et.al, 2016; Ribul, et.al, 2021). Accordingly, high quality postconsumer textile recycling that enables chemical and biological recycling of cellulosic fibers, of polyester, or of cotton/ polyester fiber blends requires careful sorting.

The fiber blends of industrial textile waste and preconsumer garment waste are usually documented. Postconsumer textile waste, such as worn garments do not provide sufficient information about the fiber material content. During usage, labels that declare the fiber composition get cut out or the printing fades. Furthermore, garments can be mislabeled. A study of more than 7000 apparel pieces available at the Dutch apparel market showed, that only about half of the garments (54%) were correctly labeled within the 5 % margin of allowing inaccuracy, e.g., other fibers (Wilting, & van Duijn, 2020). While some garments are produced with only one fiber material (e.g., cotton shirts, polyester track pants), a huge amount of apparel consists of fiber blends to combine properties. To name some examples: elastane provides elasticity, adding polyester to cotton to increase abrasion resistance and decrease costs; or blending wool with polyacrylics for the same result of reducing costs, increasing longevity by higher abrasion resistance and improved washability. As the percentages of blends vary, and with labels often missing or not readable when garments are disposed, sorting postconsumer textile waste is particularly challenging.

Fibers can be analyzed through visual and chemical methods. However, as many textiles consists of fiber blends in different yarn constructions, e.g., blended as staple fibers or mixed as core spun yarns, to enable precise analysis of the fibers, the fibers need to be disentangled and individually separated from the yarns. Because these methods for determining fibers are not cost-efficient for sorting, there are currently a number of technological solutions proposed and tested. These solutions differ in terms of complexity of integration in the value chain and whether they can already be used for textile waste sorting, or if they need to be introduced in the fiber, fabrics, or garments, hence, only provide value in the future if applied broadly. The different technological solutions to support fiber identification are categorized in Table 1, whether they are for future waste streams – when markers or labels have to be included first – or applicable to current postconsumer garment waste streams.

Chemical markers for fibers and yarns enable to provide information using special chemical detection methods, depending on the marker material, such as fluorescent lamps and UV-sensors (Peek, & Swiegers, 2012; Gaynor, et. al, 2015). Businesses promote them as “DNA” markers (Proneem, 2022; ADNAS, 2022). They can be also combined as cryptographic markers with block chain technology to increase traceability of supply chains and prevent fraud (Agrawal, et. al, 2021; Agrawal, et. al, 2016), e.g., for luxury brands or expensive, branded fibers (Ahmed, & MacCarthy, 2021). Recent developments also show fibers that contain all necessary information, which can be included in the yarns and sewn into the garments (Iezzi, et. al, 2023).

NIR spectroscopy uses the physical principle that certain molecules absorb light in the infrared region of the electromagnetic spectrum and reflects the remaining wavelengths. This absorption and reflection is specific to the bonds between atoms present in the molecule. With a NIR spectrometer, the reflection of the infrared light by the sample material is measured as a function of the wavelength. Such NIR sensors are usually distributed over sorting conveyor belts. After identifying the reflection of a material, they automatically convey it to the appropriate material fraction. Accordingly, the technology does not require specific treatment of the fibers or garments in advance and can be used for current postconsumer textile waste. Thus, giving it a high potential for the application in textile sorting (Iezzi, et. al, 2023).

QR codes can be applied to labels. Each code contains material data that can be accessed by scanning using an application. They represent a cost-efficient method and thus one of the most effective methods of recognizing textile fibers during the sorting process. However, they hold the disadvantage that the code is washed out already after a short period of use and a few washing cycles. Accordingly, it is only interesting for specific applications in lease businesses, e.g., for work apparel.

Table 1. Technologies to improve fiber identification

Technology	Only for future waste streams (insert in fiber or label)	Applicable for current waste stream
Markers (in fiber or as fibers)	X	
Block chain (in combination with markers)	X	
NIR-Spectroscopy		X
QR Codes	X	
RFID tags	X	

Radio frequency identifier (RFID) chips are usually applied to either packaging or a hangtag. They can also be sewn into the seam of joints of garments. Any information can be allocated to the identifier. Accordingly, they can provide information about the type of fiber and the appropriate recycling route, but also supply chain information, lifetime and cleaning cycles. RFID is a technology used for textile sorting systems in shops and warehouses, but also at textile leasing businesses.

It requires the use of readers. Although RFID technology is claimed to be an inexpensive technology, for garments which are rather price-sensitive products it poses an extra cost. Furthermore, it is not particularly cost-effective in terms of recycling, as it is usually used for newly manufactured textiles (Niinimaki, and Karell, 2020). This means, that it is a practical solution for work apparel, linen and towels, e.g., at hospitals, health care, gastronomy and hotel sectors where apparel and textile products which are cleaned and recycled in closed loop systems. For dealing with textile waste from communal collections and containers with a huge mix of worn apparel, it does not appear to be a cost-efficient, practical solution, given the global sourcing of apparel and textile products.

Methodology

For testing sorting with a NIR device, unsorted postconsumer textile waste was used. A total of 600 kg of postconsumer garments, disposed in garment collection systems, were sourced from two regions in Germany: From the North near Bremen and from the South near Munich. The textiles are pre-sorted into three different categories: (a) single layer textiles consisting of one fabric, (b) multi-layer textiles – such as coats, jackets and skirts with lining, and/or paddings consisting of different fabrics, and (c) shoes, bags and others, allowing for a smoother NIR sorting process.

For the textile sorting with NIR spectroscopy, a handheld NIR device was used: “EVK HELIOS EQ32”, manufactured by EVK DI KERSCHHAGGL GmbH, Graz (Austria). The device operates in the NIR spectrum between 930 – 1700 nm and has a resolution of 312 pixel (30 x 30 µm) (EVK DI KERSCHHAGGL GmbH (Hrsg.) EVK HELIOS EQ32, Aug. 08 2019; EVK DI KERSCHHAGGL GmbH: EVK HELIOS EQ32, Aug. 04 2019). It was mounted over a sorting table. The garments were manually placed underneath the device for analysis.

Aside from the material composition of the sample, additional attributes like type of clothing, weight and accessories or haberdashery were recorded during the manual sorting process. Especially the accessories and haberdashery attached to a garment can impact its recyclability and act as contaminants during the recycling process. **Figure 1** (not presented in this document) pictures the outline of the NIR-aided sorting process applied in the study.

Before material analysis can be conducted via NIR spectroscopy, a database has to be trained. NIR spectroscopy compares and matches the current sample with its database to determine the material composition (Manley, 2014). Therefore, an accurate database is essential for material analysis with NIR spectroscopy. A custom database was built with a software complementary with the used NIR device. A total of 33 samples were analyzed and saved to form the database used for material analysis. To ensure the accuracy of the database used for the manual sorting, the fiber composition of six random samples were analyzed through solution tests based on DIN EN ISO 1833.

Figure 1 (not presented in this document) details the process of the NIR sorting. The items were smoothed out and folded if necessary to fit onto the conveyor belt. The NIR analysis was performed and afterwards for documentation purposes to gain better insights into the apparel, the accessories such as zippers and buttons were recorded in detail, the weight of the garments was recorded with a precision scale and documented. -

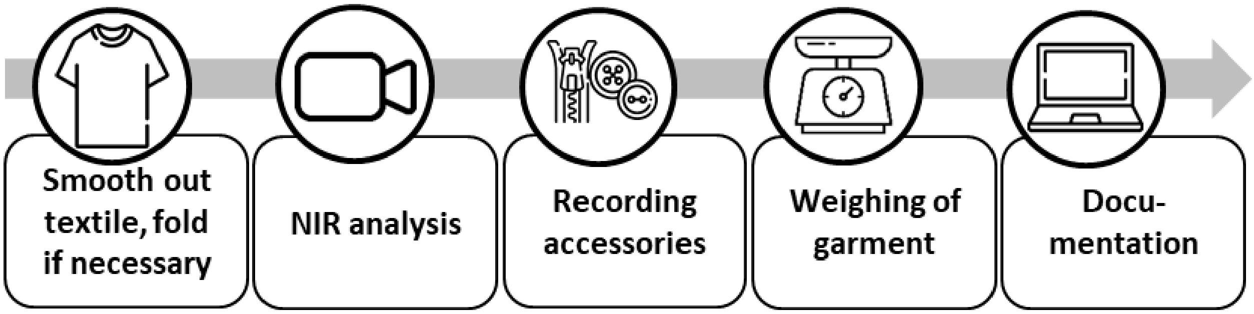

Figure 2: Process of conducted NIR-supported sorting. Source: Own depiction

Results and Discussion

After the removal of bags, shoes and various other contaminants, a total of 506 kg of textiles were left, resulting in 2309 garments suitable for the test. Out of those textiles, 87 % (2.011 garments) were single layer (SL) garments, such as shirts, pants, underwear, jumpers, and 13 % (298) were multi-layer (ML) garments, e.g., coats, jackets and skirts with lining, and paddings.

a. Results of fiber blends analysis of garments with NIR Spectroscopy

A total of 0,38 % of all 2309 analyzed garments were NIR inactive. Hence, the determination of the material composition was not possible. This might be due to the usage of certain chemicals, dyestuffs or other finishings. An analysis of these items may reveal more insights into why they were not detectable.

On 68,5 % of all analyzed SL garments was at least one type of accessory or haberdashery present. Especially buttons, zippers and other accessories like elastics were recorded. Apparel without any non-textile attachments such as buttons and zippers are e.g., T-shirts, jumpers, underwear and dresses. 92 % of analyzed ML garments were recorded to have at least one type of accessory. The few ML garments without attachments are e.g., slip-on dresses with linings. On most of the garments, more than one accessory was present, resulting in a wide range of different possible combinations. In this study, one sample could have up to three different accessories, but samples with even more were found. Up to 76 different combinations were recorded for SL garments.As pictured in Figure 3, about 37 % of the analyzed SL garments consisted of fabrics made from cellulosic materials (e.g., cotton, viscose, linen) and 9 % of garments were made from fabrics with a polyester content of at least 95 %. As expected, due to the popularity of fiber blends in garments, about 43 % of all analyzed SL garments consisted of fabrics made from at least two different types of fiber. The most common fiber combination was cellulosic fibers and polyester, with blends of different fiber type percentages. The remaining 11 % of SL garments are composed of other materials. For ML garments, both layers of textile have to be analyzed separately. Figure 4 pictures the different material compositions of the two recorded layers. Especially the inner layer of ML garments is composed to 49 % out of fabrics made from at least 95 % (95+ %) polyester while the material composition of the outer layer is more diverse. This is not surprising, as typical linings are polyester fabrics or at more formal garments' acetate, while the outer layer is made out of natural or manmade cellulosic fibers, or wool and synthetics.

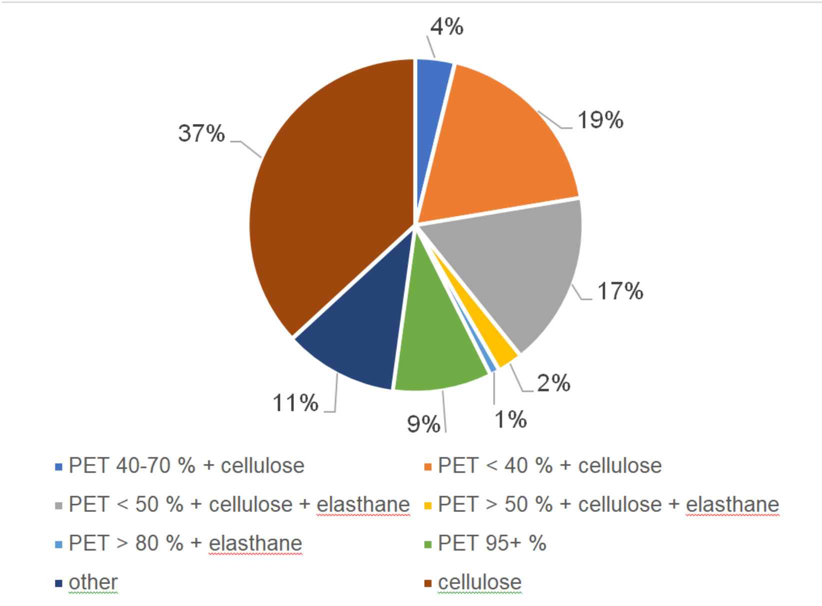

Figure 3. Material compositions NIR sorting of single layer garments Source: Own depiction

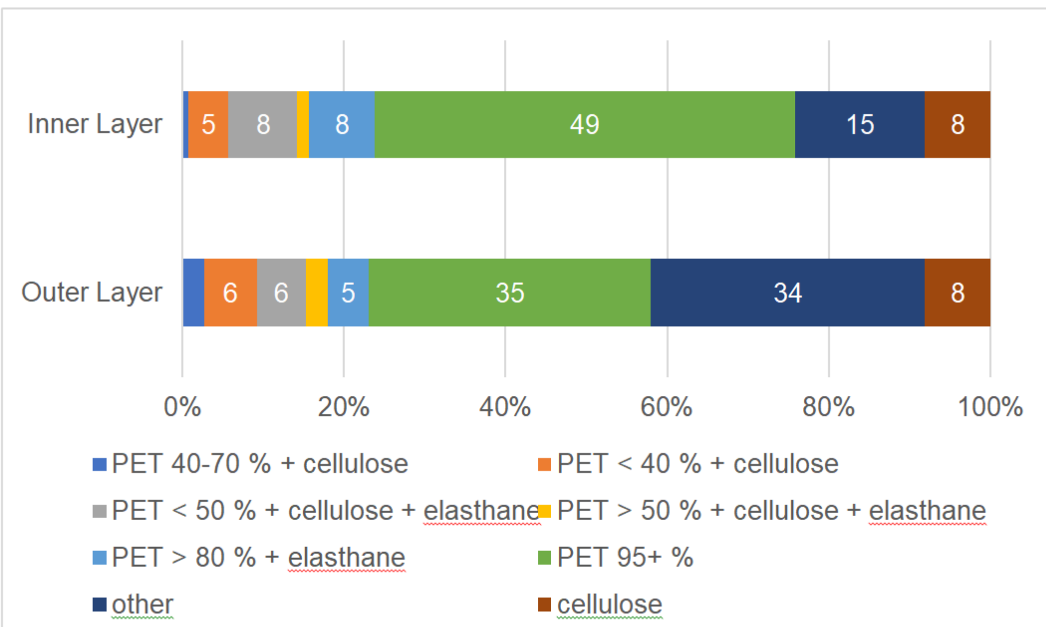

Figure 4. Material compositions NIR sorting of multi layer garments Source: Own depiction

b. Discussion: – Improving postconsumer textile waste sorting with NIR Spectroscopy

The fraction of unidentified fiber blends with 11,5 % can be considered high but is probably due to the library that we set up. Notably, for building the library, 33 garments of different fiber blends were used but only six were analyzed. Analyzing all 33 samples might have resulted in less unidentified fiber blends.

Also, more categories could have been built. Again, depending on the purpose of sorting, the library has to be built and the categories should be defined accordingly.

When identifying the fiber composition, it is important to scan the fabric and not accessories or prints. Accordingly, during fully automated sorting without careful preparation of the garments that are placed onto the conveyor belt, the fraction of unidentified fibers may probably increase when the analysis is conducted on printing or other accessories instead of the fabric. This can result in a wrong material being compared to the database instead of the actual fabric of the garment. Hence, for automated sorting with NIR spectroscopy it is important, that the fiber material is analyses at different spots of a garment. Accordingly, for fully automated sorting, the NIR devices could capture the reflection of two or three spots of the garment. Also, a library of prints and accessories, typical material of buttons and zippers should be built, to compare the data accordingly.

In a fully automated sorting line, the NIR device built into a sorting machine, equipped with conveyor belts and air valves and is able to automatically sort a specific type of garment out of the mixed input stream. This can be done by airflow when a pre-specified item is detected with the NIR spectroscopy device and blown out of the whole sample onto a different conveyor belt or into a box ((Manley, 2014).

For handling ML garments, the sorting line requires either presorting (manual or with visual recognition if it is a typical ML garment) or an apparatus that turns the garment insight out, e.g., with robotic arms, to detect and analyze both layers. As the quantities of SL garments are larger and the fiber blends of ML items are more diverse, depending on the further use and purpose of sorting it might be more cost efficient to process only SL items with automated, NIR spectroscopy supported sorting.

Conclusion

Garments are complex objects made from a broad variety of different fibers, dyestuffs, finishings and accessories, thus complicating their recyclability. To conduct both economically and ecologically feasible textile recycling, the material composition of the garments has to be known. To ensure smooth recycling processes, a material-based sorting of the garments has to be applied. With the current technology available, NIR spectroscopy appears to have high potential in the sorting of used garments as it allows fast, contactless and economical material analyzation.

With the current NIR technology available, especially the sorting of SL textiles can be realized. The size of the unidentified rest fraction can be minimized with the usage of a bigger, more defined database as well as the implementation of several cycles of NIR spectroscopy. Building the library is a critical step for the NIR process, which should be done with known fiber compositions.

For an automated process, the distribution of the individual garments on the conveyor belt with robotic systems is critical to avoid overlaps and reduce misanalysis or unidentifiable garments.

Additionally, a verifying NIR spectroscopy of the sorted-out fractions seems useful, to confirm the accuracy and remove potential impurities resulting from faulty sorting by compressed air. Figure 5 proposes a possible process of an automated textile sorting process utilizing NIR technology, that sorts of step wise garments into defined categories and verifies the first analysis to assure, that the correct item was sorted out.

Overall, the NIR spectroscopy appears to be a suitable approach to increase textile recycling. Compared to other technological solutions, it holds the advantage that it can be applied for current textile waste without having to integrate special marker or RFID tags in the fibers and garments.

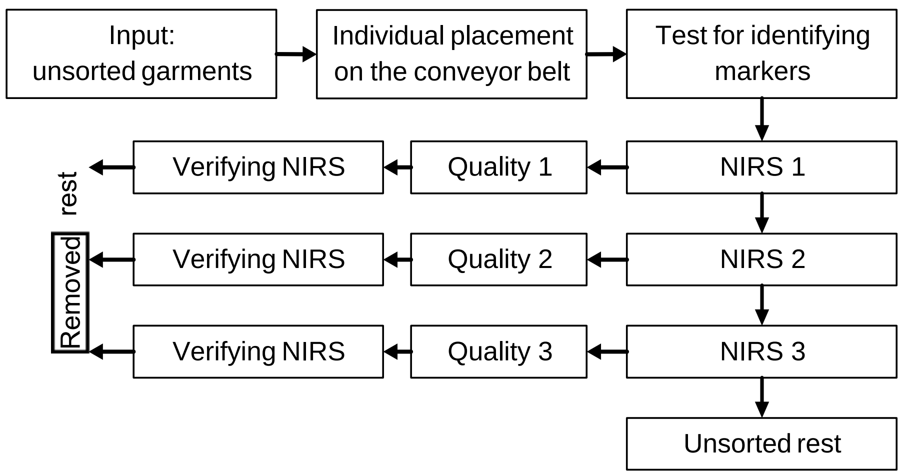

Figure 5. Possible automated textile sorting plant with NIR spectroscopy, Source: Own depiction

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