Identification technologies

Niko Rintala, Anna Keskisaari & Enni Arvez
LAB University of Applied Sciences
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Content

1. Introduction
2. Method
3. Machine vision
4. Near Infrared (NIR)
5. Hyperspectral imaging
6. Automated sorting – operational sorting lines around the world
7. Related projects
8. SWOT
   - Machine vision
   - Near infrared (NIR)
   - Hyperspectral equipment
9. Conclusions

Introduction

- Identification of textile based on fibres, weave structure, colour, etc. can be used to improve textile recycling processes – requirements vary according to the recycling process and quality of the recycled textile fibres and end product
  - Chemical recycling requires homogenous streams
  - Mechanical recycling benefits in knowing wether structure is woven or knitted
  - Color separation increases value of mechanically recycled fibres and removal of unwanted chemicals
  - Sorting is integral in determining the recovery processes
- Machine assisted (optical, machine vision, etc.) identification is the ’missing link’ between manual sorting and fibre recycling when moving towards efficient and sustainable textile recycling economy
  - Automation lowers overall costs and offers potential scalability
  - Vision systems essentially see what human eye sees
  - AI systems may be integrated for easier implementation
- In this study, different identification methods have been studied based on the literature

Method

- Over 30 studies related to NIR spectral methods (NIR, FTIR, NIR-HSI) related to textile identification tasks were found
- The tasks were most often related to distinguishing different textiles or textile blends from each other (classification)
- In addition, the percentage composition of different fibre blends, virgin vs. recycled fibre content as well as moisture content were studied (regression)
- Most often used wavelength range was around 1000 – 2500 nm
- The most common algorithm was PLS, although some studies utilized advanced neural network and generative models
- *All used studies used in the study are listed in separate PDF-file*

Machine vision

- In a way machine vision cameras can be thought as eyes for a machine
- Most operate with visible light:
  - Color separation
  - Black and white operation used for increased contrast of structures
  - Only what can be seen can be noticed
  - All that can be seen can be noticed

- Utilization in textiles to observe:
  - Structural irregularities – holes, buttons

- Addition of AI to determine value based on condition, assumed age of textile

- Current machinery:
  - 3D vision systems Resolution X -plane (mm) 0.059–0.457 - Resolution Z (mm) 0.004-0.265
  - Up to 10kHz scan rate
  - ”Microscope with high speed video”

Near infrared (NIR)

- Electromagnetic radiation between wavelengths of 800 – 2500 nm is considered as NIR spectrum
    - Chemometric recognition of organic component structures when observing energy absorption to sample
    - In general, most monomaterials contain different structures
    - Difficulties in differentiating between same bases – Cellulose-I in cotton and linen
    - NIR spectra can be analysed with different data analysis methods for best effect e.g. PCA, SIMCA and/or LDA
    - Energy penetration limited -> mostly surface reading
- Organic and synthetic materials can be identified from each other, while same bases pose difficulties
    - Cotton, Tencel, Silk, PLA, PP, PET, PA, PU
    - Wool and cashmere, cotton and linen, for example, presented variable cross-recognition rate
    - For example, Cellulose-I vs Cellulose-II (cotton vs. viscose)
- Different animal fibers (Wool, Cashmere, Yak, and Angora Rabbit Fibers) can be identified from each other with NIR-spectroscopy
    - NIR results may be validated with other chemometric evaluation for rabid screening of cashmere
- Determination of material, impregnation or lamination
- Data handling
    - Recognition time of the material depends on where the data is handled → slower when handled in the cloud
- Current machinery:
    - Laboratory machinery for wider waverange – up to whole scale
    - Hand-held spectrometers generally for narrower waveranges but through the whole scale – e.g. 800-1100nm or 1750-2150nm
    - Spectroscopic operation 0,01 – 0,05 seconds – data-analysis 1-15 seconds

Hyperspectral imaging

- Essentially compacts Machine vision with NIR-Spectroscopy
  - HSI machinery may operate in 400-2500nm waveranges
  - Colors 400-800nm
  - 800-2500nm contains NIR spectrum data
  - Observed area is separated into pixels which can be analysed separately
- Strengths include both MV and NIR qualities
  - Can be used to detect impregnation or lamination materials from technical textiles at least in manufacturing phase
  - Material identification, Color separation
  - NIR data-analysis for each pixel separately improves surface irregularity observations
- Slower than either MV or NIR separately
- Most HSI machinery operate with visible light and limits NIR ranges for cost efficiency
  - Narrower range translates to limited functionality and separation possibilities
  - Wider range increases integration / data analysis time
- Spectral correlation with physical properties being studied
  - Polymeration
  - Being NIR – results may be convertible to regular NIR equipment
- Current machinery:
  - As accurate as MV cameras
  - Material determination of pixels –> individual yarns

Automated sorting – operational sorting lines around the world

- SIPTex. Sysav, Malmö, Sweden
  - *First fully automated sorting facility in the world*
  - Devices by Tomra and Stadler
  - Baler -> pickup (with a rotating drum) -> conveyor -> NIR -> actuation
  - Link: https://www.youtube.com/watch?v=aJ4ON4aZHJA , https://www.tomra.com/en/discover/waste-metal-recycling/customer-stories/sysav-industri-ab
- Wargön Innovation, University West, Sweden
  - Demo facility
  - 46 different fractions
  - Apparently utilizes a FIBERSORT machine
  - Manual placement -> conveyor -> identification (NIR) -> actuation
  - Link: https://www.hv.se/en/news-archive/fiber-scanner-for-automated-textile-sorting-of-the-future/

Automated sorting – operational sorting lines around the world

- Valvan, Wieland Textiles, Wormerveer, NL
  - Apparently 3 versions of FIBERSORT are available:
    - Manual (single station, person scans with NIR, puts to bag)
    - Semi-automated (conveyor belt, person puts each textile online, actuation by NIR + pneumatic, apparently also RGB or VIS for color)
    - Fully automated
    - Link: https://smartfibersorting.com/
- SOEX & City of Copenhagen
  - Automated sorting test facility in Hamburg
  - 17 fractions
  - Link: https://circularcph.cphsolutionslab.dk/cc/news/automatic-sorting-of-textile-waste

Related projects

- Resyntex, Germany. VIS HSI for textile recycling
  - https://www.impopen.com/jsi-abstract/I08_a17
  - https://www.ecologic.eu/sites/default/files/publication/2022/50030-study-textile-recycling-web.pdf

- Tex.IT, RISE, Sweden. RFID tags for textile recycling
  - https://www.ri.se/en/what-we-do/projects/rfid-information-system-for-future-textiles
  - https://www.ecologic.eu/sites/default/files/publication/2022/50030-study-textile-recycling-web.pdf

- mIRoGun (GUT): handheld NIR scanner & uniSPEC2.2USBx: stationary NIR unit (much like illuminated desk)
  - https://static1.squarespace.com/static/5891ce37d2b857f0c58457c1/t/5a0049d26c3194747a7de384/1509968342157/october_2017_rise_report.pdf

- HKRITA (Hong Kong). Automated sorting system (residual metals, color) with robotics and conveyor
  - https://www.hkrita.com/en/our-innovation-tech/projects/smart-garment-sorting-for-recycling
  - https://sustain.ubc.ca/sites/default/files/2018-25%20Textile%20Recycling%20Technologies%2C%20Colouring%20and%20Finishing%20Methods_Le.pdf

- tExtended project (a Blueprint, a knowledge-based masterplan for the optimized cycling for different textile flows):
  - https://textended.eu/about/

SWOT

Machine vision

Strengths	Weaknesses
- Fast - Inexpensive - Accurate - comparable to microscope - 2D and 3D capabilities - Color identification - Surface irregularity identification	- Requires samples to be handled manually for optimal visibility - Light conditions must be regulated
Opportunities	**Threats**
- Reduction of manual labor in evaluation of post-consumer textiles - Condition of textiles, resellability, quality, worth - AI integration for greater effect	- HNIR equipment combines solutions - Value increase for value chain unrecognized

Near infrared (NIR)

Strengths	Weaknesses
- Generally quick - Inexpensive - Non-destructive - Many organic compounds identifiable	- NIR wavelengths dictate material identification - Surface reading method – inhibited by impurities - Some colorants affect low NIR wavelength ranges and may corrupt recognition
Opportunities	**Threats**
- Equipment and methods can be produced into handhelds - Assisting manual labor for cheaper solutions - Online equipment for larger masses - NIR spectral correlation with physical properties e.g. polymerization analysis	- Hyperspectral machinery has greater potential as one-for-all solution - MIR, which may offer increased accuracy for material identification

Hyperspectral equipment

Strengths	Weaknesses
- Combines machine vision with NIR for their strengths - Color recognition, positioning of irregularities, changes in material – dirt, prints etc. - Non-destructive	- NIR wavelengths dictate limited material identification - Surface reading method – inhibited by impurities - Generally slower than regular NIR - Generally narrower waverange compared to regular NIR
Opportunities	**Threats**
- One-for-all solution for on-line - Color, buttons, holes, material identification - NIR spectral correlation with physical properties	- Expensive – greater expense from wider waveranges - NIR and their handheld solutions - High cost per increase for value

Conclusions

- Most research seems to have been done earlier than 2022, the amount of the research last years has not remarkably increased
- Each identification method has its strengths and weaknesses
  - External factors such as impurities in the surface of the material, lightning etc. affect the reliability of identification method
- Refashion consortium has released their SotA analysis of textile recycling sector in 2020:
  - https://refashion.fr/pro/sites/default/files/rapport-etude/Terra%20summary%20study%20on%20textile%20material%20sorting%20VUK%20300320.pdf
- Interesting studies related to sorting:
  - Refashion consortium has released a report "characterization study of the incoming and outgoing streams from sorting facilities" in 2023: https://refashion.fr/pro/sites/default/files/rapport-etude/Synth%C3%A8se_Caract%C3%A9risation_Refashion_2023_EN.pdf
  - Circle Economy, EigenDraas and Fashion for Food have published a report "sorting for circularity – Europe - an evaluation and commercial assessment of textile waste across Europe" in 2022: https://reports.fashionforgood.com/report/sorting-for-circularity-europe/

References

The list of references used in this study can be found in a separate PDF-file "Identification technologies – references"