



Efficient Recognition and Automatic Sorting Technology of Waste Textiles Based on Online Near infrared Spectroscopy and Convolutional Neural Network

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ABSTRACT

In order to better recycle waste textiles and save resources, intelligent identification and sorting equipment and technology are urgently needed. In this work, an online near infrared (NIR) spectral library was established by utilizing self-developed online NIR device, including polyester, cotton, wool, silk, viscose, nylon, acrylic, polyester/cotton, polyester/wool, polyester/nylon, polyester/viscose, nylon/spandex and silk/cotton. Importantly, artificial intelligence technology was introduced into the identification and sorting of waste textiles, and two online NIR qualitative identification models covering above 13 kinds of waste textiles were constructed by the convolutional neural network (CNN) and Baidu deep learning platform PaddlePaddle. First, the input one-dimensional spectral data (901–2500 nm) was normalized and converted into a two-dimensional grayscale image of 40*40 pixels. Then feature extraction, compression and dimension reduction of multiple spectra were carried out through convolution and pooling. Finally, the category probability value of each kind of waste textiles was calculated by the CNN model and the maximum value was taken as the final classification of the fabric. Online identification tests were performed using 526 samples as an external validation set, presenting an accuracy of two CNN qualitative identification models were both more than 95.4%. In addition, the accuracy of online identification and sorting was above 95%, and the recognition and sorting time of each sample is less than 2 s, which can perform the efficient identification and automatic sorting of waste textiles.

1. Introduction

China is a big producer and consumer country of textiles (Li et al., 2021a). In 2020, China's total textile fiber processing reached 58 million tons, accounting for more than 50% of the world's total fiber processing, and chemical fiber production accounted for more than 70% of the world's total output (China National Textile and Apparel Council, 2021). Accordingly, the world produces 150 million tons of waste textiles every year, of which China's annual output of waste textiles is 26 million tons (Yu et al., 2021). With the growth in world population and income level, the production and consumption of textiles have increased steadily (Piribauer and Bartl, 2019; Sandin and Peters, 2018; Silva and Byrne, 2017; Stanescu, 2021). But the reduction of production costs, the improvement of logistics speed and the rapid change of fashion trends

have led to a decline in the life cycle of textile products (Du et al., 2021). The requirement for the development of the China textile industry during the 14th Five-Year Plan period is that the annual recycling fiber processing volume accounts for 15% of the total fiber processing volume by 2025 (China National Textile and Apparel Council, 2021). Therefore, the recycling and reuse of waste textiles are imperative. It can not only alleviate the shortage of resources in the textile industry, but also reduce the environmental pollution caused by incineration or landfill disposal of waste textiles, which has huge economic and social benefits (Hole and Hole, 2020; Leal Filho et al., 2019; Nørup et al., 2018; Oliveira et al., 2021); Shirvanimoghaddam et al., 2020).

In theory, 95% of waste textiles can be recycled, but in practice the recycling rate is very low, such as only 10–15% in China, 15.2% in the United States and 25% in the European Union (Li et al., 2021a). The

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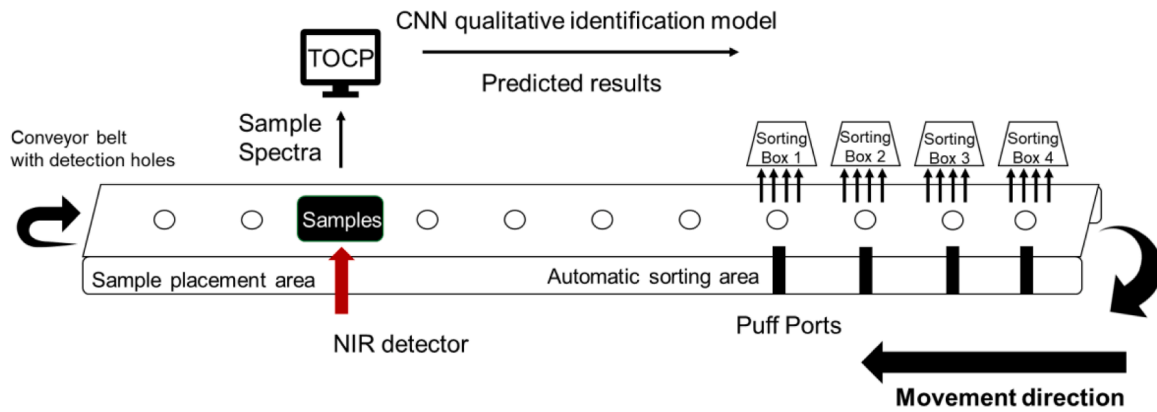


Fig. 1. Online NIR device and sorting process

main reason for the low utilization rate of waste textiles is that some technical bottlenecks need to be solved urgently, such as the rapid and efficient identification and sorting technology of fiber components (Kessler et al., 2021; Xia et al., 2021). Different fiber components require different later reuse methods. In order to realize targeted recycling, the composition and content of waste textiles must be known. (Guo et al., 2021; Tedesco and Montacchini, 2020). At present, the sorting of waste textiles mainly relies on manual operation, and the labor cost of the manual sorting process accounts for 30% of the entire recycled textile cost (China Association of Circular Economy, 2020; Zhou et al., 2019a). One of the key development tasks in the 14th Five-Year Plan of the China textile industry clearly requires the strengthening of pivotal technological breakthroughs in the separation and identification of waste textiles (China National Textile and Apparel Council, 2021). With the support and standardization of national macro policies, the recycling and utilization industry of waste textiles actively constructs the industrial chain of recycling, sorting, disassembling, processing and utilization of waste textiles, and gradually realizes the development of standardization and regulation modeling. Therefore, the research and development of accurate, efficient, professional and intelligent sorting technology and equipment are vital to ensuring the high-value recycling and reuse of waste textiles.

Near Infrared (NIR) Spectrum refers to the electromagnetic spectrum between 780 and 2526 nm (Pasquini, 2018). The frequency of this spectrum region is consistent with the multiple frequencies and combined frequency of various vibrational frequencies of the main groups of organic molecules (C-H, N-H, O-H and other hydrogen-containing groups) (Chen et al., 2019). The one-to-one correspondence between different groups and corresponding characteristic spectral regions can be used to achieve the identification and composition prediction of fiber species. This technology does not require sample preparation and does not damage the fabric, which is the best means to perform fast, accurate and low carbon sorting of waste textiles (Zhou et al., 2019b). Nowadays, NIR spectrometers in the textile field are mostly laboratory and portable instruments (Cleve et al., 2000; Li et al., 2021b; Zhao et al., 2019), while online instruments are seldom used in industry. There are mainly two kinds of textile automatic sorting lines using this technology, namely Fibersort by Valtech and SIPTex by Swedish ivl (Cura et al., 2021). However, their sorting lines can pick up only a few types of fabrics, mostly pure textiles. Nowadays, the establishment of NIR analysis models mostly adopts chemometric methods, and there are few studies on the introduction of deep learning into NIR modeling (Chen et al., 2019; Liu et al., 2020). The big data of NIR spectroscopy collected by waste textiles and the increase in the types of samples to be classified are more suitable for the application of deep learning. Through the convolutional neural network (CNN), the deep abstract features contained in NIR spectral data can be explored, and the interference of external background factors can be reduced or eliminated (Li et al., 2020).

In this paper, artificial intelligence technology is introduced into the identification and sorting of waste textiles. Based on NIRS technology, an online NIR qualitative identification model of 13 kinds of waste textiles is established by CNN and Baidu PaddlePaddle platform. This model can be applied to the self-developed online NIR high-efficiency recognition and automatic sorting device for fiber products, which can perform the online efficient identification and automatic sorting of 13 kinds of waste textiles, to provide an intelligent, efficient, environmentally friendly and non-destructive identification and sorting technology for grading recovery and high-value reuse of waste textiles.

2. Experimental section

2.1. Online NIR device and test conditions

The self-developed online NIR device, "BIFT NIRMagic 6701 efficient identification and automatic sorting device of fiber products", consists of four parts, which are sample delivery system, NIR detection system, intelligent identification system and purge sorting system. The intelligent identification system is mainly controlled by Textile Online Master Control Program (TOCP). In addition, the detector of this device is an array type, which can meet the requirement for fast online detection of waste textiles. The spectral test method is diffuse reflectance, and the wavelength range is 900-2500 nm. The device and sorting process are shown in Fig. 1.

In this experiment, the test conditions of this device are as follows: the speed of the conveyor belt is 0.282 m/s; the measurement integration time of the reference and the sample both are 10 ms; the average number of sample measurements is 1; the test thickness of the compact fabric is above 1 mm, and the test thickness of the loose fabric is above 2.5 mm. If the sample thickness is low, the spectrum will shift up from the baseline and lose part of the characteristic peak. Additionally, there is an optical path switcher in the online NIR device, which can realize the switching of sample optical path and reference optical path. The absorbance correction is achieved through internal and external references so that the absorbance value appears negative in the NIR short-wave region.

2.2. Sample collection and selection

A total of 13 kinds of waste textile samples were used in this experiment, including polyester (T), cotton (C), wool (W), silk (S), viscose (V), nylon (N), acrylic (A), polyester/cotton (T/C), polyester/wool (T/W), polyester/nylon (T/N), polyester/viscose (T/V), nylon/spandex (N/SP) and silk/cotton (S/C). These samples were provided by Chuangyi (Fujian) Textile Technology Co., Ltd., Wujiang Yuehua Weaving Co., Ltd., Zhejiang Gerial Environmental Protection Co., Ltd, National Wool Textile Quality Inspection Center, Ningbo Inspection

Table 1
Quantitative chemical analysis of textiles

Fabric type	Standard Number	Methods
Polyester/cotton and polyester/viscose	GB/T 2910.11-2009	Textiles - Quantitative chemical analysis - Part 11: Mixtures of cellulose and polyester fibers (method using sulfuric acid)
Polyester/wool and silk/cotton	GB/T 2910.4-2009	Textiles - Quantitative chemical analysis - Part 4: Mixtures of certain protein and certain other fibers (method using hypochlorite)
Polyester/nylon	GB/T 2910.7-2009	Textiles - Quantitative chemical analysis - Part 7: Mixtures of polyamide and certain other fibers (method using formic acid)
Nylon/spandex	GB/T 38015-2019	Textile for import and export - Method for quantitative analysis of fiber - Polyurethane fiber mixture textiles (method using hydrochloric acid)

Bureau and so on.

These samples were qualitatively identified by mid-infrared, according to FZ/T 01057.8-2012 *Test Method for identification of textile fibers Part 8: Infrared absorption spectrum* (Ministry of Industry and Information Technology of the People's Republic of China, 2013). For cotton and viscose fibers which were not easily identified by mid-infrared, they were identified by microscope according to FZ/T 01057.3-2007 *Test Method for identification of textile fibers Part 3: Microscopy* (National Development and Reform Commission, 2007). All

mid-infrared measurements were carried out using Nicolet iS10 from Thermo Fisher Scientific Technology Co., Ltd., with a “Smart Orbit” accessory. Its wavenumber range is 400–4000 cm^{-1} , its resolution is 8 cm^{-1} , and its number of scans is 32. The composition of blended fabric samples was determined by the chemical dissolution method (General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China and Standardization Administration of China, 2010a; 2010b; 2010c; State Administration for Market Regulation and Standardization Administration of China, 2020) as shown in Table 1.

2.3. Online NIR spectrum library for waste textiles

The samples were scanned by the online NIR device to obtain the original NIR spectra, and two sides of each fabric sample were scanned



Fig. 3. Fabrics with non-obvious characteristic peak spectra (a) polyester; (b) nylon; (c) polyester

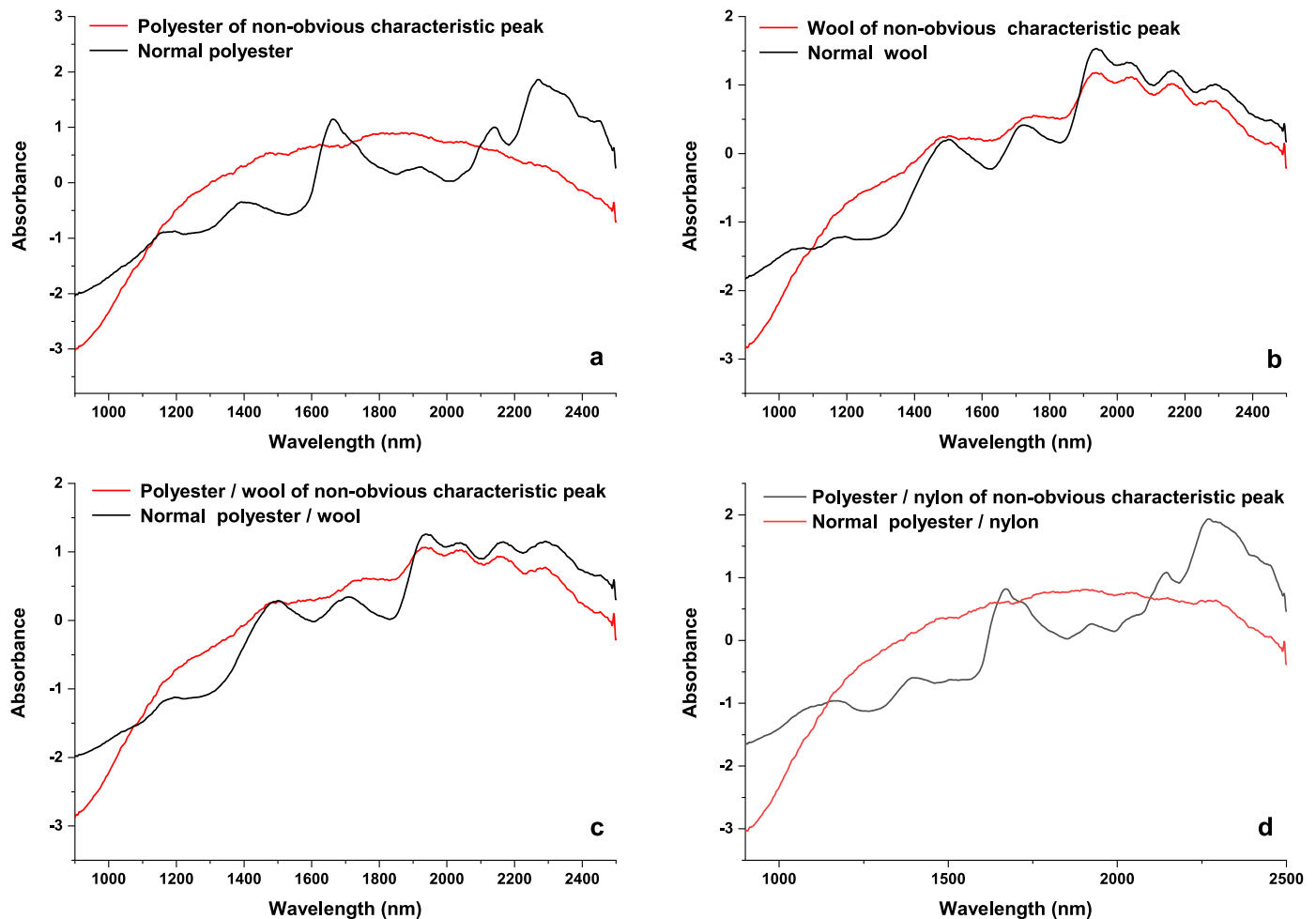


Fig. 2. The comparison of normal spectra and non-obvious characteristic peak spectra (a) polyester; (b) wool; (c) polyester/wool; (d) polyester/nylon

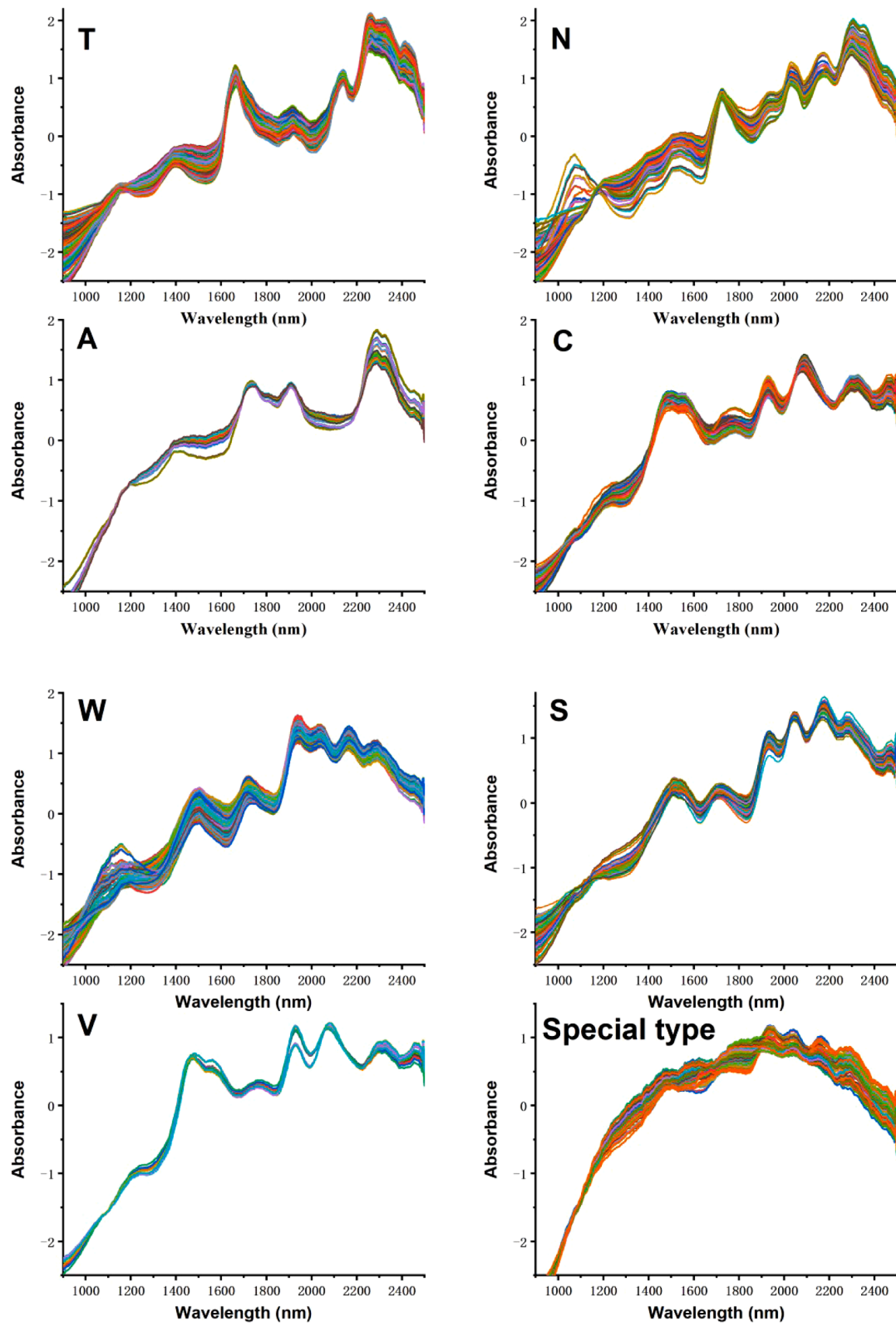


Fig. 4. Online NIR spectrum library for waste textiles (Polyester-T; Cotton-C; Wool-W; Silk-S; Viscose-V; Nylon-N; Acrylic-A; polyester/cotton-T/C; polyester/wool-T/W; polyester/nylon-T/N; polyester/viscose-T/V; Nylon/Spandex-N/SP; Silk/Cotton-S/C)

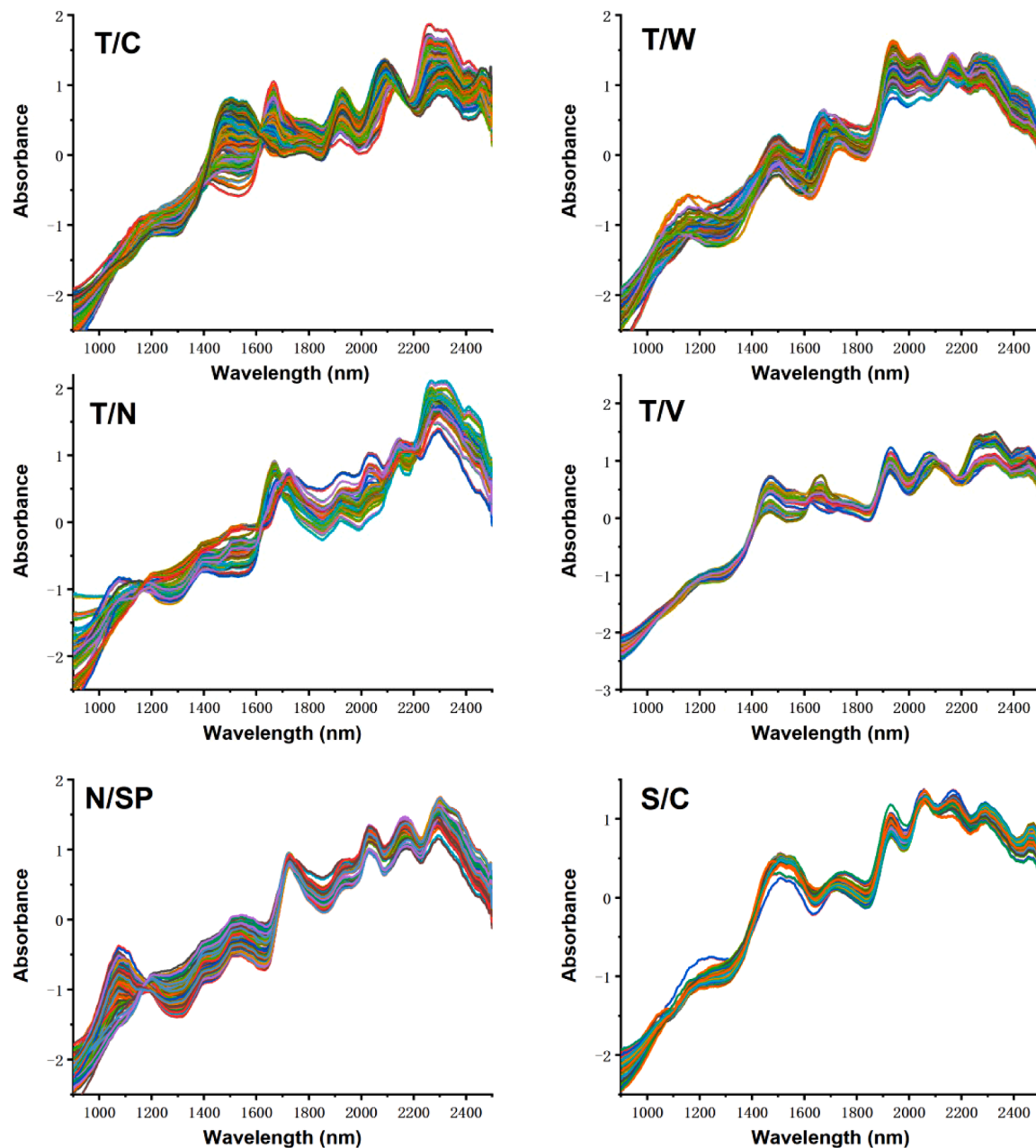


Fig. 4. (continued).

more than three times to obtain spectra with good repeatability. In addition, the spectra for the two sides of fabric samples selected in this experiment are consistent, and the component content of the fabric is uniform. The online original NIR spectra library of waste textiles was established using the selected 2764 NIR spectra samples.

2.4. Online NIR qualitative analysis model based on CNN

Nowadays, NIR qualitative discrimination methods are mainly divided into three categories: supervised methods, unsupervised methods and spectrum retrieval methods. The supervised method is to train with samples of known categories, such as k-nearest neighbor (k-NN), artificial neural network (ANN), deep learning, and so on (Chu et al., 2014). As a common deep learning architecture, CNN can directly use images as network input, avoiding traditional recognition algorithms. In the field of spectral analysis, using traditional methods such as multiple linear regression to establish qualitative or quantitative analysis models,

it is usually necessary to preprocess the spectrum and select the modeling band to eliminate random noise and interference signals. However, different combinations and sequences of preprocessing methods lead to the different performance of the model, and misuse of preprocessing methods may distort the original spectral signal and reduce the performance of the model. CNN, without the user's data preprocessing and feature extraction operations, can automatically extract the inherent features of the data (Chen and Wang, 2019).

CNN mainly has two types of network layers, namely the convolution layer and the pooling layer (Chen and Wang, 2019). The function of the convolution layer is to extract various features of the image, and the function of the pooling layer is to carry out the sub-sampling of the output signal of the convolution layer, so as to greatly reduce the dimension of the output signal and reduce the degree of model overfitting (Chen et al., 2020). There are two common pooling ways, namely max-pooling and mean-pooling (Liu et al., 2020). Max-pooling adopts the largest eigenvalue in the range of the obtained down-sampling filter

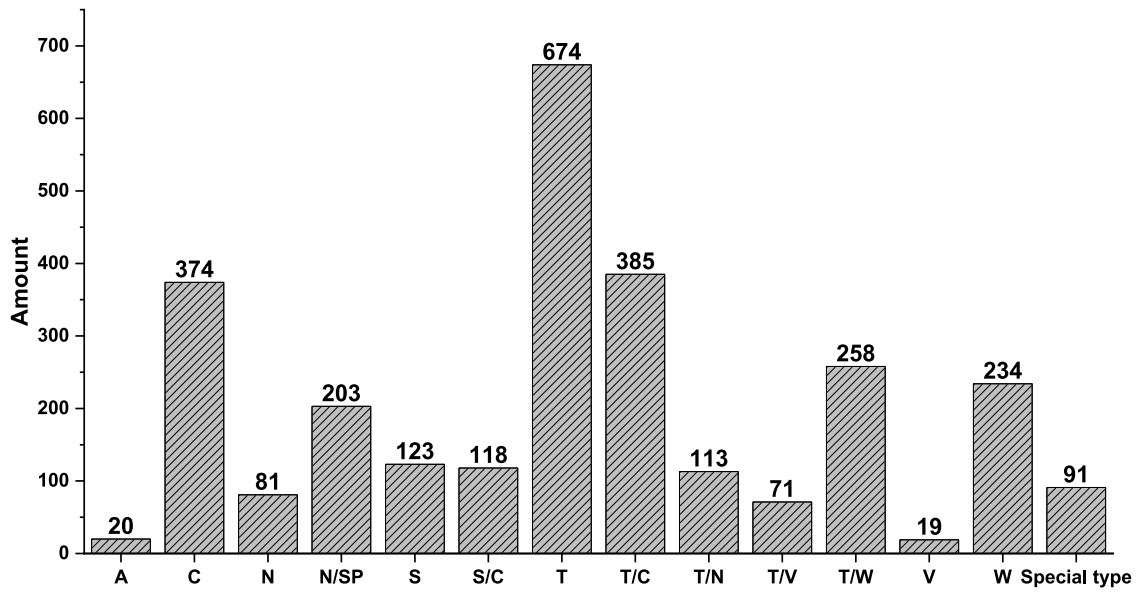


Fig. 5. Amount distribution of waste textile samples

Table 2
Structure parameters of CNN models

Model	Input	Convolution layer Number	Kernel size	Pooling layer Number	Kernel size	stride	Fully connected layer	Output
CNN1	40 × 40	3	3 × 3	2	2 × 2	2	2	14
CNN2				3			3	

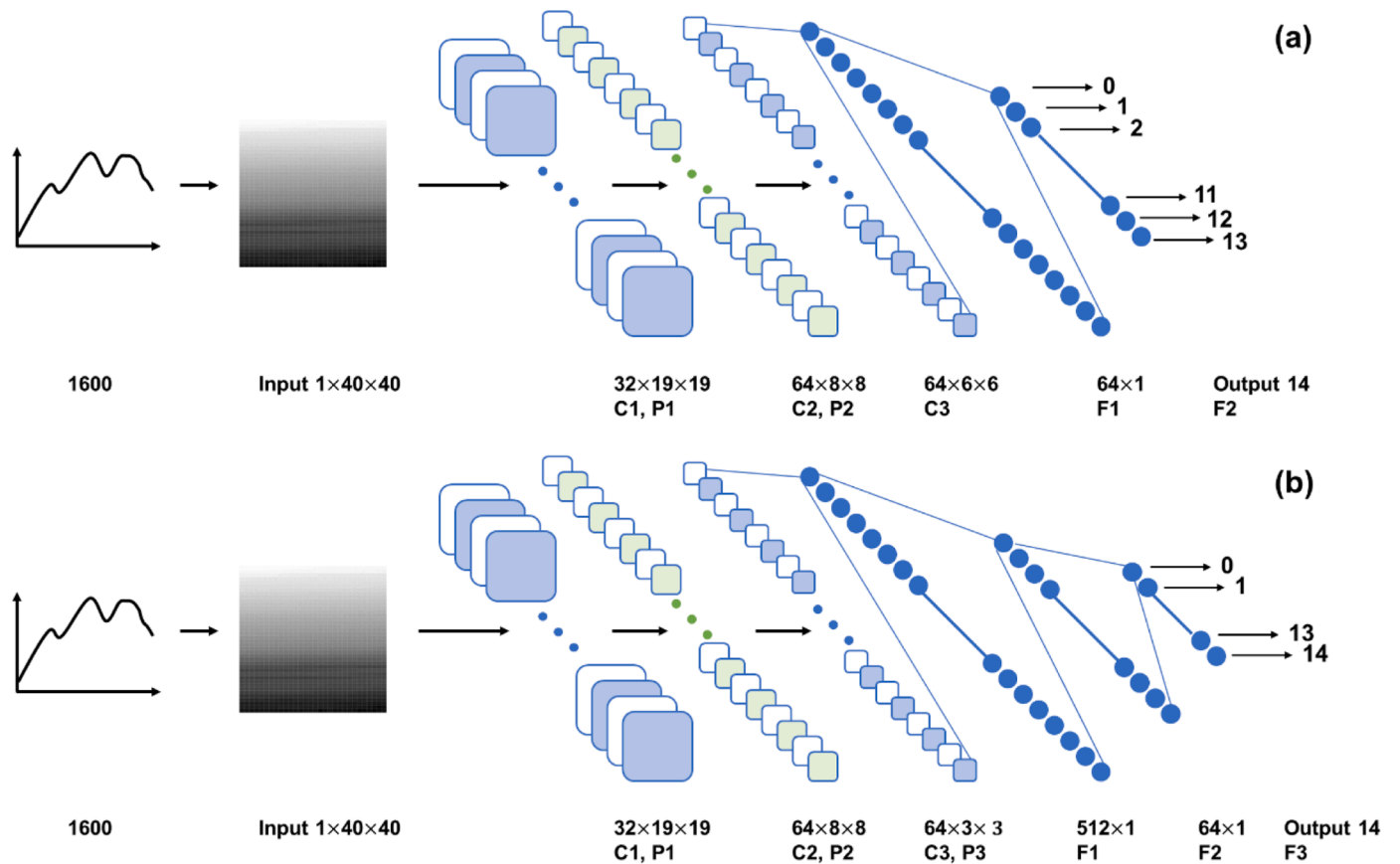


Fig. 6. The structure of CNN models (a) CNN1; (b) CNN2

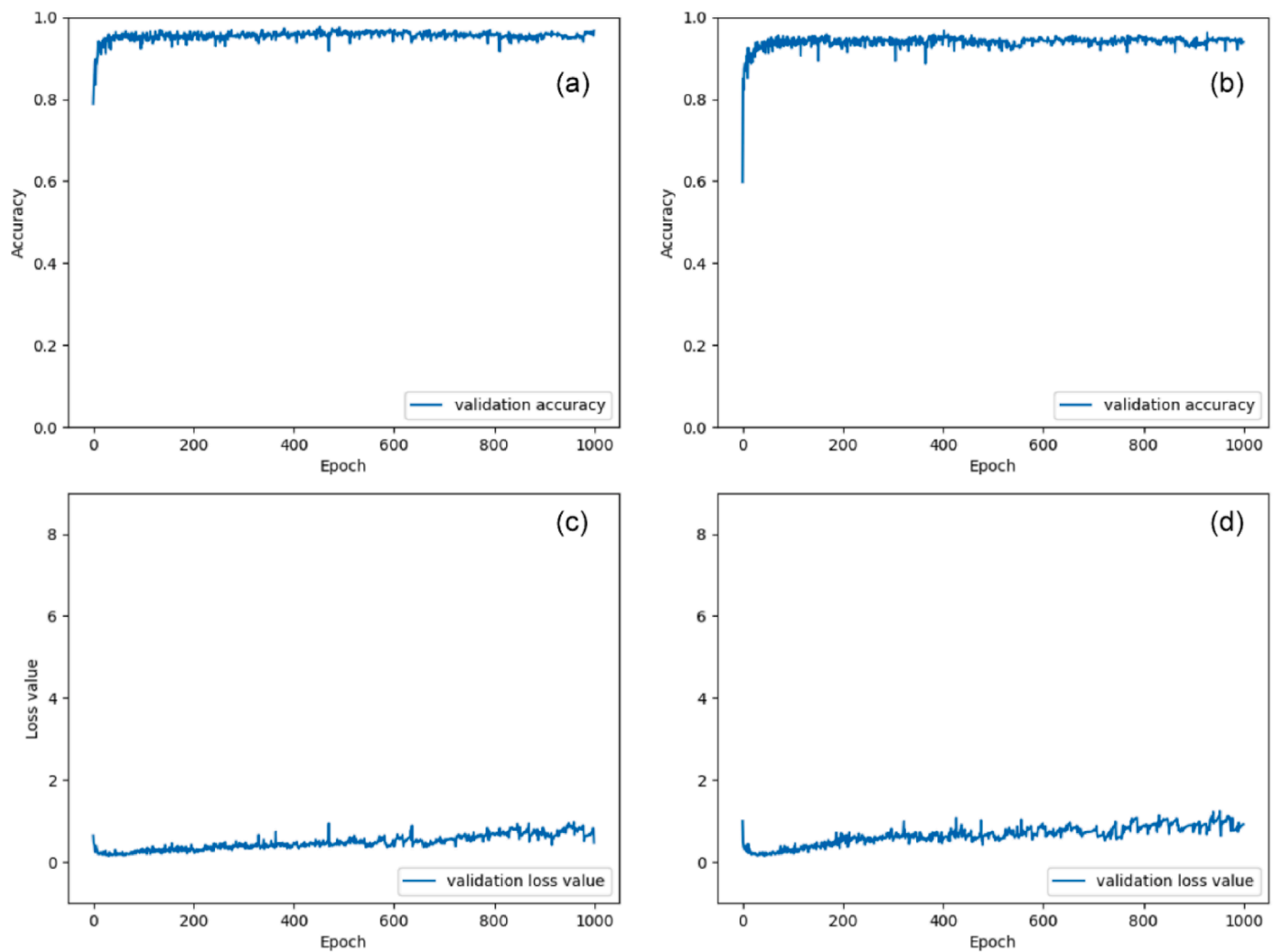


Fig. 7. The verification accuracy and loss value of CNN models (a) The verification accuracy of CNN1; (b) The verification accuracy of CNN2; (c) loss value of CNN1; (d) loss value of CNN2;

Table 3
Results of the external test using CNN models

Fabric type	Sample number of the external test	CNN1 Number of wrong samples	Recognition accuracy/%	CNN2 Number of wrong samples	Recognition accuracy/%
W	41	0	100	0	100
V	6	1	83.3	1	83.3
T/W	52	8	84.6	7	86.5
T/V	9	0	100	0	100
T/N	35	0	100	0	100
T/C	85	3	96.5	12	85.8
T	96	0	100	0	100
S/C	27	0	100	0	100
S	16	0	100	0	100
N/SP	39	0	100	0	100
N	24	0	100	1	95.8
C	76	3	96.1	3	96.1
A	5	0	100	0	100
Special type	15	0	100	0	100
Total	526	15	97.1	24	95.4

matrix and is often used to obtain the detail features, while mean-pooling adopts a new feature matrix constructed by the mean value of the feature matrices within the range of the down-sampling

filter matrix and is often used to obtain the overall features of the image. In this experiment, the local maximum of the NIR spectra represents the feature of the characteristic peak. Therefore, max-pooling is appropriate to obtain the local maximum for the feature extraction.

2.5. Recognition and automatic sorting of online NIR device

Through loading the CNN qualitative analysis model in TOCP, the online NIR device can identify and sort waste textiles. With the rotation of the conveyor belt, the sample passes through the NIR detection area, and the obtained sample spectral data is recognized by the CNN model. Meanwhile, the sample is purged into the corresponding sorting box according to the result of model recognition, and this recognition and sorting process is less than 2 s. In this experiment, 281 samples of different types were tested for online identification and automatic sorting and the automatic sorting results were statistically analyzed.

3. Results and discussion

3.1. Analysis of online NIR spectra of waste textiles

The online NIR spectra of textiles are divided into two types: normal spectra and non-obvious characteristic peak spectra, and the spectral comparison is shown in Fig. 2. It can be seen that the baseline of non-obvious characteristic peak spectra drifts upward. It is necessary to

Table 4
Analysis of the external verification using CNN models

Serial number of samples	Corresponding fabric sample	Misjudgment		Reason analysis
		CNN1	CNN2	
43 [#]	V-20170618-020-write	T/C	T/V	The base line of the spectrum moves up a little bit
48 [#]	T2W98-20170914-28#-yellow	W	W	The polyester/wool sample was misjudged as pure wool, because the polyester content was less than 3%.
49 [#]				
50 [#]				
51 [#]	T2.8W97.2-	W	W	
52 [#]	20170926-30#-blue			
53 [#]				
58 [#]	T2.215W97.785-	W	W	
59 [#]	20170914-1#-plaid	W	/	
149 [#]	T16.5C83.41-	/	T/V	The polyester/cotton sample was misjudged as polyester/viscose, due to the similar chemical construction of viscose and cotton.
150 [#]	20170618-M-004-grey			
151 [#]				
164 [#]	T33.31C66.69-BIFT-lyard	T/V	T/V	
165 [#]				
166 [#]				
196 [#]	T86.73C13.27-DHM-9#-yellow	/	T/V	
197 [#]				
204 [#]	T43.91C16.09-	/	T/V	
205 [#]	20170618-D-015-black			
206 [#]				
224 [#]	T15.8C84.2-HB-2019-02865-write	/	T/V	
413 [#]	N-20180626-1#-red	/	N/SP	Some polyamide samples contained polyurethane coating and were misjudged as nylon/spandex.
489 [#]	C-BIFT-20180418-17#-write	V	V	The cotton sample was misjudged as viscose, due to the similar chemical construction of viscose and cotton.
490 [#]				
491 [#]				

distinguish and classify the normal and non-obvious characteristic peak spectra to achieve better recognition of models in subsequent experiments. In this paper, non-obvious characteristic peak spectra were identified as belonging to the "special type".

Further analysis is required for fabrics with non-obvious characteristic peak spectra. These fabrics have a high gloss and smooth surface, probably due to calendering (Hadjianfar and Semnani, 2011; Kim et al., 2004; (Pan et al., 2010)). Therefore, fabrics have high reflectance, resulting in a large amount of mirror reflected light, as shown in Fig. 3.

3.2. Establishment of Online NIR spectrum library for waste textiles

A total of 2764 samples of 13 categories are collected to establish an online NIR spectrum library for waste textiles, as shown in Fig. 4. And the sample distribution is shown in Fig. 5. Among the collected waste textiles, polyester, cotton, wool, polyester/cotton, polyester/wool, nylon/spandex samples account for a large number of spectra, and the content of blended samples is relatively uniform. However, the sample number of nylon, acrylic, viscose and polyester/viscose fabrics is small. In follow-up research, the sample system of the model can be supplemented and improved according to the content distribution and the content gradient of the existing blended fabric, so as to improve the practical scope of the model.

3.3. Establishment of online NIR qualitative analysis model based on CNN

In this experiment, Baidu deep learning platform PaddlePaddle was used to build CNN qualitative analysis models. PaddlePaddle, a deep learning platform developed by Baidu, is a fully domestic product in the mainstream deep learning framework. Using a deep learning framework

to complete model building can save a lot of low-level code work and lower the threshold to enter deep learning.

2764 samples in the online NIR spectrum library were divided into training sets and verification sets in a ratio of 7:3, and the samples were randomly assigned each time when the model was trained. According to the known input and classification label, the CNN model structure was designed and trained to meet the classification label prediction results of the training samples as far as possible. Because the CNN is a feedforward neural network with the pixelated image as the basic input unit. Excessive manual intervention with sample pictures is unnecessary in the feature extraction process, and the CNN is particularly suitable for image processing. Therefore, it is worth noting how to convert one-dimensional NIR spectra into two-dimensional images. The input variables included data of NIR spectra from 901 nm to 2500 nm, a total of 1600 dimensions. The normalized 1600-dimensional one-dimensional array was transformed into a two-dimensional 40*40 pixel grayscale image, which was convenient for the subsequent design of CNN structure. The method of image conversion was to distribute 1600 data on 40 points and rearrange them into new row vectors, and then arrange the 40 row vectors into a 40 × 40 matrix, which could be regarded as the image data of a channel. Then, multiple spectral feature extraction, compression and data dimension reduction of two-dimensional images were carried out by alternating convolution and pooling. Finally, the category probability value of each waste textile was calculated by the CNN model, and the maximum value was taken as the final classification of this kind of fabric. In the training process, the epoch number was 1000, the batch size was 32, and the learning rate was 0.001.

Two CNN qualitative analysis models are established in this paper, and their training parameters are shown in Table 2. The input for both models is a two-dimensional image of size 40*40, transformed from one-dimensional array of 1600 dimensions. They both use three two-dimensional convolutions, and the ReLU activation function is used after each convolution. The difference is that CNN1 uses two max-pooling and two fully connected layers, while CNN2 uses three max-pooling and three fully connected layers. Finally, a 1600-dimensional spectral data is mapped to 14 outputs through CNN, which correspond to 14 categories of classification. The structure, verification accuracy and loss value of CNN models are shown in Fig. 6 and Fig. 7.

3.4. Forecast test and misjudgment analysis of CNN qualitative analysis model

526 samples were used for the external test, and the test results were shown in Table 3. The identification accuracy of CNN1 and CNN2 were 97.1% and 95.4%, respectively. Among them, some samples were identified incorrectly, such as cotton, viscose, polyester/cotton, polyester/viscose and nylon, while the other samples were identified correctly. Specific analysis of these misidentified samples is shown in Table 4. As each fabric sample was scanned more than three times, there was a case where multiple misidentified spectra were actually scanned with the same fabric sample.

There are four main cases of sample identification errors:

- (1) The base line of the spectrum moves up a little bit. The reason may be that the density of the fabric sample is low, but the yarn twist is high and the fabric is stiff, which makes it difficult to be folded, and there is a large space gap between the layers of the fabric sample after folding. Fig. 8(a) shows a spectral comparison between the misidentified viscose sample 43[#] (V-43[#]) and the normal viscose sample (V).
- (2) The polyester/wool samples are misjudged as pure wool because the polyester content was less than 3%, as shown in Fig. 8(b).
- (3) Due to the similar chemical construction of viscose and cotton, polyester/cotton samples are misjudged as polyester/viscose and pure cotton samples are misjudged as viscose. Fig. 8(c) shows a spectral comparison between cotton and viscose, and Fig. 8(d)

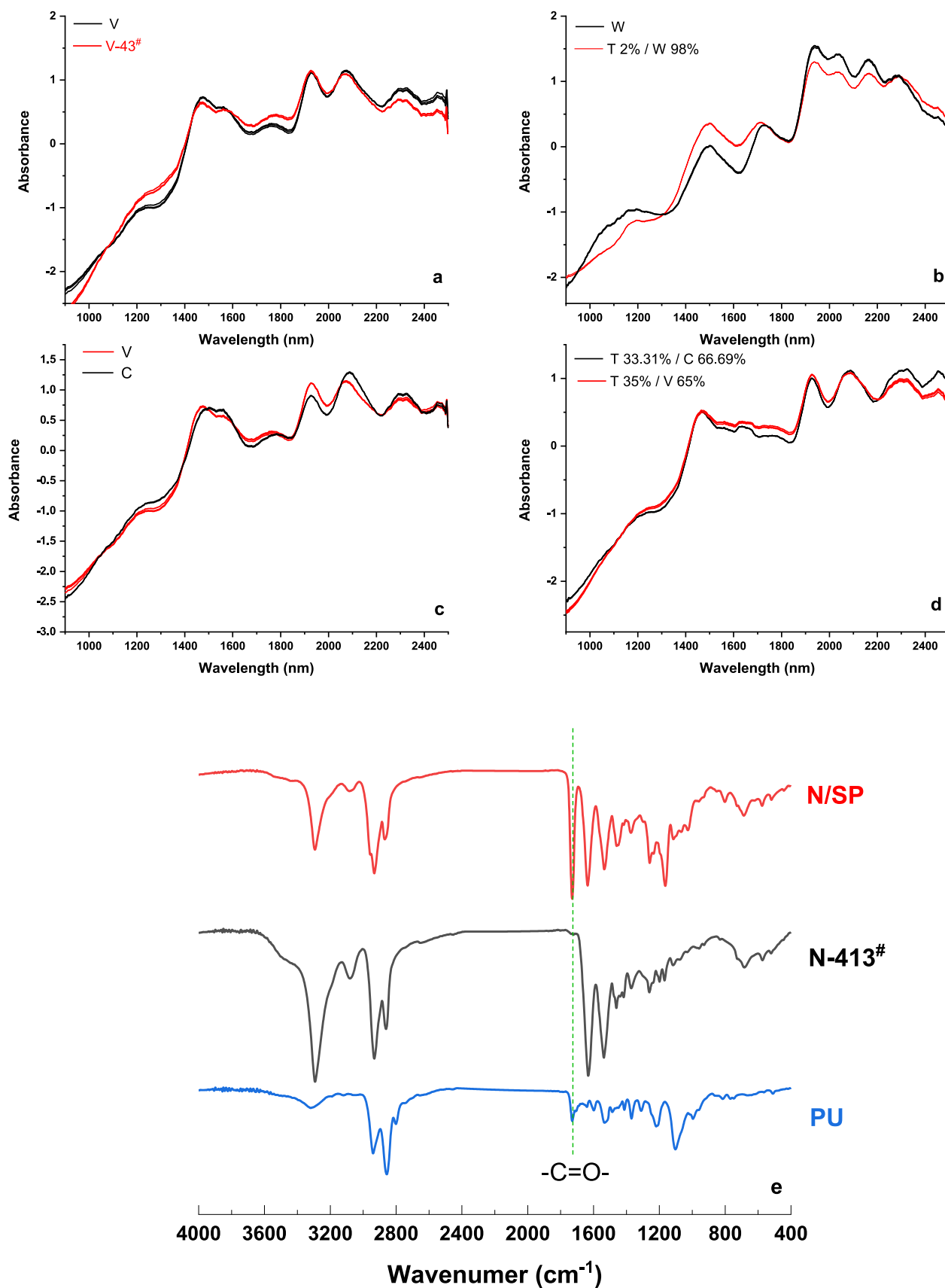


Fig. 8. Analysis of misjudgment samples (a) NIR spectra of V-43[#] and V; (b) NIR spectra of wool and polyester/wool (polyester content in samples is less than 3%); (c) NIR spectra of viscose and cotton; (d) NIR spectra of polyester/viscose and polyester/cotton; (e) MIR spectra of N, N-413[#] and PU

Table 5
Analysis of online external verification using CNN1

Fabric type	Number of samples	The number of samples correctly identified	Accuracy of model online recognition/%
T	65	65	100.0
W	21	21	100.0
C	25	22	88.0
N	8	8	100.0
V	6	4	66.7
S	24	24	100.0
A	5	5	100.0
T/W	31	30	96.8
T/V	9	7	77.8
T/N	7	7	100.0
T/C	25	23	92.0
S/C	10	10	100.0
N/SP	39	37	94.9
Special type	6	6	100.0
Total	281	269	95.7

shows NIR spectra of polyester/cotton and polyester/viscose with similar contents.

- (4) Nylon samples are misjudged as nylon/spandex, the reason may be that the fabric contains a small amount of polyurethane coating. The mid-infrared spectrum of normal nylon sample (N), the misidentified nylon sample 413[#] (N-413[#]) and polyurethane (PU) is shown in Fig. 8(e). Obviously, the difference between polyamides and polyurethanes is the carbonyl stretching vibration peak of 1730 cm^{-1} .

3.5. Recognition and automatic sorting test of online NIR device

CNN1, with higher internal validation accuracy, was imported into TOCP, and online identification and sorting of 281 samples were carried out. Its online verification and sorting results are shown in Table 5. It can be seen that the identification accuracy of cotton, viscose, polyester/cotton, polyester/viscose and polyester/wool are still low, while the rest of the fabrics are 100%. An analysis of the sorting result is as follows:

- (1) Cotton and viscose are cellulose fibers and have little effect on the subsequent recovery and utilization process of regenerated cellulose fibers.
- (2) According to GB/T 38923-2020 Classification and code of collection of textile waste, there are different classification indexes and quality requirements for all kinds of post-consumer textile waste. Polyester waste textiles are divided into three levels, and the polyester content of first-level textiles is higher than 95%. Therefore, this technology can meet the current quality requirements of waste textile recycling, and provide technical support for the implementation of the national standard.
- (3) For coated textiles, further research is needed in the future. There are many types of fabric coatings on the market, but there is no good method for fast and non-destructive identification of coated fabrics. Nowadays, coatings show a trend of diversification and functionalization. How to identify the coating without affecting the recycling of waste textiles is a question worth considering.

4. Conclusions

Artificial intelligence technology is introduced into textile identification and sorting, and two CNN qualitative recognition models covering 13 kinds of waste textiles are established based on NIR, using Baidu deep learning platform PaddlePaddle. By applying the model to the self-developed online NIR device, it can perform online recognition and automatic sorting of waste textiles covered by the modeling fabric types. The online recognition and sorting time of each sample is less than

2 s, and the accuracy of the online identification and sorting is above 95%. It is expected to solve the bottleneck problem of difficult sorting of waste textiles and provide an intelligent, efficient, and non-destructive sorting technology for the classification and high-value utilization of waste textiles.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

CRediT author statement

Wenqian Du: Writing-Original Draft, Formal analysis; **Jiahui Zheng:** Investigation, Data Curation; **Wenxia Li:** Writing-Review & Editing, Conceptualization, Funding acquisition; **Zhengdong Liu:** Methodology; **Huaping Wang:** Supervision, Project administration; **Xi Han:** Resources, Software;

CRediT authorship contribution statement

Wenqian Du: Writing – original draft, Formal analysis. **Jiahui Zheng:** Investigation, Data curation. **Wenxia Li:** Writing – review & editing, Conceptualization, Funding acquisition. **Zhengdong Liu:** Methodology. **Huaping Wang:** Supervision, Project administration. **Xi Han:** Resources, Software.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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