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Significant characteristics in VIS- and IR-spectrum of construction and demolition waste for high-precision supervised classification

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Abstract This paper discusses the possibility of automatic classifying of construction and demolition waste (CDW) by using methods of spectral analysis and supervised classifiers. The classification performances in colour images shown, that we have to use additional spectral information to solve the recognition task in a satisfactory manner. Therefore, investigations in visible (VIS) and infrared (IR) spectrum were done for analysing significant characteristics in spectrum, which are useful for automatic classification of C&D aggregates.

1 Introduction

Construction and demolition waste (CDW) are with around 53 million tons per year one of the biggest waste flow in Germany [1]. Certainly, the rate of the recyclable amount depends on the composition and heterogeneity of the material. For recycled masonry aggregates and recycled mixed aggregates, the lowest recycling rates are found because of the high heterogeneity and the mineral admixtures. Therefore, the reuse of these materials is very difficult. As in other sectors of recycling, for example the glass or plastic recycling, the sensor-based sorting has been becoming more interesting in the recycling of building materials and sorting of minerals in the last years.

The application of automatic sensor sorting in the areas of mining and recycling is successful in Europe and will increase in the following years. The benefits are the increase of the end product value and the cost reduction of downstream handling steps in the processing [2].

The results of object recognition in colour images [3], [4] shown, that we have to use other added spectral information to solve the recognition task in a satisfactory manner. Therefore, investigations in VIS and IR spectrum were done for analysing significant characteristics in spectrum, which are useful for classification the C&D aggregates.

We used two different spectrometers for analysing the CDW classes, the VIS spectrometer Ocean Optics USB2000+ with a detector range of 200 to 1100 nm and the Polytec PSS 2120 with an InGaAs detector and a range of 1100 to 2100 nm. In our classification routine we used supervised machine learning classifiers on the basis of PCA-processed feature vectors.

The investigations were done on new, not used building materials, which were crushed for obtaining homogeneous recyclates. The investigations were done on particles of a particle size of 8/16 mm. Several spectral attributes were found, which have discriminatory power to classify the chosen materials.

2 Analysis of VIS Spectrum of Several CDW Classes

First investigations of the specific VIS spectrums are shown in Figure 13.1 (left side). We used a light source, which shows a stable emitted lightning till 720 nm. The wavelength range from 420 to 470 nm are not useful because of the low signal-to-noise ratio in this range.

In the spectrum range of 470-720 nm some materials show significant features, for example the classes of brick show significant characteristics in VIS for identifying in context of the classes of concrete. Other materials are similar in first derivation like concrete, gypsum, aerated concrete etc. And also phenotypic very similar classes like sand-lime brick and aerated concrete. The separation on the basis of the VIS spectra was tested by a classifier on a small dataset. By using random forest classifier, the recognition rate reached the value of 72.4%. It needs the use of other wavelength ranges (like IR spectrum information) for auspicious results.

3 Analysis of IR Spectrum of several CDW classes

Within a research project at the Bauhaus University Weimar were carried out studies on the spectral characteristics of building materials forming pure minerals in cooperation with the firm LLA Instruments GmbH [2]. Many pure minerals have spectral features (absorption bands) in the near infrared wavelength range between 1100-2500 nm. The characters appearing in construction materials are minerals, especially the mineral classes carbonates, silicates (including layered silicates), and sulfates (especially gypsum products) and oxides (e.g. hematite) assigned. In further investigations a bigger amount of samples (nearly 1100 samples out of the 9 superordinated classes: lightweight concrete, concrete, aerated concrete, sand-lime brick, dense and porous brick, gypsum, asphalt and granite) was used by capturing and analysing their IR spectrum. Figure 1 (right side) [4] shows that the class specific characteristics in IR are more useful for classification between the different classes as in VIS (see Figure 13.1 (left side)). Figure 13.1 (right side) shows a good distinction of some of the defined categories of building materials in the IR-spectrum. The mineral composition of normal concrete and lightweight concrete varies depending on the used aggregates. However, the mineral calcite is detectible by near infrared at 1911 nm. Aerated concrete can be seen very well based on the formed tobermorite phase in the IR spectrum. During the steam curing in the autoclave of aerated concrete tobermorite formed between 30 and 40 percent by mass. The spectrum of the aerated concrete show adsorption bands at 1430 and 1920 nm and additional a less intensive band at 1680 nm.

All sulphates like gypsum, plasters and plasterboard show high characteristic absorption bands at 1440, 1750 and 1930 nm, which is very good detectable. There is a small shifting about 10 to 15 nm in the spectrum of gypsum and plasterboard, which can be used for the differentiation of these materials. The examined sand-lime bricks consist is also

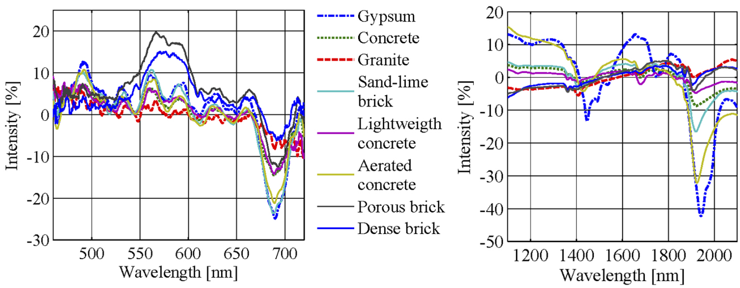

Figure 13.1: First derivation of VIS (left) and averaged and centered IR spectrums (right) of several CDW classes.

detectable by the mineral tobermorite. As a vapour cured product the sand-lime brick also contains the mineral tobermorite. The characteristic absorption bands are at 1410, 1680 and 1920 nm. The bricks are very variable in its mineralogical composition depending on the used clay for the production. The peak in the spectrum is at 1900 nm and is different from the concrete peak at 1911 nm, which is the feature for differentiation. From the recycling point of view a brick with a minimal bulk density of 2.0 g/cm^3 can also be used for the production of recycling concrete so that a separation is desirable.

After analysing the IR spectrums, a feature selection by principal component analysis was done. Figure 13.2 shows the recognition rates by using 1 up to 10 principal components. The first 10 principal components with highest information content were used for the application of a supervised classifier for differentiation between the given classes. For the use of the first three principal components the highest information content (cumulative variance) of 98.4% was reached. The classification with the classifier random forest resulted in a recognition rate of 88.9% by using the first three principal components. The application of the first 10 principal components instead of the 501 dimensional wavelength-specific information accelerated the classification time significantly without producing a loss of information. A total recognition rate of 98.3% was achieved by using the first 10 principal components (cumulative variance = 99.995%) and of 91.5% by using only the first 5 components (cumulative variance = 99.95%) and by using a 10-fold

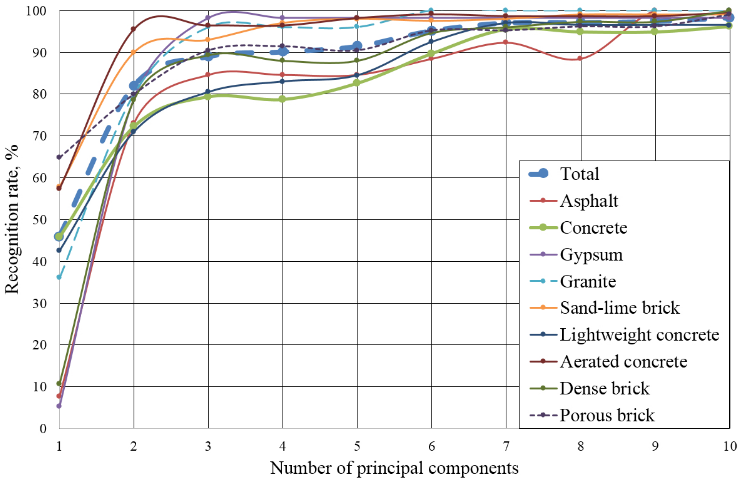

Figure 13.2: Total and single recognition rates by using the first 10 principal components.

cross validation. The achieved individual recognition rates are 100% for asphalt, 96.1% for concrete, 98.2% for gypsum, 100.0% for granite, 99% for sand-lime brick, 96.5% for lightweight concrete, 99.5% for aerated concrete, 100% for dense brick and 99% for porous brick by using the first 10 principal components. The most false classifications appear between the classes lightweight concrete and concrete. To get a recognition rate of higher than 90% for the main class concrete, it is possible to use more than 6 principal components for training the classifier. In the result the application of the PCA provides good performances with a low computational effort.

An alternative method for feature selection is the InfoGain filter. The results of the analysis are shown in figure 13.3. This method shows not so good results, because the reduction of the total number of wavelengths had no significant influence. The total recognition rate amounts to 87.25%, if all 498 wavelengths were used in the classification. For a decreased number of best wavelengths, between 250 and 300, the recognition rate increases minimally up to 88.1%. If only 50 of best wavelengths were used, the recognition rate decreases again to a value of

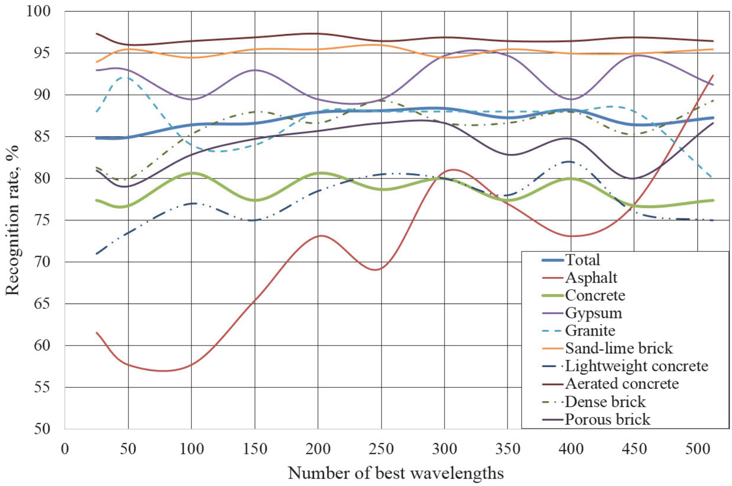

Figure 13.3: Performance of random forest on selected wavelengths from IR spectrums of CDW by InfoGain filter

84.91%. Therefore, we can conclude that InfoGain does not bring any significant improvement. That means no comparable efficiency for less calculation effort.

In addition to PCA and filter methods for feature selection, a wrapper method for feature selection was tested. This method use a classifier for feature selection. This method has an advantage in a direct integrating of the classifier into the selection process, which leads to the increase of the recognition rate, but a given disadvantage is the higher calculator effort. The classifier random forest was used for feature selection. After calculating with the 11 best wavelengths a recognition rate of 87.9% could reached by using the classifier random forest and 92.5% by using the Nu-SVM classifier. The direct comparison of different feature selection methods shows that the best performances have wrapper method and PCA (see figure 13.4). Wrapper method improved the total recognition rate, compared to standards datasets by 5%. The PCA still shows better results – here the increase is 4% for 5 principal components and 10% for 10 principal components.

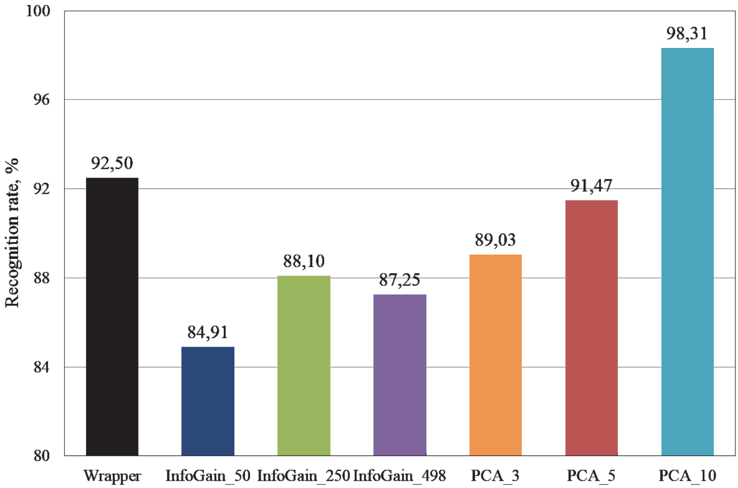

Figure 13.4: Comparison of classification performance by several feature selection methods

4 Summary

The first investigations in the VIS spectrum range showed that some materials show significant spectrum characteristics for identifying (e.g. brick). Other materials show only differences in intensity like concrete, gypsum, aerated concrete. Classes with similar chemical substances (lightweight concrete and concrete) showed very similar spectral characteristics without significant differences in intensity. The achieved recognition rate by using classifier random forest on the VIS spectrum is 72.4%. This causes the necessity for additional using of colour image information and other spectral information.

The first investigations in the IR spectrum range showed that concrete and brick in the infrared spectrum are well distinguishable in principle. Gypsum as impurity in the C&D waste is very well detectable by IR. Aerated concrete and sand lime brick can also be very well recognized by IR sensors. Lightweight and normal concretes and dense and porous brick show a little amount of false classifications in the IR spectrum. A total recognition rate of 98.3% was achieved by using the first 10 principal components of the IR spectrum and of 90.8% by using the first 5 principal components of the IR spectrum. InfoGain filter showed insufficient results and small improvement of total recognition rate. An opposite to InfoGain, the wrapper method showed a good performance with a total recognition rate of 92.5% by using Nu-SVM classifier on selected 11 best wavelengths. Therefore, the best way for solving the analysing task is to complete the IR information by information of the colour image analysis and to use supervised classifiers of machine learning.

Further investigations are planned for combining feature vectors of colour image analysis and IR spectrum analysis.

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