

# Comparison between Supervised and Unsupervised Feature Selection Methods

Lilli Haar, Katharina Anding, Konstantin Trambitckii and Gunther Notni

*Institute of Mechanical Engineering, Department of Quality Assurance and Industrial Image Processing, Ilmenau, University of Technology, Gustav-Kirchhoff-Platz 2, Ilmenau, Germany*  
{lilli.haar, katharina.anding, konstantin.trambitckii, gunther.notni}@tu-ilmenau.de

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**Abstract:** The reduction of the feature set by selecting relevant features for the classification process is an important step within the image processing chain, but sometimes too little attention is paid to it. Such a reduction has many advantages. It can remove irrelevant and redundant data, improve recognition performance, reduce storage capacity requirements, computational time of calculations and also the complexity of the model. Within this paper supervised and unsupervised feature selection methods are compared with respect to the achievable recognition accuracy. Supervised Methods include information of the given classes in the selection, whereas unsupervised ones can be used for tasks without known class labels. Feature clustering is an unsupervised method. For this type of feature reduction, mainly hierarchical methods, but also k-means are used. Instead of this two clustering methods, the Expectation Maximization (EM) algorithm was used in this paper. The aim is to investigate whether this type of clustering algorithm can provide a proper feature vector using feature clustering. There is no feature reduction technique that provides equally best results for all datasets and classifiers. However, for all datasets, it was possible to reduce the feature set to a specific number of useful features without losses and often even with improvements in recognition performance.

## 1 INTRODUCTION

One of the goals of image processing is the automated classification of objects into classes. For this purpose, machine learning is used, which performs a grouping based on image or object features. In order to ensure a high accuracy, it is essential to use features that allow an adequate separation of the classes. However, it is difficult to assess, which features are important and which are not. If there are only a few features, satisfactory results could not be achieved, as the features may be unsuitable for class separation. The accuracy can be increased by adding more relevant features. However, this is possible only up to a certain number of features. When this critical number of features is reached, the growth of accuracy stagnates or even decreases. This behaviour is well known as the peaking phenomenon (see Figure 1). Furthermore, feature selection can help to avoid the curse of dimensionality (Bellman 1961). The recognition performance of a classifier depends on the relation between the number of training objects and the number of features. If the number of features increases, the quantity of objects must increase expo-

nentially (Theodoridis and Koutroumbas 2009).

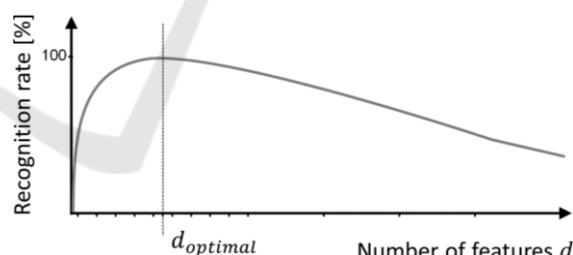


Figure 1: Illustration of the peaking phenomenon.

To counteract these two phenomena, the feature vector should be reduced. In addition, the computational effort and the time required for training a classifier or for the classification process itself can be reduced. This is especially important for neural networks, as they require a lot of time for training (Han et al. 2012) and also for real-time recognition tasks, particularly in hyperspectral data. Furthermore, a reduced number of features can avoid overfitting. There are many different methods available to perform this task. This paper aims to compare different supervised and unsupervised

methods for feature selection. Different datasets, which are presented in section 3.1, were used for the evaluation. The comparison was made using the recognition rate.

## 2 STATE OF THE ART

The feature vector can contain redundant and/or irrelevant features. Feature 2 in Figure 2a can separate the given two classes alone. Instead, Feature 1 is similar for both classes. Such a feature is considered irrelevant. The Features, which are shown in Figure 2b, are redundant because they carry similar information. Thus, one of the two features could be left out without suffering any loss of information.

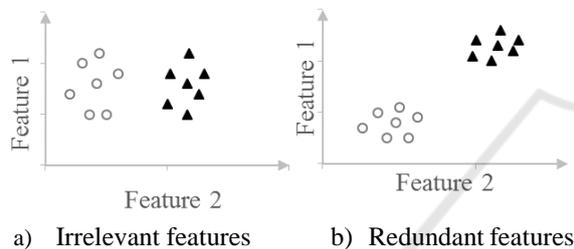


Figure 2: Illustration of irrelevant and redundant features.

Three different approaches for feature selection can be distinguished, these are filters, wrappers and embedded methods (García et al. 2015). The filter methods act independently of the selected classifier. In advance, features are filtered out using heuristics or the characteristics of the given data. This paper uses techniques from this approach. The wrapper methods involve the classifier to decide which features should be removed or added. The accuracy is determined with each new feature subset and the one with the best results is selected. Examples of this type of feature selection are sequential forward or backward selection. Embedded methods use the classifier for decision making, too. The features are selected within the training of the classifier.

The methods for feature selection can be categorized into supervised and unsupervised. As with machine learning, this means that the labels of the objects are integrated into the reduction process or not. In the case of unsupervised methods, the selection is done based on the attributes and their characteristics without the inclusion of the labels. When basically no labels are known in clustering, only unsupervised methods can be used for feature selection. A selection based on variance or correlation is unsupervised. (Dy and Brodley 2000), (Mitra et al. 2002) and (Cai et al. 2010) present unsupervised

feature selection methods. Clustering can also be used for this task.

Common supervised methods of feature selection are, for example, InformationGain (InfoGain) (Han et al. 2012), GainRatio (Quinlan 1993), Relief (Kira and Rendell 1992), ReliefF (Kononenko 1994), Gini-Index (Breiman et al. 1984).

An overview of different feature selection methods is given in (Li et al. 2017).

### 2.1 Information Gain

The Information Gain score is calculated for each feature based on entropy and indicates the level of information about the classes to be predicted (Han et al. 2012). Thus, it can be determined which features are suitable for a separation of the classes. A high value indicates a high information content. In this way, a ranking of the features is created. This method can distinguish irrelevant features.

### 2.2 ReliefF

In process of ReliefF, features are weighted, and a ranking is created. First, an object is selected and the nearest neighbour from the same and from the other classes are determined (Kira and Rendell 1992), (Kononenko 1994). The weights of the features in which the objects of the same class match and objects of different classes do not match are increased. On the other hand, the weights of features in which objects of one class differ or whose expressions are equal between objects of different classes are reduced. Using ReliefF allows removing irrelevant features.

### 2.3 Based on Variance

The characteristics of some features are almost the same for all objects and therefore vary only slightly (Han et al. 2012). Such features are irrelevant and add no value to the classification, which is why they can be removed from the feature vector.

### 2.4 Based on Clustering

The natural grouping tendencies of clustering can also be used to perform a feature selection. The Generalized Hebbian Algorithm (GHA) and the self-organizing map (SOM) can, for example, be used to perform a principal component analysis (RapidMiner Inc. 2014). (Roiger 2017) proposes a wrapper approach for feature selection using unsupervised learning. Furthermore, it is possible to transpose the input table and to perform the clustering on the

features instead of the objects. This process is illustrated in Figure 3.

	$M_1$	$M_2$	...	$M_m$
$O_1$	$x_{11}$	$x_{12}$	...	$x_{1m}$
$O_2$	$x_{21}$	$x_{22}$	...	$x_{2m}$
...	...	...	...	...
$O_n$	$x_{n1}$	$x_{n2}$	...	$x_{nm}$

	$O_1$	$O_2$	...	$O_n$
$M_1$	$x_{11}$	$x_{21}$	...	$x_{n1}$
$M_2$	$x_{12}$	$x_{22}$	...	$x_{n2}$
...	...	...	...	...
$M_m$	$x_{1m}$	$x_{2m}$	...	$x_{nm}$

Figure 3: Left: Original input table, right: Transposed input table for feature clustering.

Such feature selection methods are called feature clustering. Similar features should be grouped in clusters. Subsequently, only the nearest feature to the centre of the cluster is used as the representative of the entire cluster (Cheung and Jia 2012), (Hong et al. 2014). For this type of feature reduction, mainly hierarchical methods, but also k-means were investigated, the former being better suited (Jain and Dubes 1978), (Guyon and Elisseeff 2003), (Krier et al. 2007), (Liu and Wu, Xindong, Zhang, Shichao 2011), (Cheung and Jia 2012). However, it is problematic to find a suitable distance measure, especially if the features are scaled differently. Clustering-based methods reduce the feature vector by removing redundant features.

### 3 COMPARISON OF FEATURE SELECTION ALGORITHMS

The presented feature selection methods are compared based on the achieved recognition accuracies of different classifiers. InfoGain and ReliefF are classical methods, which are very common and therefore very often used.

Instead of hierarchical clustering or k-means, the Expectation Maximization (EM) algorithm was used for unsupervised feature clustering (Dempster et al. 1977). Here, a mathematical model, which consists of  $k$  probability distributions, is created. The aim of this clustering method is to find those model parameters of the probability distributions that represent the data in the best way (Dempster et al. 1977) and thus to optimize the fitting of the mathematical model to this data (Aggarwal 2015). The EM algorithm is very popular because of its simple implementation (Aggarwal and Reddy 2014) and flexibility (Aggarwal 2015). Probabilistic methods often surpass other clustering methods (Kononenko 1994) and can be used in many fields (Dempster et al. 1977). It is

also a stable process that is robust to outliers (Gan et al. 2007). This paper aims to investigate whether this type of clustering algorithm can provide a proper feature vector using feature clustering. The features are normalized by using Gaussian z-score normalization before clustering.

The investigations were carried out in the data mining program KNIME (Konstanz Information Miner) based on the Weka plug-in and thus on Weka implementation of these methods.

### 3.1 Used Datasets

Four different real datasets are used in the investigations of this paper. The first two datasets consist of light scattering images. These represent reflective, industrially produced surfaces without defects, with scratches or point defects. The Autopetrography dataset is based on a developed method for automatic recognition of mineral aggregates to solve automatic analysis for all petrography classes according to legal requirements. Furthermore, a dataset with images of metal surfaces with and without defects is used. In Table 1, all datasets are listed. Figure 4 shows an example of each dataset.

Table 1: Overview of used datasets.

Name	Number of Objects	Number of Features	Number of Classes
Scattered_Light_1	300	182	3
Scattered_Light_2	900	182	4
Metal Surfaces	273	123	3
Autopetrography	15907	234	4

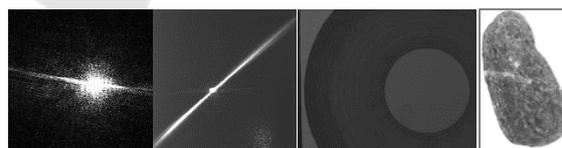


Figure 4: Example images of each dataset. From left to right: Scattered\_Light\_1, Scattered\_Light\_2, Metal Surfaces, Autopetrography.

### 3.2 Used Classification Algorithms

Three different classifiers are used. Random Forest is insensitive to irrelevant or redundant features. Naïve Bayes is sensitive to redundant features, whereas  $k$  Nearest Neighbour is sensitive to irrelevant ones. For all used classifiers the achieved results are measured as recognition accuracy in percent. The

required computational effort is not included in the assessment.

### 3.2.1 Random Forest

In some cases, a single tree classifier has an insufficient accuracy. A combination of several trees and randomly chosen features can improve the results significantly. This is the keynote of Random Forest classifier (Breiman 2001). It is based on the bagging and random feature selection. Random Forest is a very powerful classifier, which delivers good results in a short time. The algorithm is understandable and comprehensible. When building the tree, an internal selection of the most important features is made, which reduces the influence of irrelevant features. A small influence remains. The number of trees in these investigations was set to 100.

### 3.2.2 $k$ Nearest Neighbour

The learning step of the  $k$  Nearest Neighbour algorithm is very simple, the existing training data is just stored (Cleve and Lämmel 2014). In the following classification step, the distances between all training data points and the new and unknown object are determined. Subsequently,  $k$  objects of the training dataset are determined, which have the smallest distance to the new object in the feature space. The parameter  $k$  is a natural number specified by the user. Assuming that these  $k$  nearest neighbours are most similar to the unknown object, their classes determines the class affiliation of the unknown object. The  $k$  Nearest Neighbour algorithm with  $k = 15$ , included in Weka, was used in this paper.

### 3.2.3 Naïve Bayes

Naïve Bayes belongs to the group of statistical or probability based classifiers (Han et al. 2012), (Cleve and Lämmel 2014). The basic idea is to calculate the probabilities of the class membership of an object as a function of its specific feature vector and to select the class with the highest result. The suffix "naïve" refers to the simplifying but mostly unrealistic assumption that the features in the datasets are independent of each other (Duda et al. 2012), (Witten et al. 2017). This assumption is not always true, which is why the classifier is highly sensitive to redundant features.

## 4 RESULTS

A ranking of the features was created with InfoGain, ReliefF and the statistic parameter variance. Afterwards, one of the classifiers was trained with the first 10 most important features of each method and the accuracy was determined. This was done using a 10-fold cross validation for the Scattered Light datasets and a 3-fold cross validation for the other datasets. With each step, the number of features was increased by adding the next 10 features with remaining highest significance, the classifier was trained, and the accuracy was determined. The procedure using the clustering-based method was similar, but the number of features was determined by the chosen number of clusters. This value started with 10 and was increased by 10 until the full number of features was reached.

### 4.1 Random Forest

Figure 5 shows the results of all four datasets by using Random Forest. The feature selection was carried out using the four methods described above. In any case, a comparable accuracy can be achieved with a significantly reduced feature vector as with a full one. The feature clustering achieved the best results for the Scattered\_Light\_1 dataset, although this method does not involve the classes. Significantly, worse results were provided for this dataset by using the second unsupervised method based on variance. The two other methods also gave worse results. Nevertheless, the accuracy increases continuously with the number of used features. This indicates that the Random Forest classifier is insensitive to irrelevant features. For the datasets, Scattered\_Light\_2 and Autopetrography, the differences between the feature selection methods are small, at most 3%. All methods are able to create a smaller feature vector, which nevertheless allows a similarly high accuracy as by using the full feature number. By using the Scattered\_Light\_2 dataset this comparable recognition performance is achieved with about 30 features and with 60 features using the Autopetrography dataset. In addition, the recognition accuracy of the method, which is based on variance, is at the beginning significantly worse than the other feature selection methods, but then it increases significantly and can obtain the same level. The progress of the accuracy indicates that these datasets consist of a large number of features which carry little additional information. The Metal Surface dataset shows a rapid increase of the accuracy, but also greater differences between the feature selection

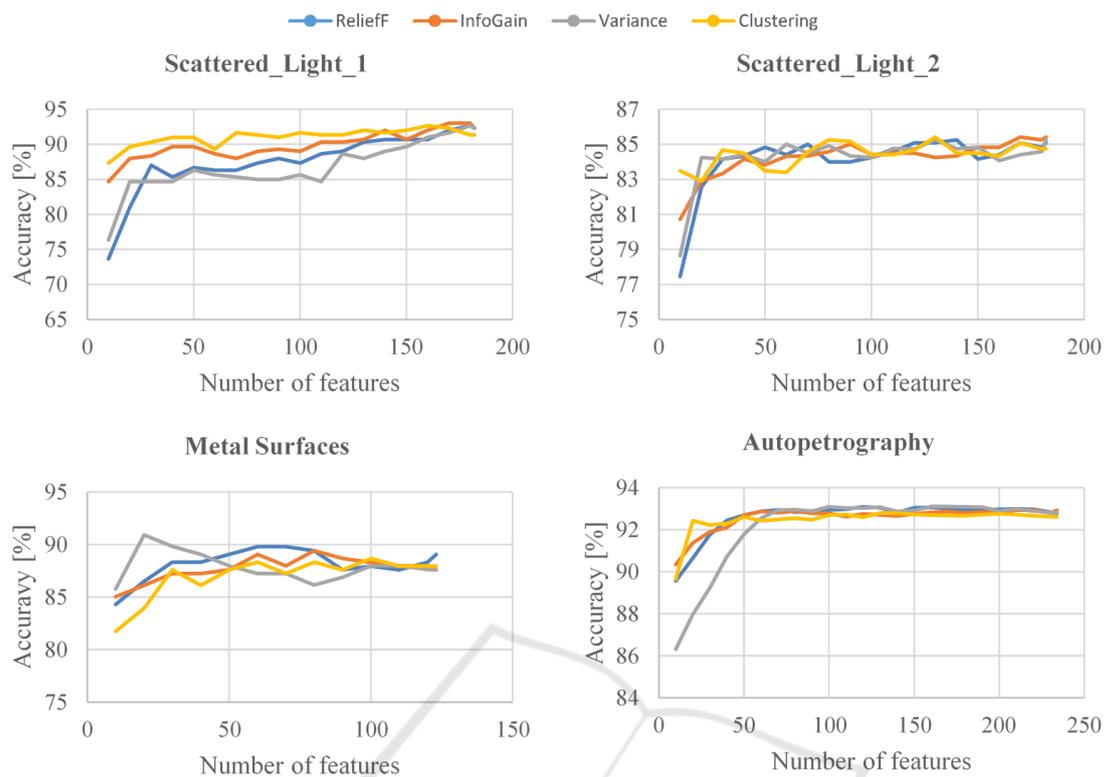


Figure 5: Recognition accuracies of different feature selection methods using Random Forest classifier.

methods and more fluctuations. Variance-based selection achieved the best results with this dataset. A significant improvement could be achieved with only 20 features. In addition, a comparable accuracy to the full feature set was achieved with significantly fewer features. The benefits are a reduction of storage capacity requirements, of calculation time and of computational complexity.

#### 4.2 *k* Nearest Neighbour

Figure 6 shows the results by using different feature selection methods with *k* Nearest Neighbour classifier. This classifier is sensitive to irrelevant features. The results of the Scattered\_Light\_1 dataset show, that there are many irrelevant features in this dataset. Using the InfoGain algorithm a significantly higher accuracy (87.7%) could be achieved with only 20 features. This value is significantly higher than 83% achievable with the full feature vector. Thereafter, accuracy decreases until a minimum at 70 used features. This indicates an increased number of irrelevant features. By removing these irrelevant features, the classification process is no longer disturbed, which is why better results are possible. Subsequently, the accuracy increases again. The accuracies achieved with the other feature selection

methods increases continuously. For Scattered\_Light\_2 dataset, InfoGain is no longer able to achieve such good results. ReliefF and variance show better accuracies. A reduced number of features (about 30) is already able to achieve similarly good results as using full feature set. The behaviour of the accuracy is especially interesting for the Metal Surfaces dataset. It was possible to increase the accuracy by about 5% - 10% with ReliefF and InfoGain. Subsequently, the accuracies decrease until the entire feature set is reached. This indicates that the dataset includes many irrelevant characteristics. The results of feature clustering are different, because this method detects redundant instead of irrelevant features. There is no significant increase in the accuracy. However, the number of features can also be reduced without lowering the recognition performance. The variance also shows a different trend, since it operates unsupervised. For Autopetrography the results of ReliefF, InfoGain and feature clustering are very similar. Variance is initially unable to keep up. First, a continuous increase can be seen in all procedures. Then it comes to a stagnation. Instead of 234 features, 70 could lead to similar results as by using the full feature set.

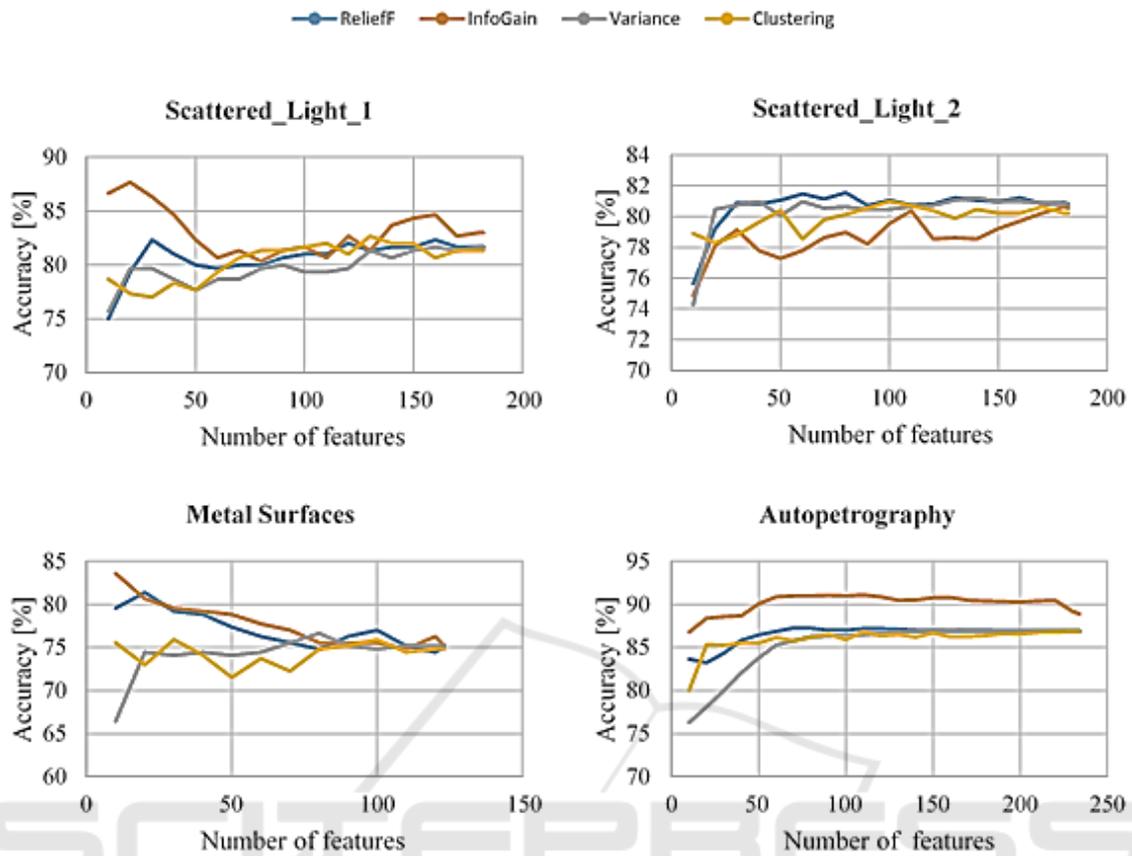


Figure 6: Recognition accuracies of different feature selection methods using IBk classifier.

### 4.3 Naïve Bayes

This is a simple classifier, which can achieve relatively high accuracies for simple classification tasks. As already mentioned, this classifier is also highly sensitive to redundant features. Figure 7 summarizes the results using Naïve Bayes. Because redundant features are removed with feature clustering, this method is best for the Scattered\_Light\_1 dataset. An accuracy, which overcomes the result of the full feature set could be achieved with only 40 features. After this peak, it decreases. It can be concluded that this dataset consists of many redundant features. A set created with InfoGain containing a lower number of features gained an accuracy comparable to that using the full feature set. ReliefF could achieve such a high accuracy with significantly more features. For the Scattered\_Light\_2 dataset, the accuracies for all four feature selection methods increase very fast, before they stagnate and decrease again. This is typical for the peaking phenomenon. The results of the Metal Surfaces dataset differ more in terms of the selection methods. Variance shows the worst results. The

gradients of ReliefF and InfoGain are similar, with the accuracy of the latter being higher. Results achieved with the feature subsets of feature clustering initially show worse results, but then surpass the other methods. Later, the accuracies of all methods are similar. The continuous increase indicates a small number of redundant features. For the Autopetrography dataset, an unusual situation is shown. InfoGain and clustering show a similar course. Both achieve an accuracy of approximately 77% with already 10 features. Subsequently, it decreases continuously with an increase of the number of features, indicating an increased number of redundant features. This also explains why the clustering-based method performs very well in this case. It is able to filter out redundant features. ReliefF is significantly worse than InfoGain and the unsupervised clustering-based method.

## 5 CONCLUSIONS

It has been shown that each of the four investigated methods is suitable for creating a reduced feature set.

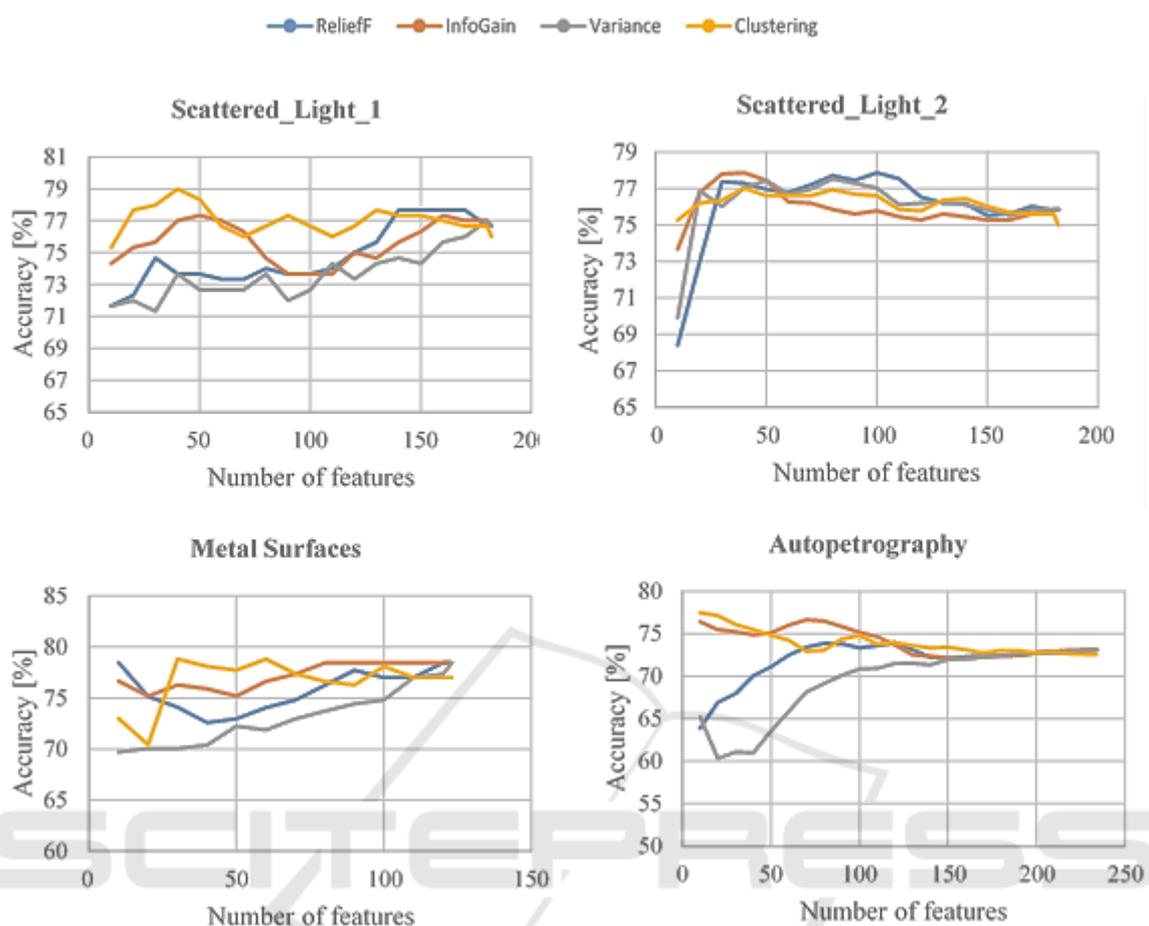


Figure 7: Recognition accuracies of different feature selection methods using Naïve Bayes classifier.

Furthermore, the results show, that EM is suitable for feature clustering and leads to good results. The number and constellation of optimal features are highly dependent on the chosen machine learning method and the given dataset. Thus, there is no feature reduction technique that provides equally good results for all datasets and all used classifiers. For this reason, a suitable procedure must be selected for each new recognition task. The unsupervised feature clustering could often provide similarly good results or even better than the two supervised working feature selection methods. Because no class-labels are included, it can also be used for datasets without known labels and thus for feature selection in case of unsupervised learning. Between InfoGain and ReliefF, there were often only minor differences. In some cases, one method was better than the other and vice versa. For all datasets, it was possible to reduce the feature set to a specific number of features without losses and often even with improvements in recognition performance. It could be shown, that a significant improvement of the recognition

performance can be achieved by using a feature selection carried out in advance for classifiers with high sensitivity to irrelevant or redundant features. Even using classifiers with low sensitivity to redundant or irrelevant features, a reduced feature vector can lead to higher accuracies. This reduction allows many advantages. From the point of view of storage capacity and computing power, it is also absolutely necessary to keep only those data, which provide added value for the classification task. This is especially important in Big Data or in spectral imaging data.

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