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An Intelligent System for Efficient Rigid Film Anticounterfeiting Inspection

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1. Introduction

The danger that results from taking ineffective pharmaceutical products or consuming food that does not comply with the requirements, leads to significant health, and life hazard for people. Anticounterfeiting of, e.g., pharmaceutical products, guarantees customers the delivery of original products. The rigid film industry is developing automated systems to detect product piracy. For this aim, an approach to an automated inspection system for rapid and reliable product verification based on optimized insertion of infrared (IR) and ultraviolet (UV) µm-pigments in rigid films has been developed in this work and statistically meaningful samplesets have been extracted. The industrial manufacturing process has been enhanced for optimized insertion of pigments in rigid films with regard to size, type, density, and process step. The pigments are activated with IR or UV light in an encapsulated laboratory system specially developed here. Filter on illumination sources and colour cameras limit the activation and the emission range. Due to optimized film manufacturing and measurement system, the evaluation of µm-pigments can be achieved by a two-stage process of state of the art supervised colour segmentation, followed by a blob analysis. The recognition results of the conceived intelligent engineering system fully meet the industrial specification requirements. The project has advanced from a laboratory, small volume production to a large volume test customer production and evaluation.

2. An intelligent inspection system

Product piracy causes a loss of 600 bn USD world wide every year (Barbieri, 2004). A product copy due to plagiarism is difficult to differentiate from originals. The danger of unknowingly consuming vitally important pharmaceutical products that are either not effective or even poisonous is a stringent societal problem. The financial situation of product markets shows the problem of capital investment in new products when no profit is realized due to illegal copies. To disclose illegal copying of original products the rigid film industry developes reliable application and authentification systems to make product packages and their content safer. As one part of the first stage of the supply chain the rigid film industry is able to achieve this goal for the whole supply chain.

The rigid film industry wants to secure the path from the producer to the customer to avoid replication at low additional costs. The package appearance should not change and the whole system has to be integrated easily in the packaging-process.

Klöckner Pentaplast, Montabaur, Germany, has been looking into ways of marking packaging film in such a way that it can be subsequently recognized by the film manufacturer and can also be used for product protection by the converter.

This work`s aim is to develop measuring systems with costs lower than 2000 € for visual detection of pigments and authentification of the product package. The variable cost of the pigment has to be lower than 0.1 Cent/kg of foil. The reproducibility of equal distribution has to be guaranteed during the production process.

The specifications of the research and development department of Klöckner Pentaplast request the ability to measure the UV- and IR-pigment density in films by using light sources, filters and cameras, and achieve a correct separation of actual pigments and fibres due to contamination.

In this work, the process of calendering is described in section 2.1 (Fig. 1), focusing on the insertion of light emitting pigments for anticounterfeiting.
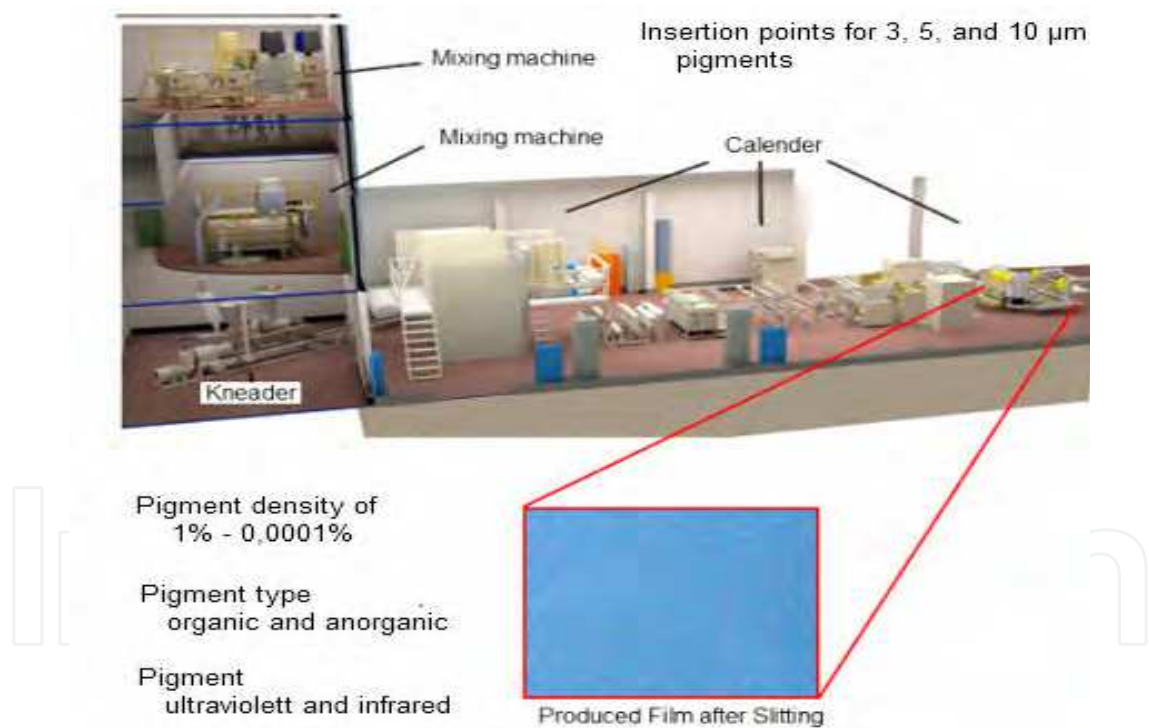

Fig. 1. Insertion points for pigments in the process of rigid film production: 1. mixing machine, 2. kneader, 3. Calendar

A short description on the kinds of pigments, which are used, their activation under IR and UV light sources and related data acquisition will be shown in section 2.2. A hierarchical, two-step classification- approach, that serves to segment the acquired images of pigmented films explained in section 2.3. An overview of the whole anticounterfeiting process is presented in section 2.4, before concluding.

2.1 Basic process and application specific adaptations

The standard production of marked transparent and coloured films can be described in a complete process diagram (Fig. 1). Additional pigments can be inserted in a master batch, which is mixed in two mixing machines with high and low temperature, and the kneader, which plastifies the batch. The insertion of pigments in the calendar where the film becomes formed is inefficient. The produced foil is slittered at the end of the calendaring process for the transport stage. Further changes on the film will be made in a printing firm or the other industrial plants after transportation.

The pigments dedicated to product identification were inserted in the recipe of the mixing machines. Anorganic and organic types have been investigated. Anorganic pigments are FDA approved and do not cause any problems to industrial usage. Thus, polymeric films can be doped with fluorescent pigments (FDA approved, anorganic) for protection of polymeric packages. Standard pigment sizes from manufacturers are 3µm, 5µm, or 10µm.

An inserted pigment density of 0.0001% up to 1% is used in this work. A higher density of more than 0.1% leads to an unintentional coloration of the polymeric film, which was a motivation for an upper and lower boundary and stepwise increment in variation.

The intensity and distribution of the pigments is depending on the thickness of the film. The following permutations have been explored by preliminary work with 300 tests on pigment size, type, density, and film thickness empirically. Starting with the smallest size, smallest density, random type, and smallest film thickness, about 1500 pigmented films were produced with 20 different pigments of three different sizes, 3µm, 5µm, and 10µm. Successful laboratory tests with films of 60µm up to 800µm thickness allow the use of product identification even for multilayered films.

Dedicated measurement laboratory equipment is developed for the detection of the pigments in the films. UV fluorescent tubes (UV-A, UV-B), and light emitting diodes (UV-A, UV-B) activate pigments, and other materials. IR light emitting diodes (880nm – 1050nm), and a laser-diode (980nm) activate the IR pigments used in the film.

The range of settings (Tab. 1) will be completed by achieving best recognition results with measuring devices in chapter 2.2.

Types : = 20	Size : = 3	Density : = 5	Film Thickness : = 5
Organic (natural)	3 µm	0,0001%	200 µm
Anorganic (synthetic)	5 µm	0,001%	300 µm
Ultraviolet (300-370nm)	10 µm	0,01%	400 µm
Infrared (940-980nm)		0,1%	600 µm
		1%	800 µm

Table 1. Ranges of preliminary tested parameters for 1500 films with 20 different pigments

The surface analysis and classification methods show advances for anorganic IR pigments with 5µm, 0.001% density, and 300µm film thickness. The whole tested setting are shown in figure 2.
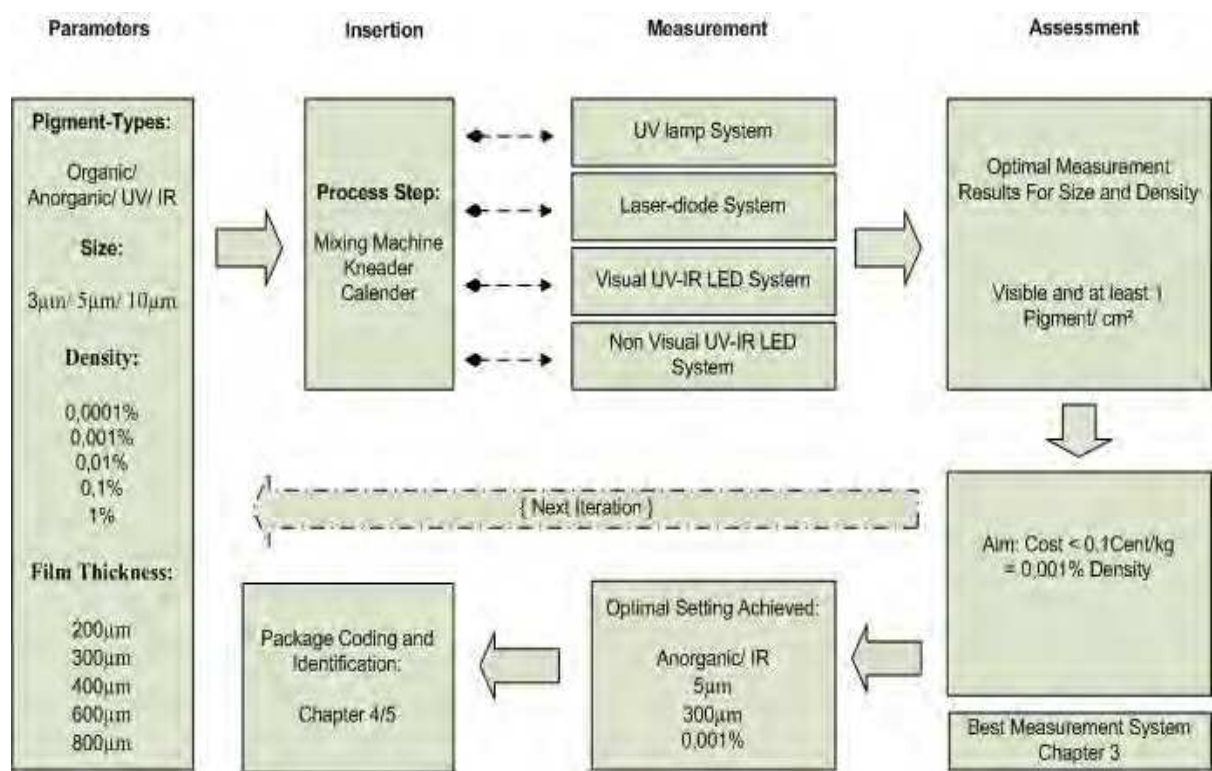
Fig. 2. Tested pigment parameters for 20 types, 3 sizes, 5 densities, and 5 film thicknesses

Four measurement units where deployed. The measurement setup and data acquisition will be explained in chapter 2.2.

2.2 Measurement setup and data acquisition

For the required measurements, four different measuring devices (UV lamp system, visual UV-IR LED system, non visual UV-IR LED system, and laser diode system) were developed in this work.

The settings from chapter 2 have been investigated during the measurement setups and data acquisition with these four units.

The UV illumination is generated by fluorescent lamps and light emitting diodes at activation wavelengths of 300nm to 370nm. Depending on the pigment emission a bandpass- filter is used to detect the pigment wavelength with a colour camera. It is very efficient to use filters for camera and light source to minimize reflections and other influences.

Pigments are activated in UV or IR light and emit in lower or higher wavelengths (Fig. 3 shows an example). These pigments are called up- and down- converters. This feature is used for the following measuring devices.

Blisters are prototypes of pharmaceutical packages that show the produced film in the way they are used later for products. The activation light source for the film is placed in 45° above the object. A camera captures the image in 90°. The coloured image acquisition allows a colour-spaced segmentation as a next step. In this work about 100 blisters were captured.
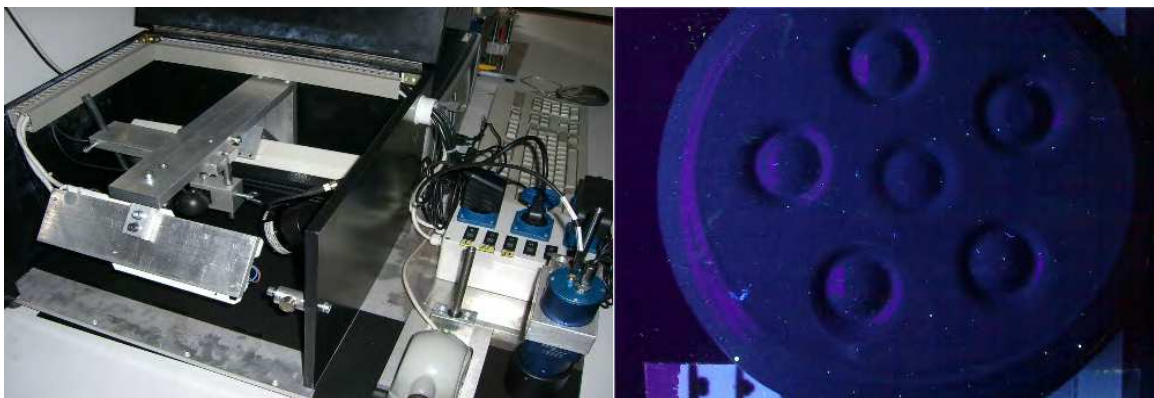
Fig. 3. Measuring device (left) for UV pigments in a blister (right)

The second system is an IR recognition system, which detects pigments with an activation wavelength from 900nm to 1000nm. (Fig. 4)
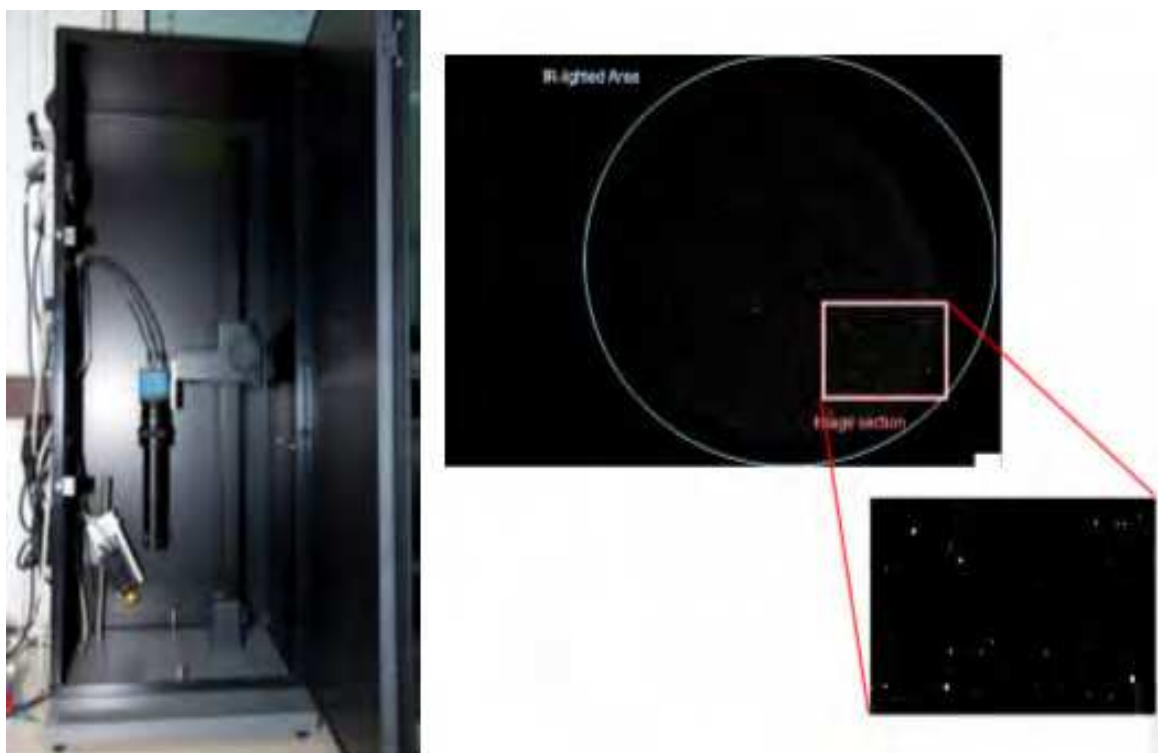

Fig. 4. Image acquisition on 10cm² with a 11-mega-pixel-camera (b/w), image section of 2cm² with a fluorescent IR pigment density of 0,001% and 5µm

A laser diode with an optical spreading device is able to illuminate an area of 10 cm² in an appropriate normalised distribution for image acquisition. The IR lighted area and the selected image section with fluorescent IR pigments are shown in Fig. 4. The illuminated pigments are captured by the black/white camera. For this specific measurement system, 100 testing films have been captured for ensuing analysis.

In Fig. 5 a measurement unit (Visual UV-IR LED System) is shown, which is in development for the recognition of UV, and IR pigments. The hand-held unit allows a fast analysis of rigid film surface at all places in the plant.

Fig. 5. Hand-held unit for internal use for fast recognition of UV, and IR pigments

Different measurement units were tested as described in this chapter. A compact installed laboratory or inline- system is expensive. (Tab. 2)

UV lamp system	Laser-diode System	Visual UV-IR LED System	Non-Visual UV-IR LED System
3000 €	15.000 €	1500 €	1000 €
365nm/ 300nm	975nm	320nm/940nm	365nm/940nm
2 lamps	1 laser-diode	8 diodes/ 8 diodes	12 diodes/ 12 diodes

Table 2. Price range for the different illumination systems

As an alternative the hand-held systems can be used after the calendaring process for fast identification in the plant, at the pharmacy or integrated in a cash terminal. In the textile industry this system can be used for identification of jackets after the production process.

2.3 Two-stage recognition system and results

Based on the optimized rigid films and measurement setups the ensuing evaluation is already feasible by state of the art techniques applied in a two stage approach. The first stage of classification separates the light emitting pigments from the background and the reflections caused by the light source of the measuring device by supervised segmentation. This stage is called here *microclassification*. To separate the pigments from contaminations (fibres) a second classification is carried out on the segmented images, denoted here as *macroclassification*. The origin image is shown in figure 6.

Supervised segmentation of images generates binary images with candidate pigment pixels highlighted. Expert knowledge is integrated during data selection and labelling in the design process. For manually selected relevant sample pixels from 30 specially fabricated films (type: anorganic, size: 5µm, density: 0,001%, not thermoformed), class affiliations were interactively generated. (Fig.7). From the RGB images LAB color-spaced images of the same size were computed, and from the selected pixel coordinates 1200 labeled three dimensional

vectors have been acquired, balanced for both classes and randomly split into training and sample sets of 600 vectors each.
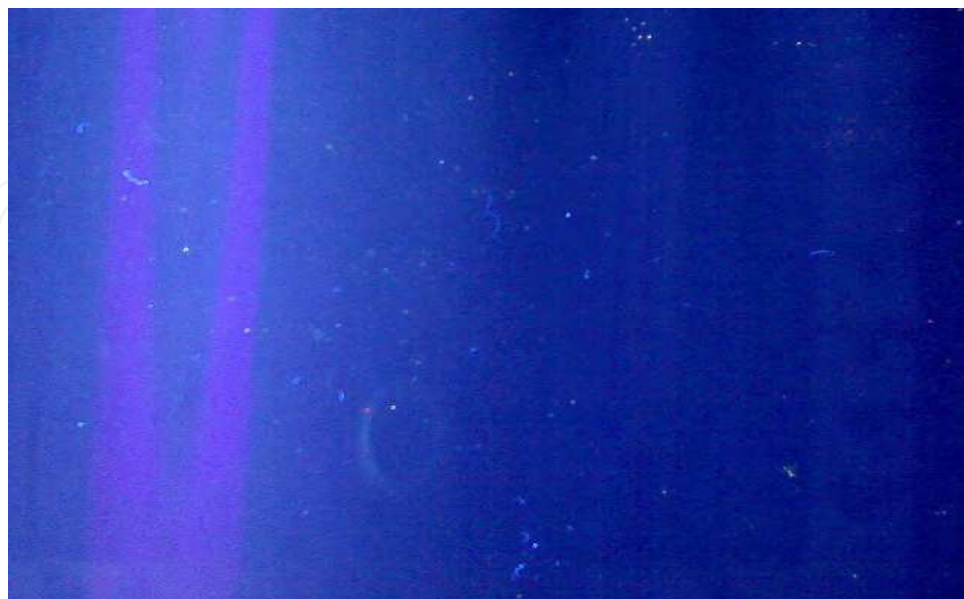

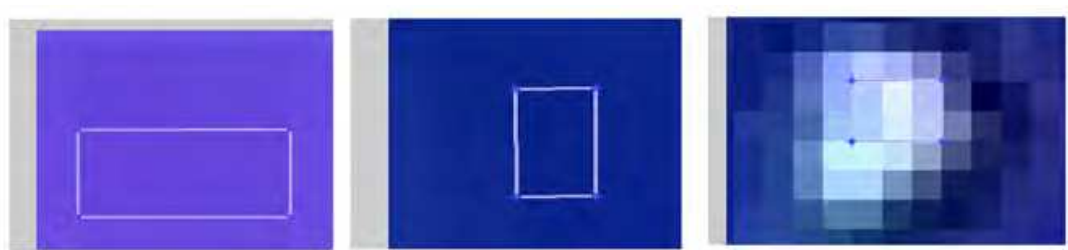Fig. 6. 640x480 pixel RGB image of a rigid film under UV (302nm)

Fig. 7. Manual selection of example pixels representing the two classes reflections/background (left, middle), and pigments (right) for segmentation classifier training

The selected pixels (Fig. 7) define vectors of LAB-colour space for each class to be presented. In a pre-examination the LAB-colour space generated best segmentation results, but other colour spaces can also be used (Hunter Labs [HL], 1996).

The classifier achieves supervised segmentation by assigning a class to each pixel of the RGB image.

For the underlying problem complexity, a non-parametric classifier should be chosen for optimum classification results.

The training vectors of the defined classes separate all samples into different classes by using the L, a, or b data of a sample.

The L, and a data of each vector achieved better results for the Support Vector Machine (Matlab-Toolbox) with 99.83%. Pigment and Background vectors can be distinguished more efficiently. (Fig. 8)

The CorrectRate defines the possibility for becoming classified as a pigment. For efficient use the whole Anticounterfeiting system has to detect 99% correct. Errors in the microclassification will be dominantly compensated in the second stage. The size parameters prevent a wrong assignment (Christianini & Shawe-Taylor, 2000).
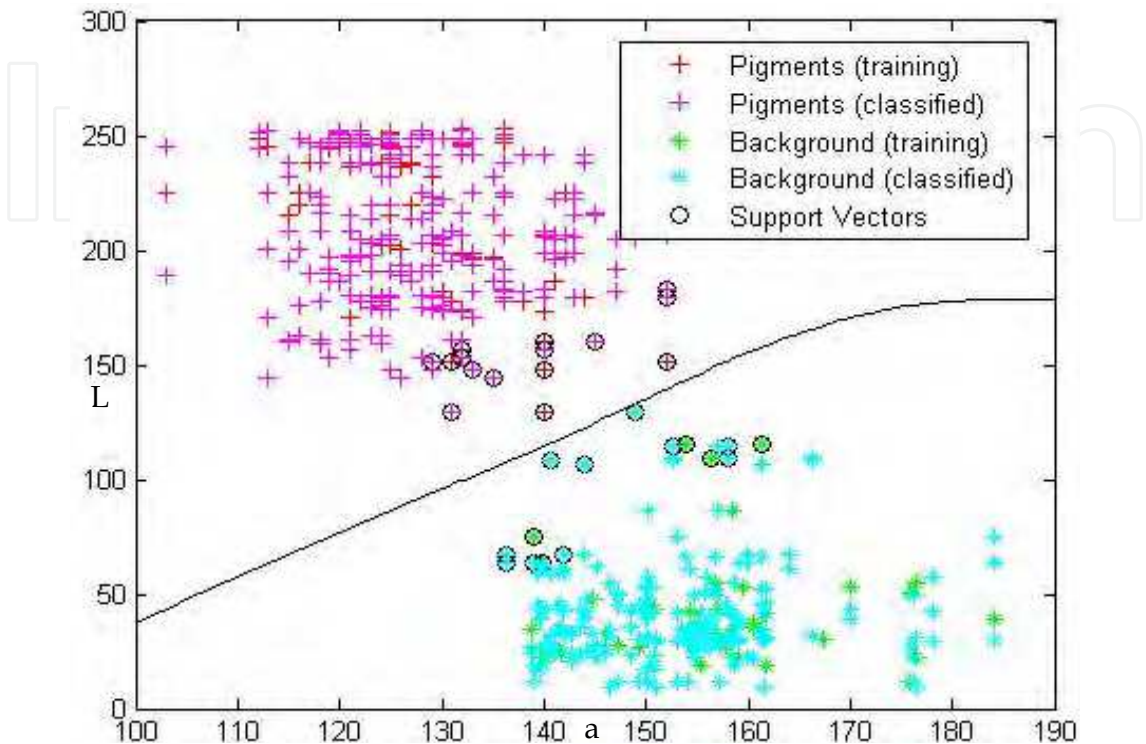

Fig. 8. Scatterplot of 600 training- and 600 testing vectors of L, and a data from L,a,b colour space (SVM – Matlab Toolbox) – CorrectRate = 99.83 %

The a, and b data of each vector showed similar recognition results in comparison with the L, and a data correlation.

Thus, the L, and b data correlates with 99.5%, the L, and a data will be preferred for further classification (99.83%).

The classification results of the training data of 600 vectors (features: L,a,b of colour space L,a,b) and the testing data of 600 vectors are shown in Tab. 3. Four classifiers (kNN, PNN, RNN, and SVM) are known as state of the art methods. These types use different mathematical algorithms for the separation, and classification of sample sets.

	kNN	PNN	RNN	SVM
Classification rate for test set using hold-out approach	k=1 99.5 % k=2 99.5 % k=3 99.5 % k=5 99.5 % k=6 99.5 % k=8 99% k=10 99 %	σ: 0.1 99% σ: 0.03 99% σ: 0.001 60%	99%	99.83 % quadratic Kernel C = 0.1 – 100000 Gamma = 0.001 - 10

Table 3. Microclassification results

Thus, the k-neareast-neighbor (kNN), the reduced-nearest-neighbor (RNN), the probabilistic neural network (PNN), and the support vector machine (SVM) classifier have been applied, and found already to be satisfactorily working (Duda et al., 2001).

The segmented images from the 99.83% correct (SVM) microclassification are used for blob analysis, which has the potential to eliminate residual erroneous pixel classification by the context of pixel cluster shapes. The macroclassification, based on geometrical features of blob analysis, separates light emitting pigments from fibres. (Fig. 9)
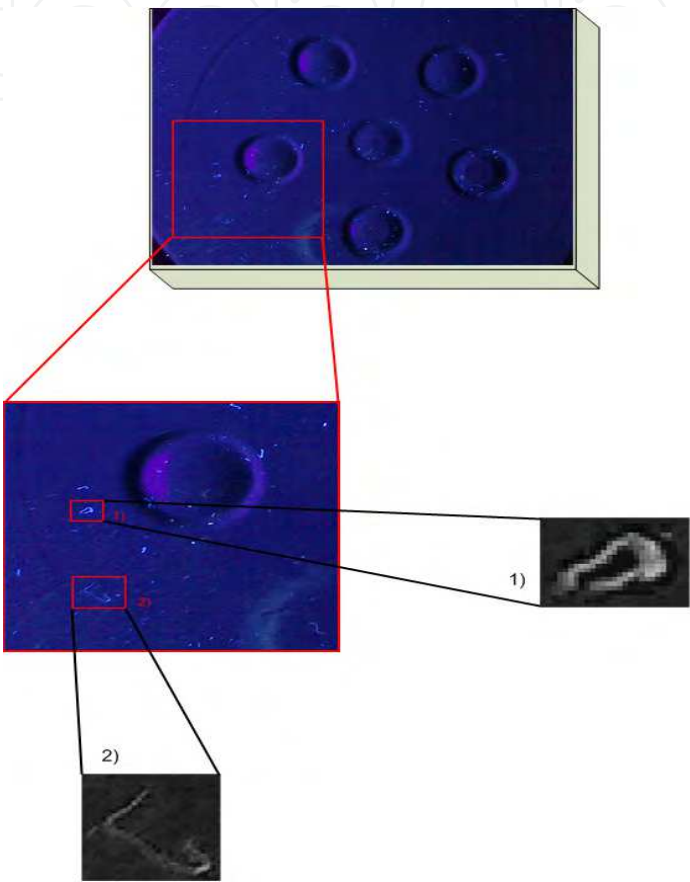
Fig. 9. Separation of fibres from true pigments after segmentation

Fibres originate from contamination or clustered particles (Fig. 10). The geometrical structure of fibres is different from the structure of the pigments.

Fig. 10. Subregions containing fibres and pigments for training and test data

From eight blob features, area, perimeter, balance point, compactness, outer circle, inner circle, symmetry, limitative rectangle, the most significant ones (area, rectangle) are automatically chosen by feature selection to distinguish between both classes.

Out of pre-selected 300 vectors for pigments, the training set of 100 feature vectors of pigments, 100 feature vectors of fibres, and the test data consisting of 50 feature vectors of pigments and 50 feature vectors of fibres from the same images were employed. (Tab. 4)

	kNN		PNN		RNN	SVM
Classification rate for test set using hold-out approach	k=1	100 %	σ: 0.1	100 %	100 %	100 % quadratic Kernel C = 0.1 – 100000 Gamma = 0.001 - 10
	k=2	100 %	σ: 0.03	100 %		
	k=3	100 %	σ: 0.02	72.5 %		
	k=5	100 %	σ: 0.001	52.5 %		
	k=6	100 %				
	k=8	100 %				
	k=10	100 %				

Table 4. Classification results for the blob analysis

The result of the k-nearest neighbor classification is an image only consisting of pigments. Classes like background, reflections or fibres are not included any more (Gonzales & Woods, 2008; König et al., 1999; König, 2001).

After detection and elimination of the fibres, the located pigments can serve for a higher-level authentification process in a following step (Fig. 11).
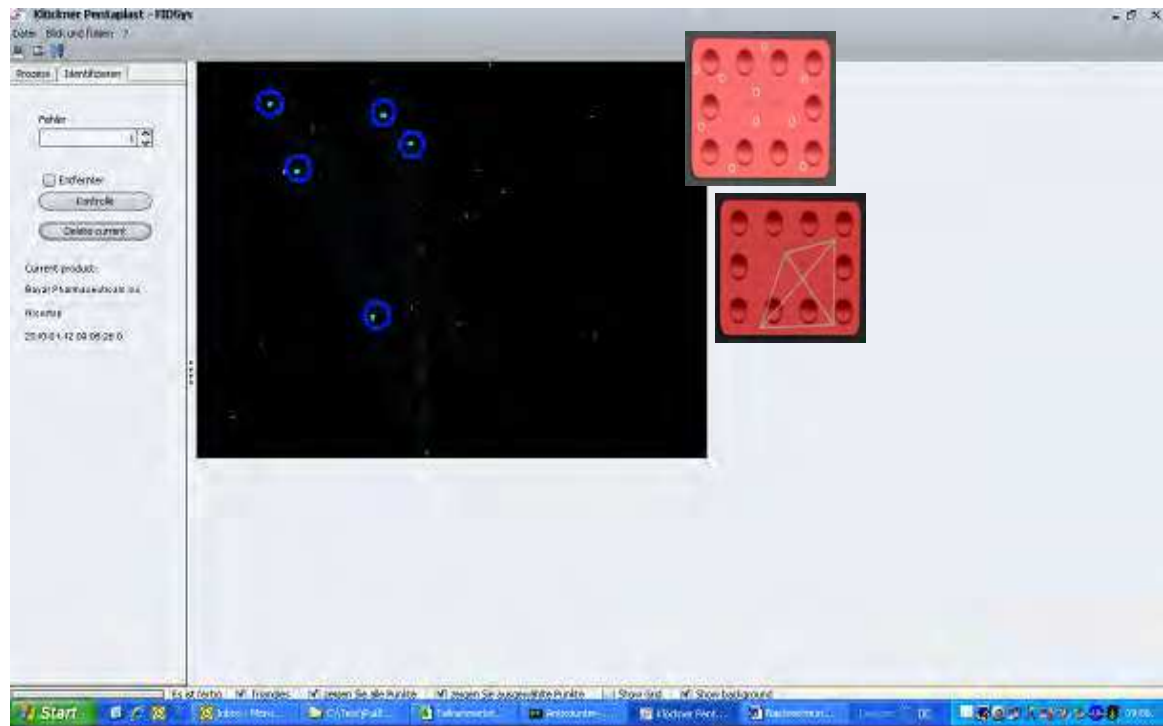

Fig. 11. Selection process (Blue identification pigments in software analysis)

Using the described state-of-the-art method for plane films or blisters as shown in the image, a selection of partial areas allows a defined analysis of completed packages at the

end of the production process. This has been experimentally verified on the detection results for three randomly chosen rigid films. The coding process separates package/production id, date, corners and angles to define a unique digital signature for each package. The selected pigments have a geometrical correlation (angles) which is saved in the digital signature of the package code. The pigments are selected randomly, but their coordinates can be recalculated in the verification process (Fig. 12).

Fig. 12. Coding process

After the polymeric coding a database server saves the scanned angles for further comparison of the packages at the client. The small code allows a fast, brand recognition (Fig. 13).
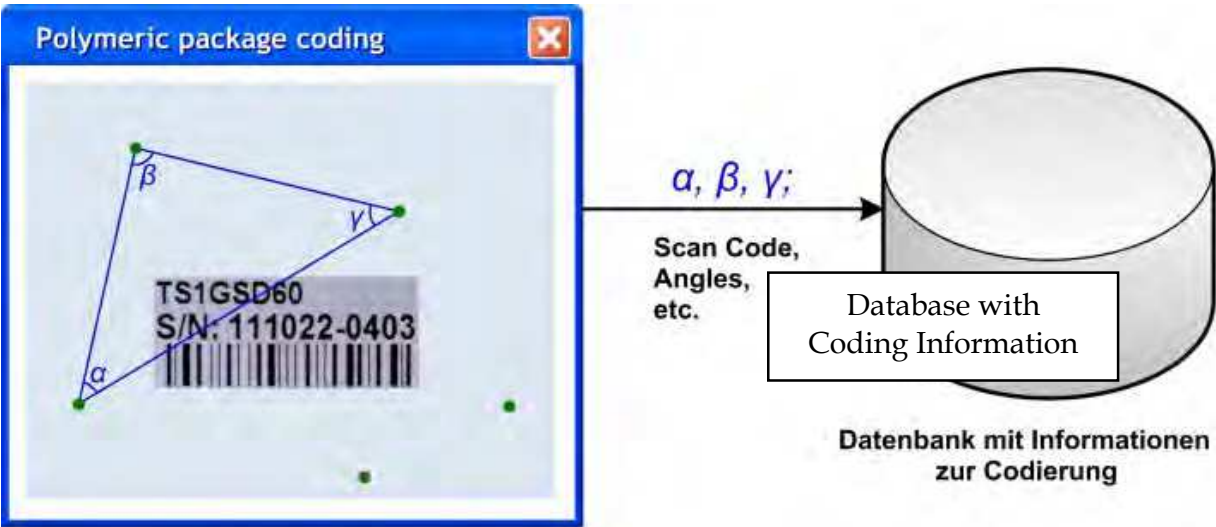
Fig. 13. Polymeric Package Coding

An inline-inspection system (see Fig. 14) is actually in progress for first detection during the calendaring process. The patented technology is available to all users of rigid film from Klockner Pentaplast. The inspection system is not implemented yet. Figure 14 shows an impression of the final system at the end of the development process.

Authentic products can be reliably protected with a fingerprint which is obtained through the incorporation of randomly-distributed pigments in the packaging, which are then made visible (C. Kohlert et al., 2010).
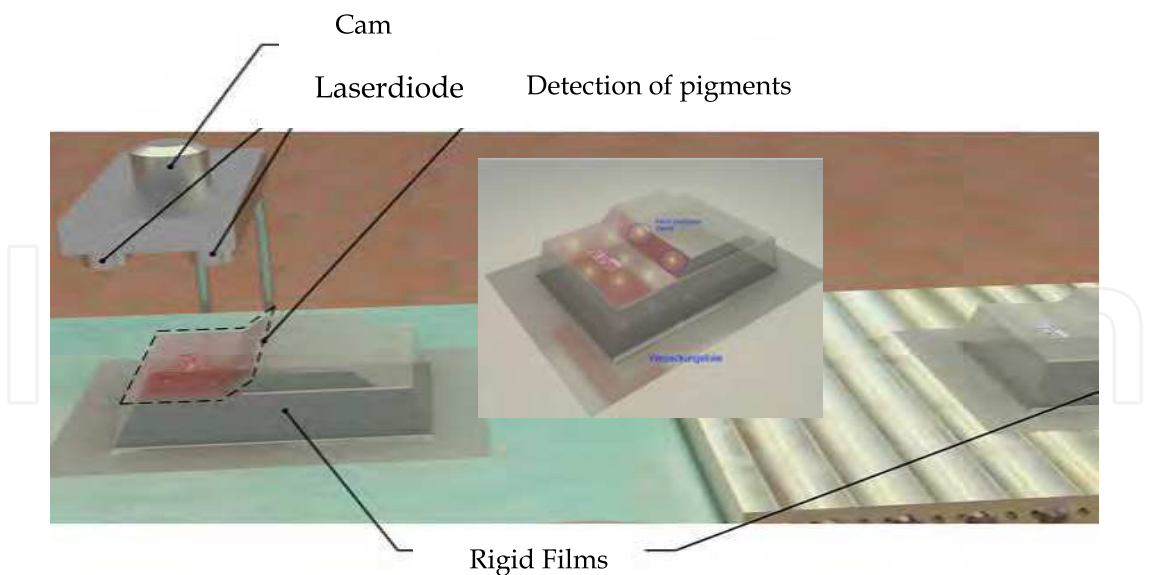
Fig. 14. Inline-Inspection system at the end of the calendaring process – shortly after the thermoforming-/ or the slitting process

2.4 Complete anticounterfeiting system

Using UV or IR pigments for anticounterfeiting is a novel approach in the rigid film industry. The insertion in polymeric recipes allows high level security for the whole supply chain. The complete process of anticounterfeiting rigid film is shown in the next figure (Fig. 15).
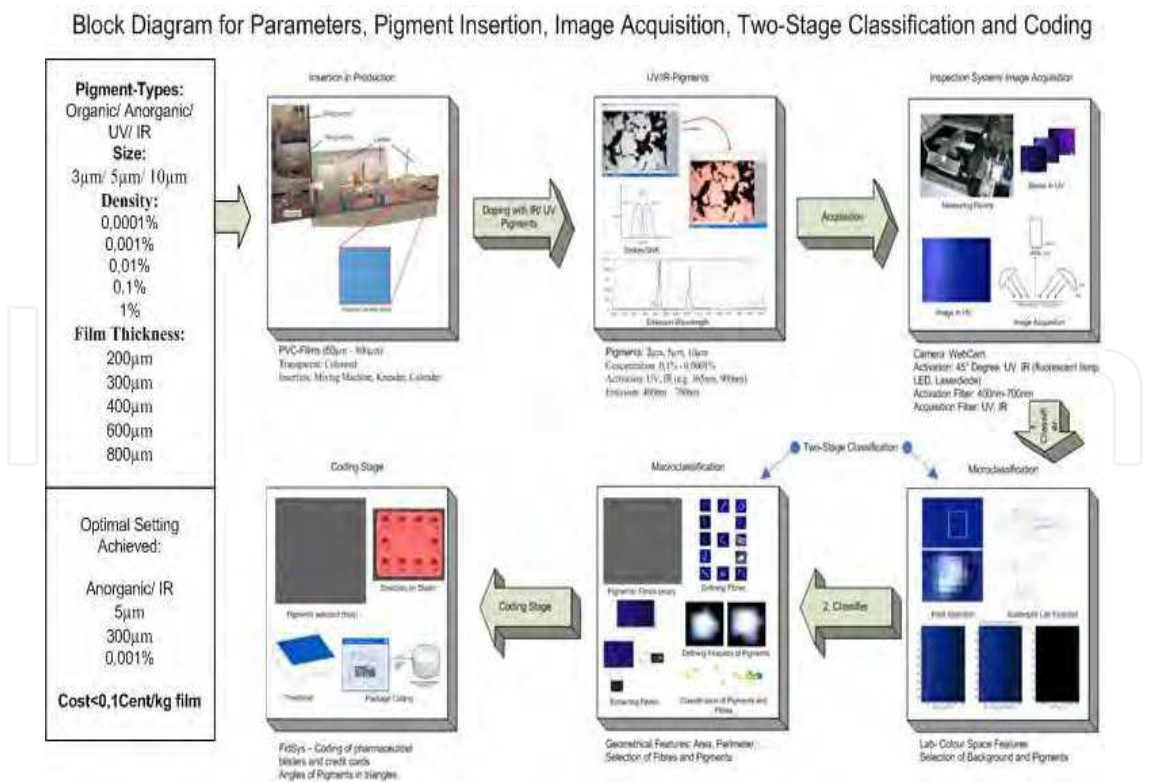

Fig. 15. Processing diagram for pigment insertion, image acquisition, two-stage classification, and coding stage

The insertion of pigments can be done at the mixing machines, the kneader, or the calender. The mixing machines, as the best insertion point, consisting of a mixture of particles (batch) allow a fast disposal of the pigments within the batch.

The choice of the pigment type depends on the measuring device. For optimal results IR pigments are better to distinguish from other batch particles. Most batch particles emit in UV ranges, so the UV emission can be ten times higher than the defined insertion.

A two-stage classification separates pigments from other materials in an image with a correct rate of 100%.

For anticounterfeiting of rigid films a specially developed software authentificates a polymeric package via recording, and reading of random pigment structures correctly. It calculates the geometrical positions of the pigments with 99% accuracy, and checks the apparent authenticity of a film, or a blister within 6 seconds.

3. Conclusion

In this work, a viable and economic implementation of a product authentification system was developed, that is able to recognize, and locate IR and UV pigments in specially fabricated polymeric films. A special feature of this approach is, that film manufacturing and measurement were optimized with regard to recognition accuracy, so that rather basic methods could be employed in the back-end for successful identification, which is also important for aspired low-cost detection devices.

The modification of the polymeric standard process of film production by insertion of pigments was implemented in two of three possible ways. The mixing machine showed best results for optimized distribution. An insertion during the calendaring process causes no optimal results. The kneader is another possibility to insert pigments as fluid, and will be tested in further tasks.

For optimal detection, and separation from fibres, anorganic IR pigments with a density of 0,001% and a size of 5μm showed best results in comparison with UV pigments.

Four different measurement systems, an UV lamp system, a visual UV-IR LED system, a non visual UV-IR LED system, and a laser-diode system were established. The IR LED systems showed best results for film recognition.

A hierarchical two-stage recognition system with state of the art methods for pigment and localization of 100% accuracy has been achieved.

Classification techniques, e.g. Support Vector Machine have been investigated with existing and new data sets to improve system reliability for viable inline-process measuring, and portable inspection systems.

The industrial specification of the company with regard to a homogenous insertion of IR and UV pigments in the calendaring process, and a separation of fibres is fully achieved. In future work, more extensive datasets will be generated, in particular for blob analysis, to ensure wider generality.

The real time behaviour and resource demands of the proposed system have to be regarded carefully, and potentially optimized for hand-held inspection devices (M. Kohlert et al., 2010).

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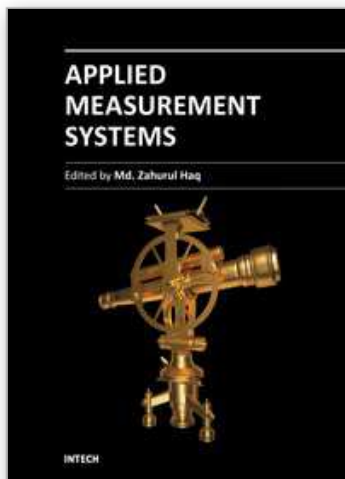
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