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3D Measurements on Extrusion Marks in Plastic Bags*

ABSTRACT: The surface of different types of garbage bags was scanned using non-contact laser profilometry. Manufacturing defects known from visual inspection of the bags (fish eyes, arrowheads, and surface scratches) appear as differences in the height profile. Extrusion lines could only be detected in low-density polyethylene bags. Their correlation length is a couple of centimeters, whereas visually they continue over meters. This can be used to link together the end of one garbage bag with the beginning of the subsequent bag. Extrusion lines are of the order of 0.1 μm for high-density polyethylene garbage bags.

KEYWORDS: forensic science, plastic bag examination, profilometry, extrusion lines

Plastic bags can play a key role in forensic investigations because they are often present as evidence material on crime scenes. Plastic garbage bags are frequently used as packing material for pieces of body or other objects related to a certain crime. The main question in all these cases is: is the recovered garbage bag part of a roll found at the suspect's home or do bags found at a different location come from the same roll? The major aim for the forensic investigator is to determine whether one garbage bag can be linked to another. For the comparison of these garbage bags, the investigator takes manufacturing defects into account (1). Plastic garbage bags are made from high-density or low-density polyethylene and can show, depending on the production process, the following defects: tiger stripes, pigment bands, surface scratches, fisheyes, arrowheads, and extrusion lines (2,3).

The extrusion lines play an important role in the comparison (and subsequent linking) of plastic bags. In a number of garbage bags, they show up as parallel lines that last over distances of the order of meters. These lines are mostly slightly inclined towards one of the edges of the garbage bags, which is due to a slow rotation of the plastic bags during the production process (1). The angle of inclination of these lines allows forensic investigators to make an estimate of the position of the questioned bag within a roll by means of transmitted light. The appearance in visual inspection can be enhanced by observing them using linear polarized light. Another possibility to link two garbage bags is by matching cut or torn edges. A number of the inconveniences of conventional lighting and comparison techniques can be overcome by 3D measurements of the surface (4).

In this paper, we will address the following questions: (a) what type of characteristic manufacturing defects can be seen in 3D measurements and (b) what is their forensic relevance? In other words, do profile measurements provide a means to characterize the above-mentioned plastic garbage bags? To answer the former questions, a thorough study of two distinct types of plastic bags was undertaken. The surface topography of these bags was scanned with a laser profilometer, a non-contact technique. This is important as a modification of the surface structure of the material renders a second examination by another expert doubtful or even impossible.

This paper is organized as follows: first the technique is briefly introduced as well as the specimens that are investigated. The obtained results can be divided into three parts: (i) we will discuss the characterizing defects that can be discerned in the topographical data. A further numerical analysis of the extrusion lines in low-density polyethylene bags (ii) and the longitudinal marks (surface scratches) in high-density polyethylene bags (iii) is also presented. The applied algorithms are based on the reduction of the massive 3D data into a one-dimensional array, the so-called feature vector. The comparison of different (parts of) plastic garbage bags can be reduced to the comparison of the corresponding feature vectors.

Methods

The apparatus used for the profile measurements was a laser profilometer (UBM Messtechnik). It allows for a measurement of the surface topography with a high resolution in all directions. The lateral resolution (X and Y directions) is about 1 μm, while the profile measurement (Z direction) is correct up to 0.1 μm. The underlying principle of laser profilometry technique relies on the principal that the intensity of the laser light reflected by the surface of the sample is maximal when the laser beam is focused on the surface (intensity focus detection system). The intensity of the reflected laser light is translated into an analogue signal that is used to alter the position of the focusing lens. This feedback system ensures that the laser remains focused on the surface (5). The measurements were performed with a point density of 400 points per millimeter in the X direction (the scanning direction) and 50 points per mm in the Y direction. The high point density in the X resolution is inspired by the small laser spot diameter of about 1 μm and the concern not to avoid characteristics on this scale (6). It implies

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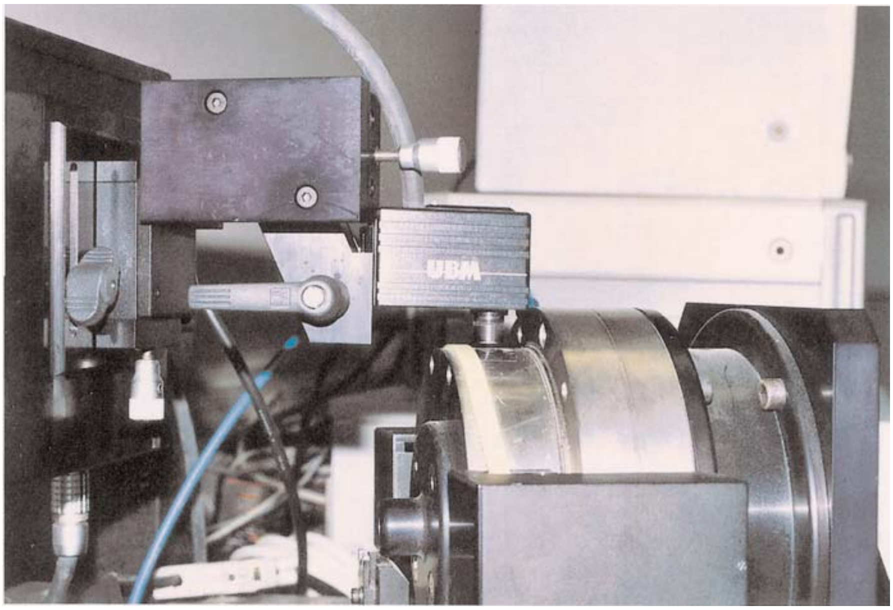

FIG. 1—*Detailed photograph of the sensor and the rotational stage of the laser profilometer with a strip of garbage bag installed.*

also disadvantages: the amount of time necessary to perform a surface measurement—to obtain one dataset, a period of 24 h has to be taken into account—and the processing time and capacity needed for numerical analysis of these large amounts of data points (one dataset contains typically 250 lines of 120 000 points).

Strips of 30 by 2 cm were cut out of the garbage bags. Their longer side was chosen to be orthogonal to the length axis of the garbage bags and the pattern of striations. Due to their length, those strips had to be fixed on the rotational stage, which allows scanning while rotating over 360°. The 30-cm length corresponds almost to a full circumference of the rotational stage. Figure 1 shows the UBM laser profilometer with the rotational stage, the sensor, and the measurement configuration. The whole measurement setup provided highly reproducible results, which was proven by scanning a surface multiple times under the same conditions. The instrument can also be equipped with a translational stage for small flat objects (6).

Two distinct types of garbage bags were investigated, first with a roll of high-density garbage bags with a thickness of 33 μm. These high-density bags were opaque, which inhibits the traditional comparison methods based on transmitted light. Strips were cut out of 14 of the 20 garbage bags on the roll. Secondly, low-density polyethylene bags with a thickness of 43 μm were examined. Several strips were cut out of a single garbage bag.

The visualization and the numerical analysis of the obtained 3D data were performed by means of the specialized software named IDL (Interactive Data Language) and its visual programming environment VIP 1.3 (Research Systems International).

FIG. 2—*Visualization by means of transmitted light of two so-called "fisheyes," dark scattered spots with light-colored tails.*

Results and Discussion

Manufacturing Defects Visible in 3D

The only manufacturing defects of forensic use that could not be discerned in the measured 3D profiles were the so-called "tiger stripes"(2,3). They were probably not present in our samples as they could not be visualized by optical inspection applying different illumination techniques. The following defects could be detected by the laser profilometer: pigment bands, several kinds of surface scratches depending on the type of garbage bags, "fisheyes," "arrowheads," and extrusion lines (2,3). Figures 2 and 3 show the visualization by means of transmitted light of two "fisheyes" and an "arrowhead," respectively. In Figs. 4 and 5, the 3D measurements of, respectively, the former mentioned "fisheyes" and "arrowhead" are represented. Comparing Figs. 2 and 3 with Figs. 4 and 5, respectively, it is clear that corresponding 3D measurements provide more detailed and quantified information on these defects. The fisheye corresponds to a local increase in thickness of the bag (corresponding to a darker, less transparent area in the transmitted light image), being on its two ends bound by a thinner area (white area in the transmitted light image). A variation in the size of these fisheyes was observed, ranging from 2 to 5 mm in length (larger and smaller artifact in Figs. 2 and 4). The arrowhead corresponds to a slight (few micrometers) increase in thickness of the garbage bag.

The most suitable defect for the linking of different garbage bags to a single roll—extrusion lines—can be detected as differences in height by the laser profilometer. A top view of a 3D measurement of extrusion lines in low-density polyethylene garbage bags can be seen in Fig. 6. The extrusion lines show an axial symmetry, but depending on the type of garbage bag, different characteristics of those lines were observed. Regardless the apparent symmetry of the extrusion lines, 250 cross-sections out of the strip of 2 cm width were measured instead of a single line. These 250 lines could then

FIG. 3—*Visualization by means of transmitted light of a so-called "arrowhead," two dark lines meeting at an apex.*

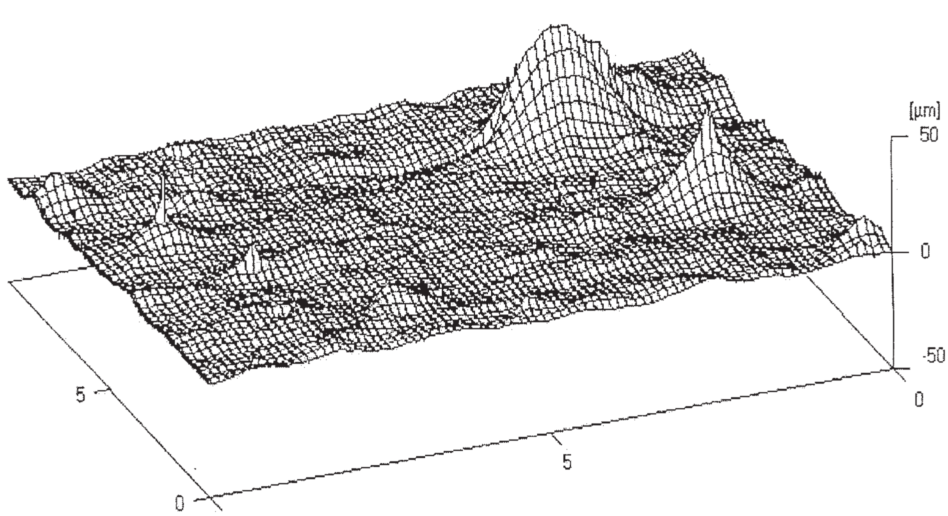

FIG. 4—*3D representation of two so-called "fisheyes": the dark spot corresponds with a local increase in height while the light-colored tails correspond with declining heights. The increase in height is different for the two fisheyes.*

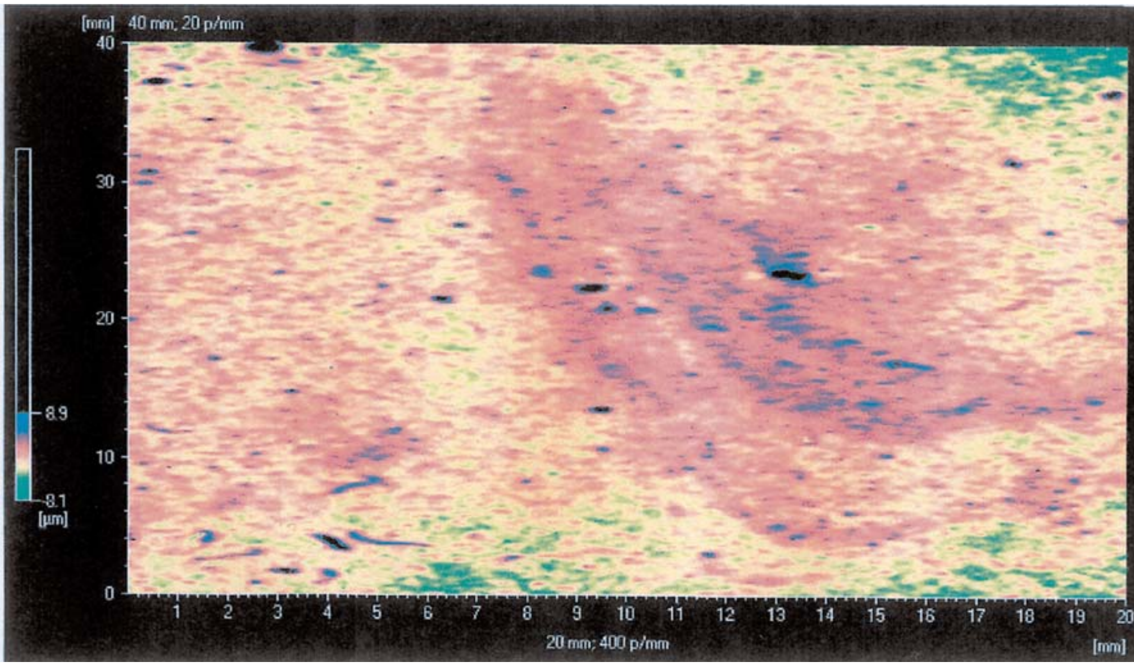

FIG. 5—*3D representation of a so-called "arrowhead" in top view: the color gradation values are a measure for the local height; the dark lines meeting at an apex (see Fig. 3) are due to a small local increase in thickness of the bag.*

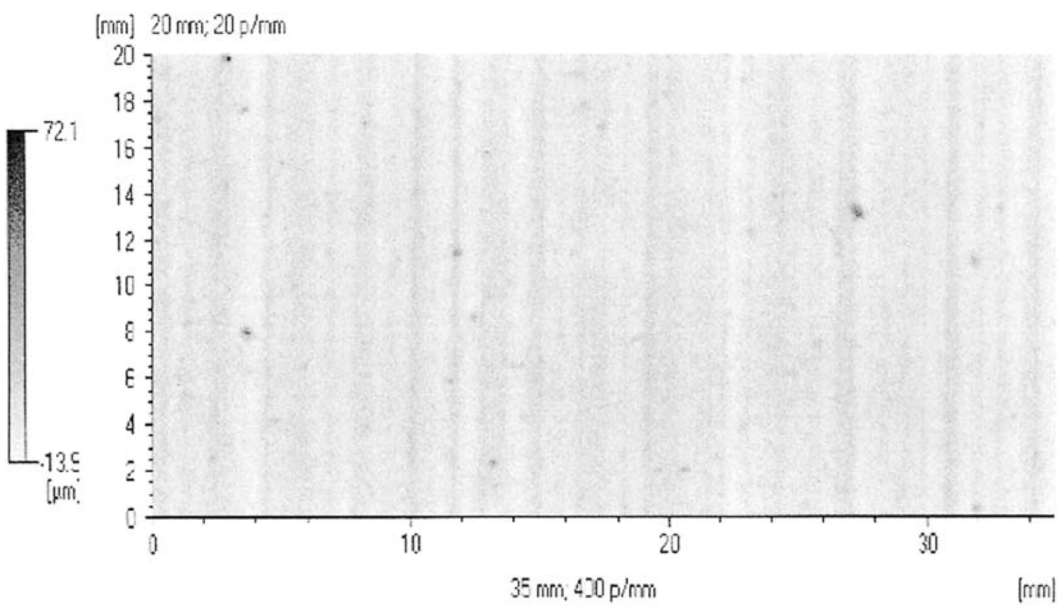

FIG. 6—*Top view of a 3D representation of a pattern of extrusion lines in low-density polyethylene bags. The gray values are a measure for the local height. The axial symmetry of the lines is clear.*

be projected onto a one-dimensional array. This procedure was followed to eliminate small manufacturing defects such as "fisheyes" and "arrowheads" and to improve the signal-to-noise ratio.

All the former-mentioned manufacturing defects can be measured on both sides of the garbage bags, indicating that they originate from a local variation in the thickness of the material.

High-Density Polyethylene Bags

Figure 7 shows a detailed photograph of a small part of the considered high-density polyethylene bags obtained by means of grazing light illumination. No transmitted light could be used, as these bags are opaque. The pattern of lines running in the vertical direction can easily be discerned. The 3D profile of a whole strip of high-density polyethylene bags is shown in Fig. 8. When one examines a cross-section of the 3D profile (represented in the top graph in Fig. 9), four levels of data can be distinguished: (i) broad and intense peaks due to plies (e.g., Peak 1 in Fig. 9), (ii) peaks due to surface scratches (e.g., Peak 2 in Fig. 9), (iii) data due to fine extrusion lines, and (iv) noise. The broad peaks representing plies are overwhelming the profile and have to be filtered out. The components on a length scale of 0.1 to 2 mm were filtered out in the fre-

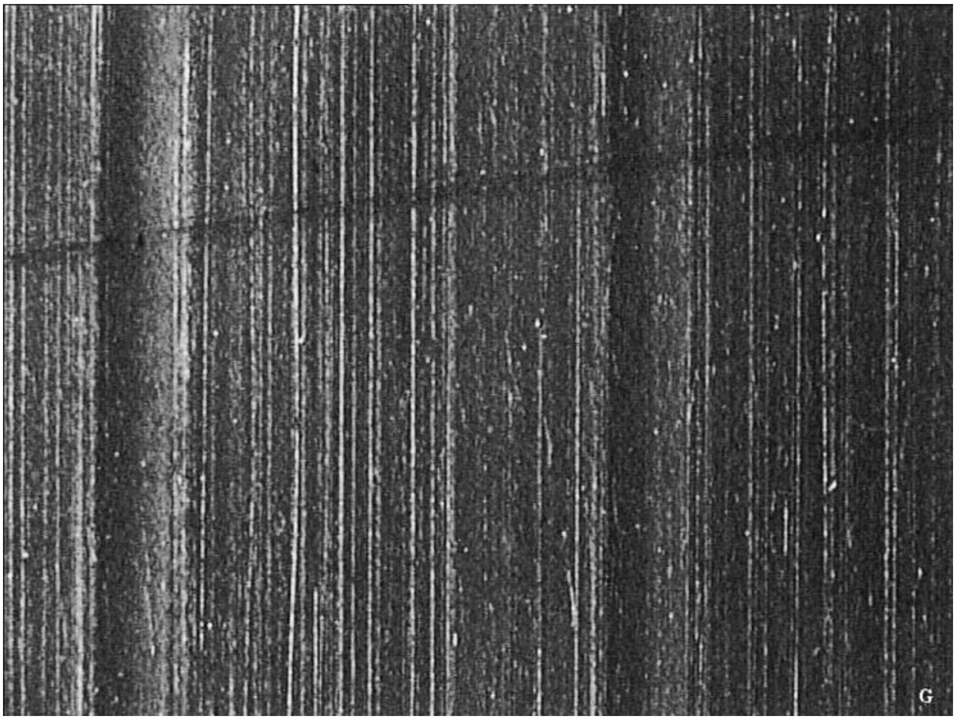

FIG. 7—*Detailed photograph, by means of grazing light illumination, of a small part (few cm) of a high-density polyethylene bag.*

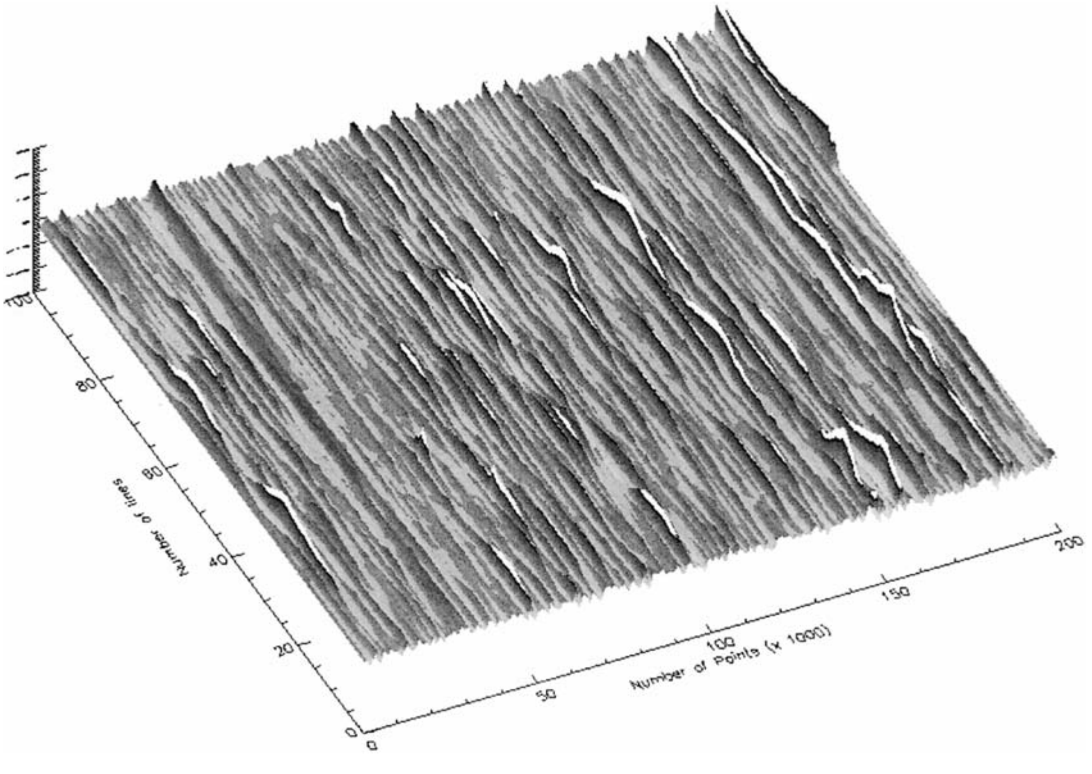

FIG. 8—*3D profile of one strip of high-density polyethylene bags. The symmetry of the lines in the Y direction is clear. For visualization purposes, the number of lines in the Y-direction was reduced from 250 to 100.*

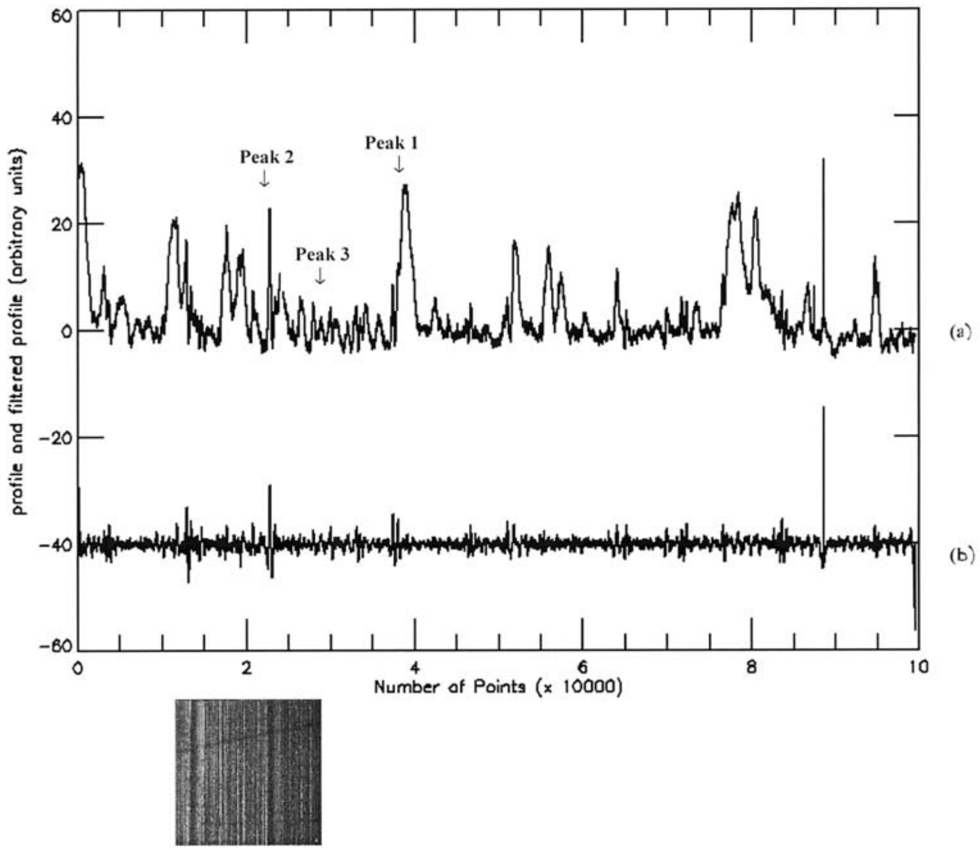

FIG. 9—(a) *Cross-section of 3D profile: four levels of data can be distinguished: broad peaks due to plies (Peak 1), peaks due to surface scratches (Peak 2), data due to fine extrusion lines and noise.* (b) *Cross-section of 3D profile after filtering the data. A photograph of a small part of a high-density bag shows the correspondence in positions of the surface scratches with peaks in the lower graph.*

quency domain (by Fourier transforming back and forth the data). The resulting filtered profile is represented in the bottom graph in Fig. 9. The most prominent peaks in the filtered profile correspond to the surface scratches in the garbage bag. The application of the filter has the advantage of removing all the high-frequency components of the noise. However, no distinction can be made between fine extrusion lines and the remaining noise components. For this reason, further investigation was based on the analysis of the surface scratches. The filter procedure was applied to all the raw data within the above-mentioned length interval.

The following algorithm was developed to reduce the strip of 250 lines, each containing 120 000 points, into a limited dataset still containing the characteristics of the surface scratches: the so-called feature vector. The first set of ten lines was combined into a single line in order to reduce the contributions of localized defects and to enhance the signal-to-noise ratio (Curve a in Fig. 10). The same procedure was applied to the final ten lines of the strip (Curve b in Fig. 10). The resulting two lines were compared using a classical correlation algorithm. The individual contributions of the peaks in the profile to the total correlation value is a measure for the persistence of that feature over the whole strip (Curve c in Fig. 10). This information was used to enhance the surface scratches in the projection by multiplication with the combined data of the full 250 lines (Curve d in Fig. 10). This results in the feature vector (Curve e in Fig. 10) of the strip. This feature vector basically contains the positions of the persisting surface scratches, which are the most important 3D characteristics of these high-density polyethylene garbage bags.

First, the correlation was calculated between the filtered last line of one strip and the first line of the adjacent strip. A correlation value of 0.77 was obtained, indicating that there is still a high correlation between two adjacent strips but there are already variations in the profile detectable over a few centimeters. This result is very interesting for forensic investigation as it provides a means for linking the end of one bag to the beginning of the following.

Our numerical analysis algorithm was applied to the two former mentioned adjacent strips. The resulting feature vectors are plotted in Fig. 11*a* and Fig.11*b*. Apparently only a few peaks corresponded in the two strips. An optical examination of the recorded strips showed only a small amount of surface scratches continuing through both strips, in agreement with the observations made for the feature vectors.

When increasing the distance between the two strips in the roll up to 20 cm, the number of corresponding peaks decreases, as is clear from Fig. 11*c*. The positions of the persisting peaks in the feature vectors are in agreement with the results obtained by means of visual inspection. When we increase the distance between the two strips up to several meters, we see in Fig. 12 that only two corresponding peaks remain. Again this is in agreement with the visual inspection of the roll of garbage bags showing only two continuous surface scratches at similar positions.

One may have the impression that 3D measurements provide similar information to optical techniques. However, they provide quantitative information on extrusion marks, and the comparison algorithm is more objective than visual inspection.

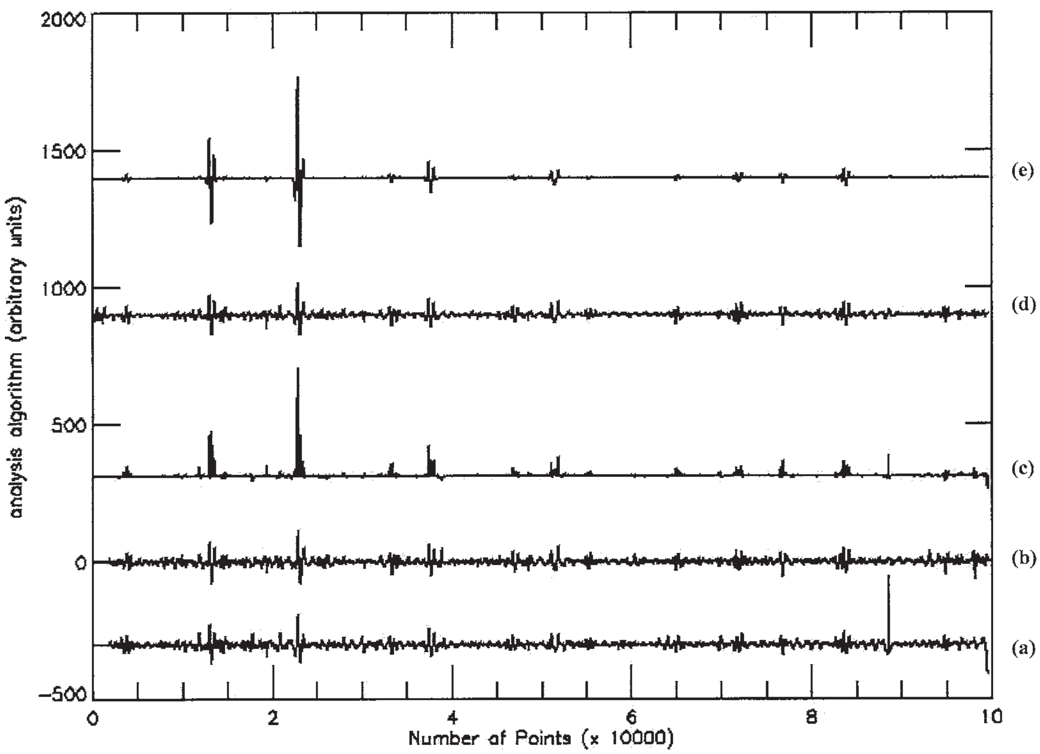

FIG. 10—(a) *Projection of the first ten lines out of 250 into one single line;* (b) *projection of the final ten lines out of 250 into a single line;* (c) *the individual contribution of each peak to the total correlation as a value for the persistence of a characteristic feature in a whole strip;* (d) *total projection of 250 lines of a whole strip;* (e) *feature vector representing one strip and containing the positions of the surface scratches.*

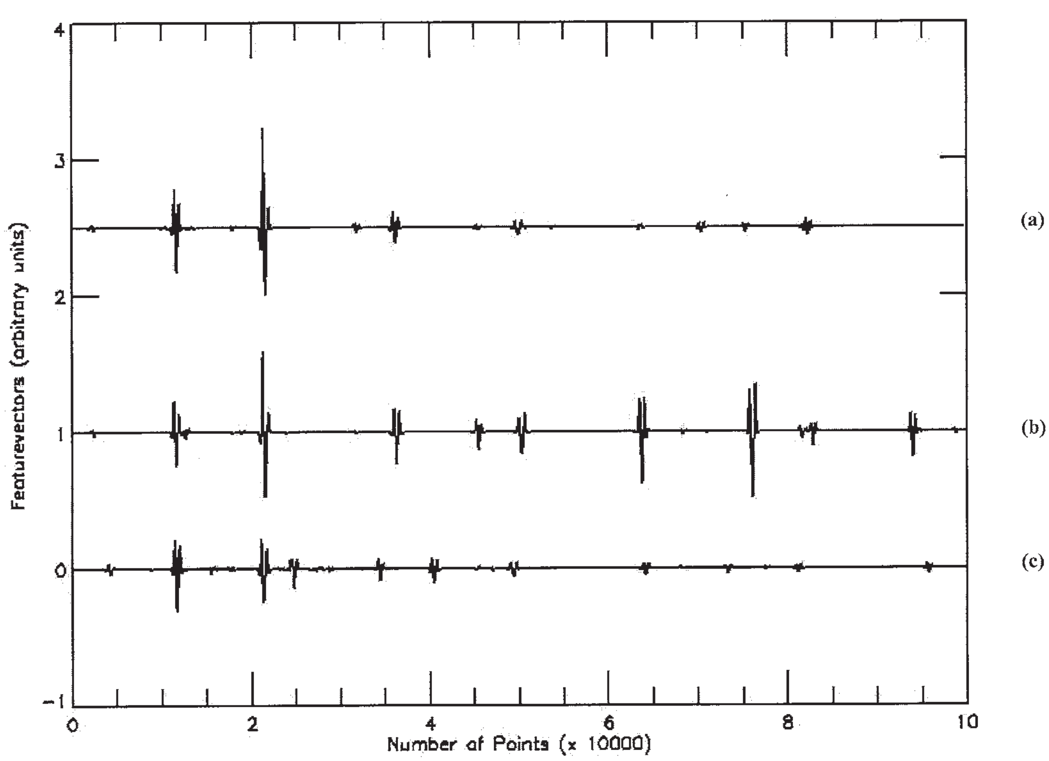

FIG. 11—(a) *and* (b)*: comparison of the feature vectors of two adjacent strips of garbage bag: a few peaks are corresponding;* (c) *the feature vector of a strip from an adjacent bag. When comparing the three feature vectors only two peaks correspond.*

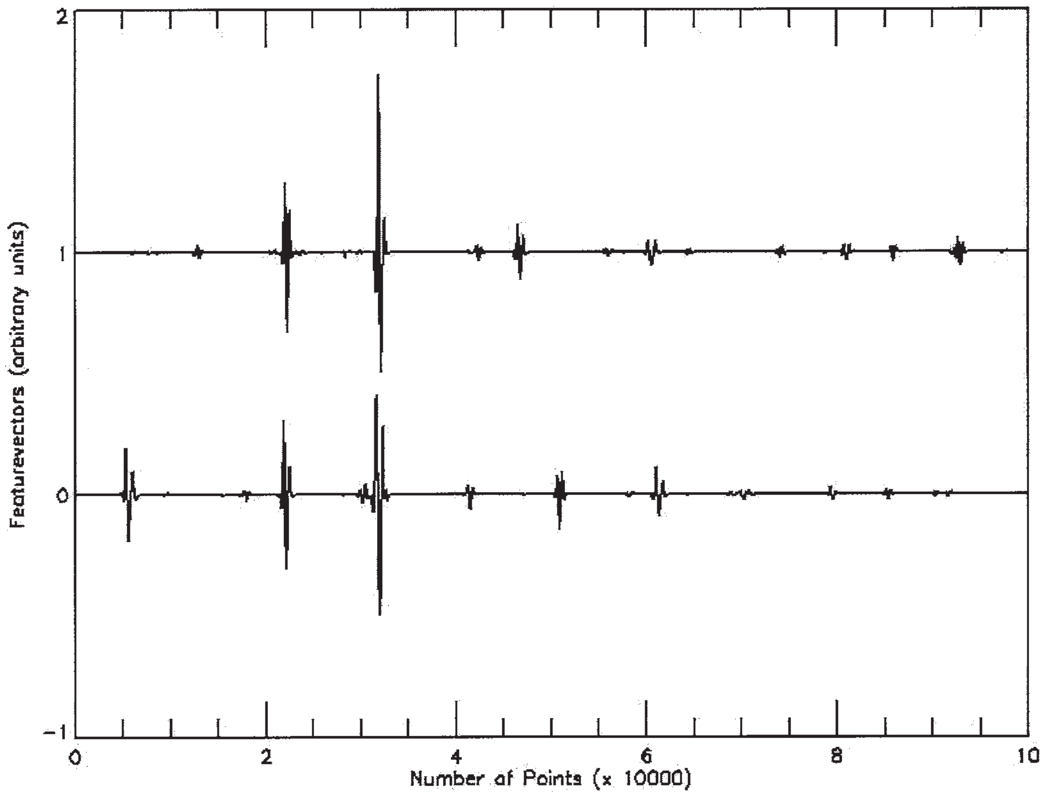

FIG. 12—*Comparison of the feature vectors extracted from strips cut out of distant bags. Only two surface scratches are continuing.*

FIG. 13—*Low-density bags: pattern of extrusion lines (over a few centimeters), visualized by means of transmitted light.*

Low-Density Polyethylene Bags

The pattern of the extrusion lines in the low-density bags was visualized using transmitted light. It can be seen in Fig. 13 that it has different characteristics from the high-density polyethylene plastic bags (see Fig. 7). In order to determine whether this pattern of lines could be detected by means of the laser profilometer, a small area was scanned using the translational stage on the profilometer. Figure 14 shows a top view by means of optical examination of the scanned surface as well as a cross-section of the 3D profile. The features in the 3D profile have the same length scale as the extrusion lines seen by optical examination. A correlation between the extrusion lines and the peaks in the profile can be seen. The sharper the lines in the pattern, the sharper the peaks in the profile. When applying two types of illumination (transmission and grazing angle, see Fig. 15), it becomes clear that not only extrusion lines but also surface scratches contribute to the resulting profile. The surface scratches are from a different nature than those seen on high-density polyethylene bags.

When scanning strips of garbage bags, surface plies turned out to overwhelm again the smaller details in the experimental results (Fig. 16*a*). They could be eliminated by a similar filtering routine as for the high-density garbage bags (Fig. 16*b*). The results show clearly different characteristics than the high-density bags (see Fig. 9). When comparing the filtered profile lines using a classical correlation algorithm, a high correlation value of 0.67 was obtained

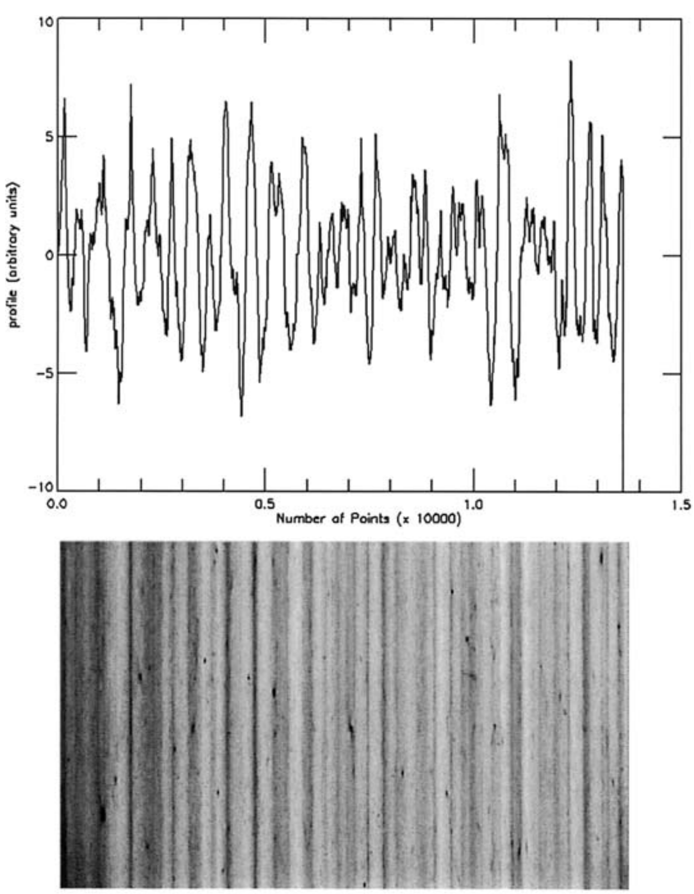

FIG. 14—*Comparison of a top view (by means of optical examination) of a scanned small bag surface with a cross-section of the 3D profile. The length scales of the features seen by both techniques correspond. A linear regression was applied to the raw 3D data to account for a slight inclination of the translational stage.*

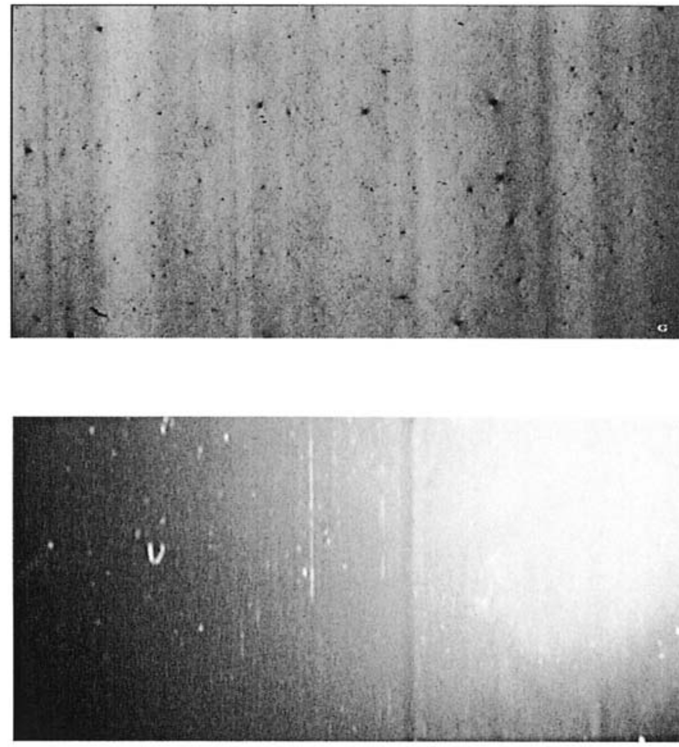

FIG. 15—(a) *Visual inspection by means of transmission: extrusion lines;* (b) *visual inspection by means of grazing light illumination: surface scratches.*

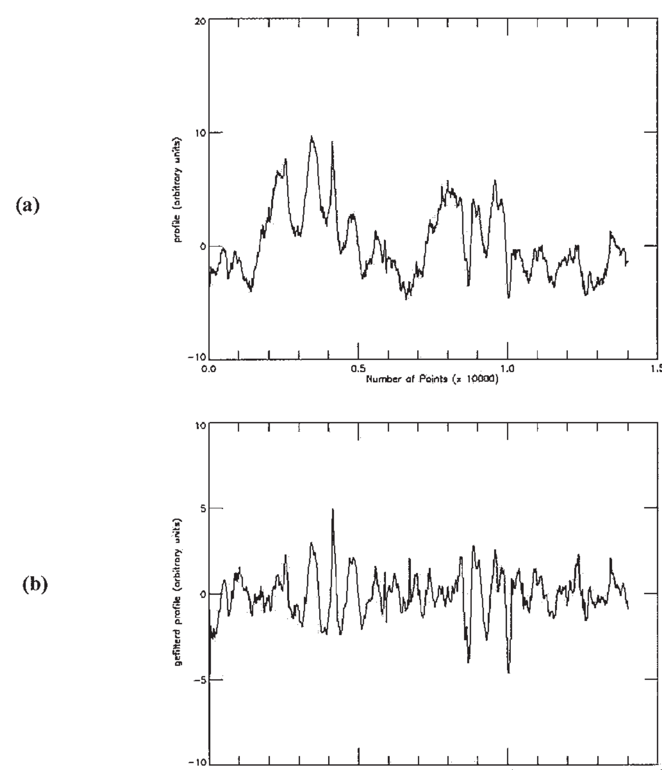

FIG. 16—(a) *Raw data: the surface plies overwhelm the smaller details;* (b) *profile after filtering.*

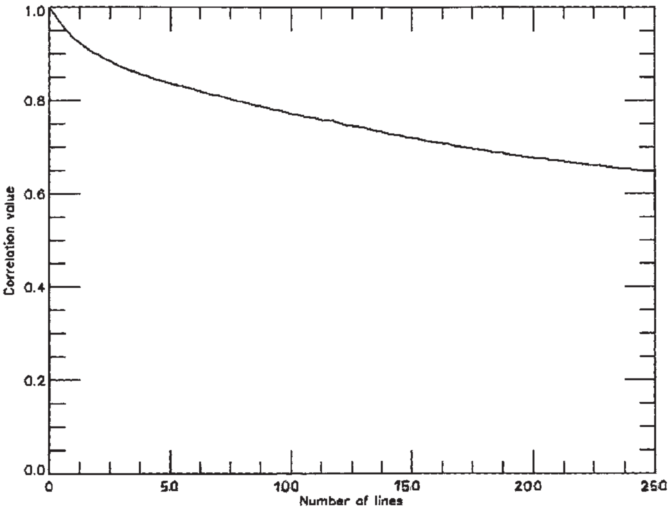

FIG. 17—*Evolution of the correlation value calculated between cross-sections as a function of distance between lines.*

for profile lines up till 2.5 cm distant from each other. In Fig. 17 the evolution of the correlation value as a function of distance (number of lines) is presented. Extended investigation of the data reveals that the algorithm to construct the feature vectors for the high-density bags does not provide applicable results. The pattern of the extrusion lines seen in the 3D measurements do show a much more rapid variation along the length axis than is clear from visual examinations, where they can easily last over distances up to meters. This result is of outmost importance when linking the end of a bag to the beginning of a subsequent bag. This technique provides a very accurate result that can be complementary to the analysis of the cut and torn edges.

An attempt was made to set up an algorithm for comparing strips further apart. It is based on the idea that the position of the extrusion lines is well fixed, but that their intensity varies randomly along the vertical direction. No correlation in the variation of the intensity of different extrusion lines was seen. Consequently, an extrusion line is present when a fixed number of peaks succeed along the Y direction of the strip. This can be numerically determined by counting the number of times a threshold value is depassed. The resulting positions were placed in a feature vector, representing a strip of the garbage bag. Two feature vectors were compared by a statistical approach comparing the number of corresponding peaks in both feature vectors to the number that is expected for random distributions. This algorithm turned out not to provide sufficient discrimination between different strips, so that further research is needed for correlation of extrusion lines over larger distances.

Conclusions

In this paper, we presented a new point of view for the analysis and subsequent comparison of plastic garbage bags. High-resolution 3D measurements of the bag surface were performed with a laser profilometer. When comparing the profilometry technique with optical measurements, we see that all the important characteristic manufacturing defects of the garbage bags are measurable by means of the profilometer. Moreover, a quantification of the features is possible. Optical examination of extrusion lines in low-density polyethylene bags shows that they continue over substantial distance. However, the obtained 3D profiles have a correlation length on a much smaller length scale. This may bring a substantial added value to the linking of the end of one bag to the beginning of the subsequent bag, which is currently performed using optical comparisons. For high-density bags, adjacent strips can be linked using surface scratches. Further, a link between distant bags can be made if the surface scratches are continuing over the considered bags.

The discontinuous intensity of the extrusion marks in the 3D measurements may be due to one of the following hypotheses: (i) the plastic bubble formed during the production process touches impurities or bulges present on the production apparatus or (ii) the presence of impurities in the extrusion mouth of the apparatus or in the "flattening" part of the manufacturing cycle; (iii) slight variations in the local pressure during the extrusion process.

Currently, we are continuing the search for the optimal comparison method for linking together low-density polyethylene bags over longer distances. We are in the process of optimizing the filtering procedure and hope to account for the variation in intensity of the extrusion marks by means of multivariate statistics, more in particular fuzzy clustering.

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