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3DAS - THREE DIMENSIONAL-STRUCTURE AUTHENTICATION SYSTEM

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1. A Case of Identity

The process of identification penetrates our lives and it may therefore be allowed to devote a few lines to this intricate process as an introduction to a security identification system. Identification is a two-step process, consisting of the initial determination of a unique characteristic of a physical object, plant, animal, human being or idea and the recognition (to re-cognize, know again) of that unique characteristic at a later point of time. This unique characteristic in fact constitutes a label that we can attach to objects, etc., as an essential but reduced copy of reality, a label that, once cognized, helps us in fast and generally secure recognition with the aid of our various senses.

Thus a trifle sound, a single glance or a brief scent may allow us to determine, with relative certainty the identity of matter or a being. A single spoken word, even if not understood, may identify a known person while the sound of a coin falling on a hard surface will tell us whether it is genuine or just a cheap lead replica. A short glance tells us whether we deal with a 25 guilder note or a 250 guilder note, although the difference in actual value amounts to a single zero. And a vague fragrance or a single thought may suddenly revive a past experience with great vividity. This ability to attach reduced labels to reality and to remember them when required, is vital for our human functioning.

Identification appears to involve several levels. Our general idea 'tree', though extremely difficult to express in exact terms, enables us without difficulty to identify very disparate objects as a tree. Identification becomes more difficult, however, if the specific type of tree must be identified, while the identification of an individual tree becomes most complex, certainly if it is borne in mind that it changes its appearance continuously in time as well as periodically with the seasons.

The recognition of individual things or beings therefore is of a very complex nature and the expression of that individuality in words generally requires a lengthy *portrait parlé*.

This difficulty to express the individuality of things and beings is eloquently phrased by Goethe in the preface to his Theory of Colours (1810):

> “Denn eigentlich unternehmen wir umsonst, das Wesen eines Dinges auszudrücken. Wirkungen werden wir gewahr, und eine vollständige Geschichte dieser Wirkungen umfaßte wohl allenfalls das Wesen jenes Dinges. Vergebens bemühen wir uns, den Character eines Menschen zu schildern; man stelle dagegen seine Handlungen, seine Taten zusammen und ein Bild des Characters wird uns entgegentreten.
>
> Die Farben sind Taten des Lichts, Taten und Leiden. In diesem Sinne können wir von denselben Aufschlüsse über das Licht erwarten.”

Although this is, in the end, undoubtedly an utterly intriguing and most rewarding approach of reality, it accordingly is the most time consuming. Really becoming to know something or someone may take years if not a lifetime. Generally we demand to identify things or individuals at least a little faster and at the same time we require this identification to be attended with virtually absolute certainty. The unique characterization of persons and objects therefore must be reduced to something much more simple and elementary than their intrinsic nature and preferably this characterization must be limited to physical objects that are relatively stable in time, instead of living creatures that constantly change appearance. At the same time the identification must be based on ample complexity to render it sufficient uniqueness and to entirely exclude confusion with similar objects. The seemingly paradoxical combination of simplicity and complexity therefore is a highly desirable property of identificators.

An example was the cunning practice of ancient rulers to randomly divide a simple object, for instance by fracturing a stone or by tearing a note, and to hand each individual part to another confidant for later mutual identification. The division thus made is totally unique because of its chaotic and irreproducible irregularity, but the act of identification is quick and secure: just try if both identificators match one another. The act is much like fitting a key in a key-hole. The difference is that most keys can be rather easily duplicated and locks can be generally unlocked with master-keys or crafty instruments, while the unique fit of both matching identificators can never be duplicated. Never will a second stone be cleaved or a second note be torn to accidentally match the original identificator. However, a deceitful shortcut might for instance be to make a matching replica of the fissured stone by secretly using the original counterpart as a mould. This reminds us of a third desirable property of identificators: their resistance against counterfeit. Not only must ideal identificators be complex in structure and at the same time allow simple authentication, they must also be hardly if at all reproducible by shortcut procedures in order to guarantee their authenticity. Last but not least, this authenticity must be easily and quickly verifiable as well. This limits the available resources and, if a further constraint is that production must be cheap, the possibilities become really scarce.

The preceding considerations may serve as a background for our discussion of what is called 3DAS, the three-dimensional-structure authentication system.

2. An Adequate and Inexpensive Identificator: 3DAS

A recent Dutch invention [1, 2] describes the application of nonwoven structures which satisfy the above reflected requirements. This nonwoven is an AKZO industrial product. It carries the tradename Colback®, and constitutes a random, three-dimensional arrangement of polymer fibers, thinner than a human hair, having a polyester core and a polyamide skin [3]. The spunlaid fibers are thermally bonded at their cross points, thus rendering the structure dimensional and thermal stability. This structural coherence is illustrated by scanning electron microphotographs in the figures 1 and 2.

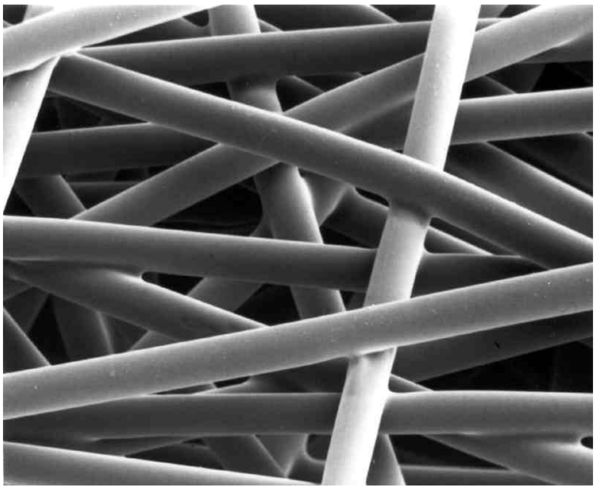

Figure 1 - Three-dimensional bonding of filaments.
(Courtesy Akzo Nobel, Arnhem, The Netherlands)

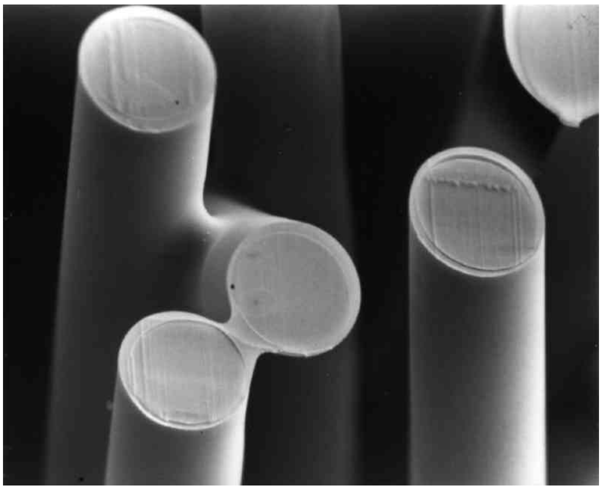

Figure 2 - Cross-section through the filaments.
(Courtesy Akzo Nobel, Arnhem, The Netherlands)

As the material is random, a small section, for instance approximately 10 square millimeters mounted for example in an ID-card or product label, may serve as a unique identificator for valuable documents and products, much like a fingerprint identifies a human. Furthermore, its three-dimensional properties may serve to completely inhibit counterfeiting of the structure by photographic reproduction techniques. In fact, because of these three-dimensional properties, the structure can be regarded as belonging to the group of 3D-tilt images that display optical variability when tilted [2].

This particular type of optical variability is brought about by the phenomenon of parallax, which is observed as a mutual shift of image elements in different layers of the structure when the angle of observation is changed. The figures 3 and 4, on the next page, show CCD-recordings of a single, 4 x 4 mm, 30 grams/m^2, nonwoven structure at two different tilt angles (enlarged 20x). The thickness of the structure is approximately 0.3 mm, while individual fibers have a 40 µm diameter. The three-dimensional characteristic of the nonwoven is demonstrated by the distinct differences in parallax between the two recordings.

If the figures 3 and 4 are observed as a stereo pair, the three-dimensional orientation of the fibers becomes obvious. The perceived stereometric depth of the 20x enlarged structure is about 1 centimeter.

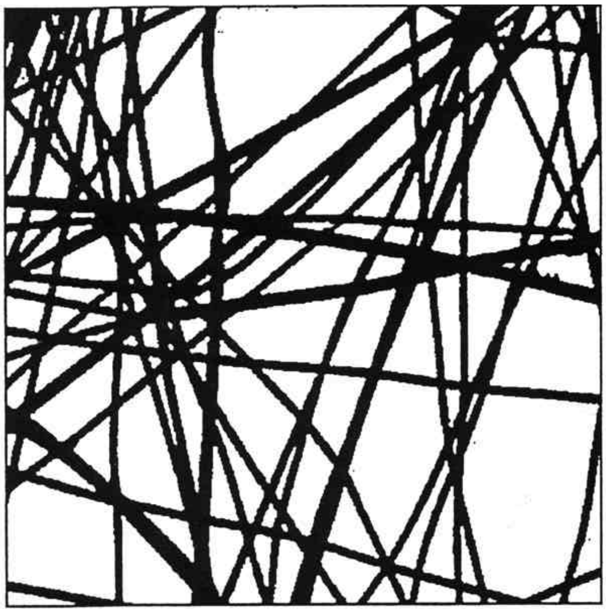

Figure 3 - CCD-recording of specimen at +20E

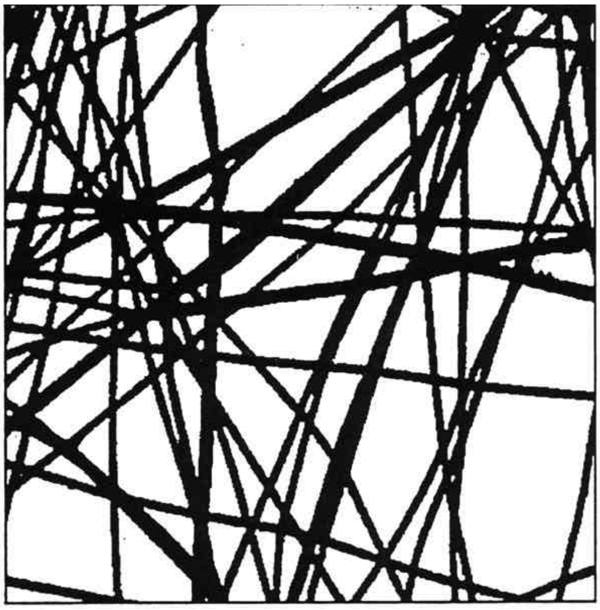

Figure 4 - CCD-recording of specimen at -20E

The following appears to be satisfied:

1.A random and robust structure serving unique and lasting identification.
2.Irreproducible three-dimensionality, serving authentication.
3.Low-cost raw material.

Obviously it remains to be demonstrated that further requisites can be satisfied: simple and fast identification as well as authentication. For this purpose it is first of all necessary to reduce the optical recording of the chaotic fiber pattern to an elementary code with sufficient uniqueness. Secondly, the three-dimensionality of the nonwoven must be verified in such a way that counterfeits will not likely pass the examination without being exposed. This verification must be simple and fast as well. A simple optical recording system, discussed in the next section, constitutes the base for these final but paramount requisites.

3. The 3DAS-reader: an optical system without imaging optics

It goes without saying that the optical recording system must be as simple as possible in order to realize a low-cost reader. The components of an optical system generally are light sources, optics and photo detectors together creating an image of the object to be examined. If three-dimensional characteristics are to be verified, a dual optical system is required or one single optical system has to be operated from two different viewpoints. The latter solution will probably require either mechanical translations or rotations or extra optical components. This all tends to complicate the system, and with it expenses increase.

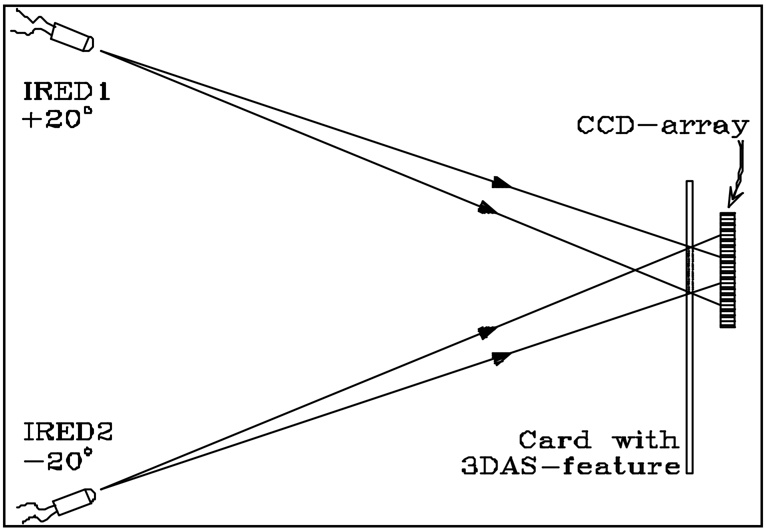

Figure 5 - Schematic of a shadow casting 3DAS imaging system

In view of the above, it was considered that the most simple method to obtain an image, is to project a shadow image of the original object. Accordingly, all imaging optics can be omitted which would be a tremendous advantage, apart from the increased robustness of a reading system without any moving parts. The proposed optical set-up might thus be limited to Light Emitting Diodes (LEDs) as light sources, or preferably Infrared Emitting Diodes (IREDs) as sources of radiation and a single two-dimensional CCD-array as a photo detector. Figure 5 illustrates the principle of such an elementary shadow imaging configuration. Both recordings are made in turn, at two different angles of illumination, by alternately switching both IREDs, to render the required parallax images. A patent is pending that covers the application of shadow imaging for identification/authentication structures.

It may be objected that shadow images tend to be vague and unsharp, which would be a serious disadvantage. An analysis of the sharpness of shadow images is therefore demanded. Shadow image sharpness is governed by two phenomena: (1) half shadows brought about by the geometry of an extended light source and the set-up and (2) diffraction associated with the wave nature of light.
Both phenomena will be discussed in the following sections.

3.1. Geometrical shadows

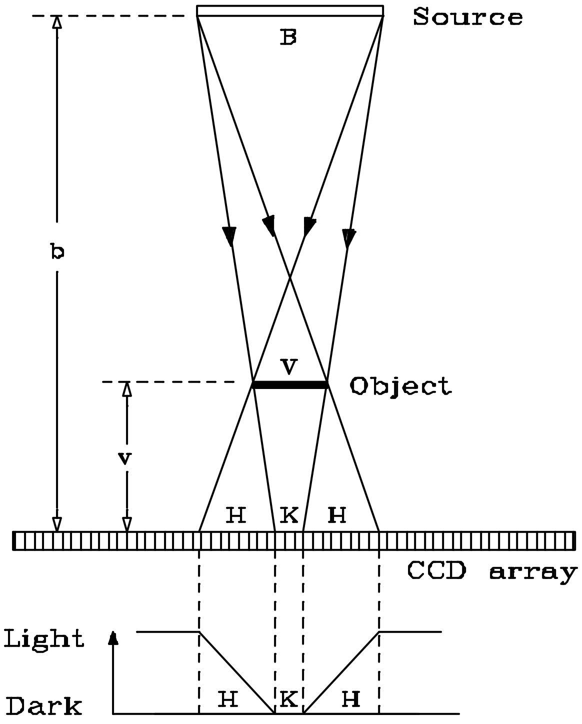

Figure 6 - Formation of cast shadow and half shadow

From simple geometrical considerations, illustrated in figure 6, the size of the cast shadow (K) and the half shadow (H) follow as a function of the size of the source (B), the size of the object (V), the distance (b) of the source to the CCD and the distance (v) of the object to the CCD:

$$K = \frac{V.b - B.v}{b - v} \qquad (1)$$

$$H = \frac{B.v}{b - v} \qquad (2)$$

From eq(1) and eq(2) it becomes evident that the smaller the source B, the smaller the half shadows will be, and the broader and sharper the cast shadow. If the shadow is cast by means of a perfect point source, it follows from pure geometrical considerations that the cast shadow will be completely sharp. For a common IRED emitting surface size B = 0.4 mm, it follows from eq(2) that the size of the half shadows may be kept within 10 µm if the extended source is placed at sufficient distance (for example b = 100 mm) and the 3DAS-structure within a few millimeters from the CCD-chip.

In the next section it will be shown however that unsharpness is not only caused by the extension of the source but also by light diffraction effects, which will appear to be predominant in all practical cases. The geometrical limitation of the sharpness by half shadows, resulting from the extended source, therefore does not play an important part in the proposed optical configuration.

If the source distance b is large with respect to the object distance v, the enlargement G = b/(b-v) of the image will be virtually unity, while the sensitivity (?G) of the enlargement G for limited axial deviations is given, to good approximation, by ?v/b. In that case, the advantage of the shadow casting set-up is, that the size of the image is virtually independent of the axial position of the object.

3.2. Diffraction of light

Apart from the geometrical formation of half shadows, the effect of light diffraction must be taken into account. Diffraction can be defined as the scattering of primary radiation by the edges of the irradiated object. These edges thus become sources of secondary radiation. As a consequence, radiation is diffracted into the geometrical shadow of the edge, which reduces the contrast as well as the sharpness of the cast shadow. But radiation is also diffracted into the area outside the geometrical shadow, which area is already illuminated by the primary source as well. If the primary source approximates a point source, interference effects between the primary wave and the secondary wave can be observed in this latter area as a periodic modulation of the background intensity.

The phenomenon of light diffraction at object boundaries is not generally observed in daily life. However, in all practical configurations the 0.4 mm emitting IRED surface is small enough to make such interference phenomena manifest in the CCD-recordings.

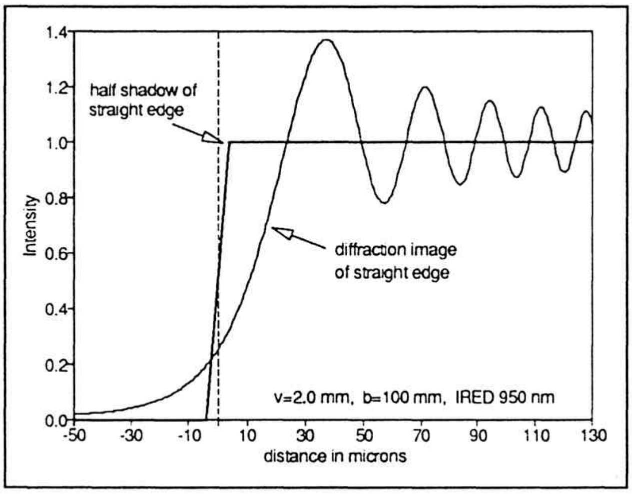

Figure 7 - Diffraction in the shadow cast by an edge

As an example figure 7 shows the graphical representation of the shadow of an edge irradiated by a 950 nm IRED beam. The cast shadow becomes smoothed as well as modulated by diffraction effects. The calculation was made for an object distance v = 2 mm and a point source distance b = 100 mm, which are fairly practical values for an optical reading system. The outline of the corresponding geometrical half shadow is represented in the figure by a heavy line. As figure 7 shows, the shadow cast by an edge becomes unsharp as a result of diffraction, however small the source is. Obviously, in this case, the contribution of diffraction to unsharpness predominates that of the geometrical contribution.

For a 0.4 mm IRED it can be shown that, with increasing object distance v, the unsharpness due to diffraction increases considerably faster than the geometrical unsharpness (H) due to half shadows. If a small point source is applied, the effect of diffraction surmounts the geometrical effect of half shadows and thus it appears useless to search for extremely small point sources like lasers or laser diodes. The optical reading system will therefore be provided with fairly simple IRED's, switched on in turn in order to capture the separate stereo images. For all practical cases, unsharpness by diffraction appears to stay well within tolerable limits.

4. Image Processing

Both images, subsequently captured by the CCD-camera, are processed in order to extract the identifying and authenticating information. As a first step a conversion of the digital images to binary images takes place by thresholding between the dark fibers and the light background. The ways in which the identification code and the verification code are derived from the binary image are respectively discussed in sections 4.1 and 4.2. When the card is issued, these codes are registered in the memory of the central computer for later confirmation whenever the card is presented to the system for identification.

4.1. Identification

For the purpose of identification the images are considered as a collection of bright convex polygonal meshes, enclosed by dark fibers. A fast and simple algorithm subsequently selects, for instance, the ten largest objects present in the pattern and labels them both by center of gravity and area.

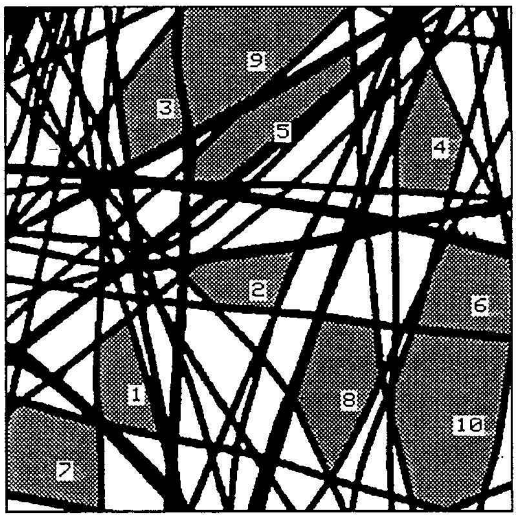

Figure 8 - The ten largest objects.

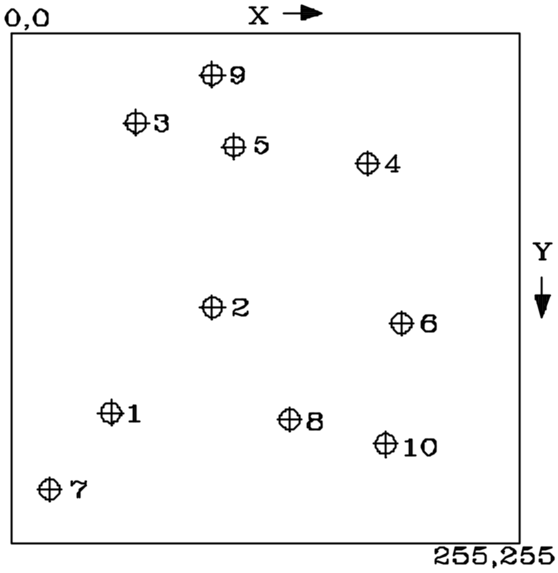

Figure 9 - Points of gravity with tolerance areas.

This is illustrated in the figures 8 and 9. The list of ten center of gravity X,Y-values is a unique identification of the original nonwoven structure. In fact, the probability of an arbitrary other piece of nonwoven by change repeating the same X,Y-values can be calculated to be in the order of 10^{-22} [4]. This figure is based on a 256 x 256 pixel image in which the 10 centers of gravity are located according to figure 9 in tolerance areas of 100 square pixels.

Each center of gravity located within this tolerance area is regarded as identical with the original center of gravity. In order to grasp a proper impression of this figure the reader is invited to imagine figure 9 as a dart board with 10 bull's eyes, in each of which one of ten darts has to be subsequently scored by a blindfolded dart player.

The identification code that the 3DAS-reader produces will thus consist of a list of 10 locations, encoded into a 20-byte identification number. At the card issue this code is registered in the memory of the central computer, together with the required personal data, for later comparison and recognition of the codes output by the 3DAS-reader. Identification is positive if this code and the typed in PIN-code match the originally recorded identification code and the corresponding PIN-code as registered in the central computer.

4.2. Verification

If the three-dimensional structure is observed under different angles, parallax between fibers in different planes appears, visualized by the differences between figures 3 and 4. These differences depend on the unique spatial distribution of the fibers in each label. Parallax will be lacking if the original label is replaced by a plain microphoto of the original nonwoven. Furthermore, counterfeits with an imitation 3D-structure will present an aberrant spatial distribution of parallax, because the exact spatial distribution of fibers is virtually impossible to reproduce.

Thus, the authenticity of the 3DAS pattern can be verified by detecting the amount of parallax present in the 3DAS-label as well as its specific spatial distribution. This is achieved by spatially matching both recordings and then subtracting them to display the differences due to parallax. The result of subtraction of the stereo images presented in figures 3 and 4 is given in figure 10. The result, due to the parallax effect, is significant. The amount of parallax and the arrangement of parallax differences is distinctive for each individual label and is appropriately encoded into a verification code. Like the identification code, this verification code will also comprise a few tens of bytes, registered in the memory of the central computer, for later verification of the 3D-structure.

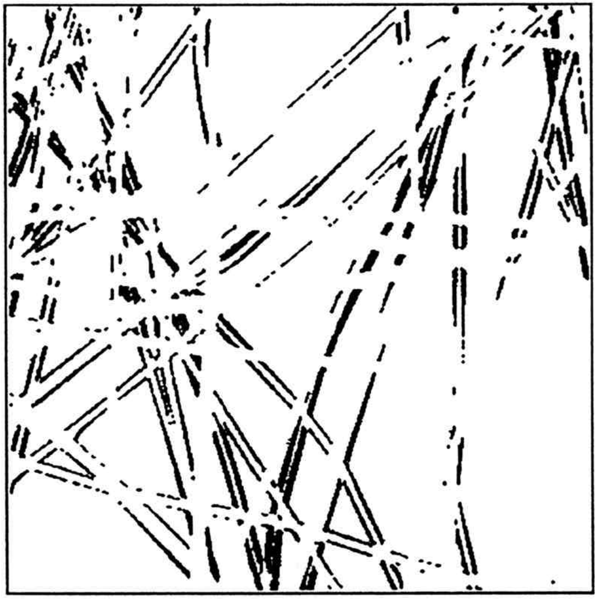

Figure 10 - Differences between the figures 3 and 4 due to parallax.

5. Discussion and Conclusions

A random, robust and inexpensive microstructure, mounted in a card or label, renders it unique identification potentiality. This valuable property is combined with an irreproducible 3D-fiber arrangement that serves unambiguous authentication and protection against counterfeit. Its incorporation in cards renders high security access keys to security systems. Such systems may be safes, rooms, buildings, security territories or data files.

The 3DAS microstructure is also particularly suitable as a physical identification for personal logistics, like in health care systems and the pharmaceutical industry, where a physical identification is often required next to a personal identification like a pin code.

Apart from operating as a stand alone system, the 3DAS system is complemantary to magnetic stripe cards, chip cards and smart cards, to which it can be added as a card authentication method in order to enhance security.

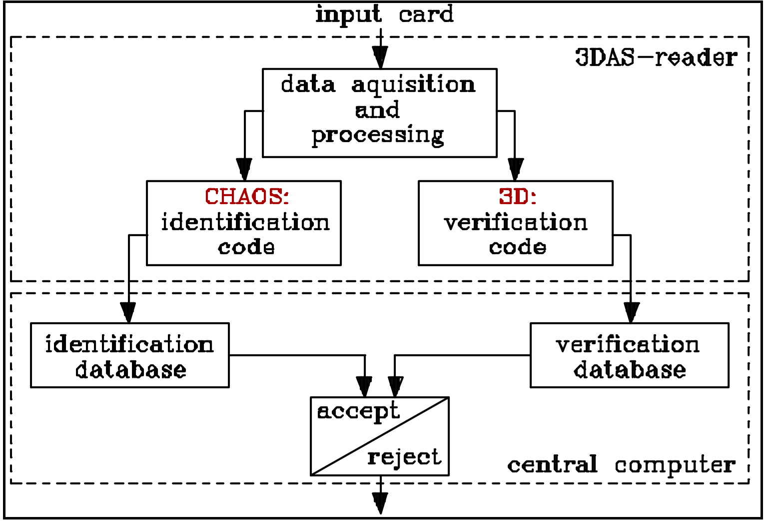

Figure 11 - Diagram of the 3DAS procedure.

A simple optical reader has been developed that converts both the random microstructure and its three-dimensionality into unique but compact codes that are stored in the memory of a central computer for later identification and verification of a presented card or label. The diagram in figure 11 presents a general overview of the 3DAS procedure.

The input of the reader is processed and an identification as well as a verification code are generated by the reader and transmitted to the main computer. Here both codes are compared with the contents of the identification and verification databases. Only if both identification and verification are confirmed, is the input accepted and is access to the system permitted.

The high security potential of 3DAS is completely founded on the unique and irreproducible 3D-structure of the feature. Neither secret properties nor secret detection techniques are required for its application. Security, based on secrecy is unreliable because, in the long run, secrecy cannot be guaranteed. Therefore security must rather be based on advanced techniques and know-how as well as the virtually insuperable difficulties involved in fraudulent reproduction.

In January 1994 the consortium Unicate [5] was founded and given the mission to commercialize 3DAS. This consortium unites the Dutch companies Digital, Philips Novatronix, Joh. Enschedé/Sdu, Akzo Nobel and Tel Developments. TNO Institute of Applied Physics operates as an independent R&D organisation and consultant on behalf of Unicate.

The development of the 3DAS system currently is in the stage of product definition. The invention will be initiated within the scope of health care. A first demonstration pilot is planned to be completed in February 1995 in a hospital in Groningen, the Netherlands.

References

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5. Unicate B.V., Verlengde Hereweg 192, 9722 AM Groningen, The Netherlands, phone +31 50 265709, fax +31 50 266345.