Optical Inspection techniques for Security Instrumentation

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ABSTRACT

This paper reviews four optical inspection systems, in which development TNO Institute of Applied Physics was involved: (1) intaglio scanning and recognition, (2) banknote quality inspection, (3) visualisation and reading of a finger pattern, and (4) 3DAS authentication.
(1) Intaglio is reserved for high security printing. It renders a tactile relief that can be recognized by a laser scanning technique. This technique is applied by various national banks to detect counterfeit banknotes returning from circulation. A new system is proposed that will detect intaglio on arbitrary wrinkled banknotes.
(2) A banknote fitness inspection system (BFIS) that inspects banknotes in specularly reflected light is described. As modern banknotes are provided increasingly with reflective security foils, a new system is proposed that inspects banknotes in specular and diffuse reflection, as well as in transmission.
(3) An alternative visualisation method for visualization of finger patterns is described, employing a reflective elastomer. A CD scanning system reads the finger patterns.
(4) A nonwoven structure has two advantageous properties for card authentication: a random structure which renders each few square millimeters of the pattern uniqueness (identification) and a 3D structure which makes it virtually impossible to be counterfeited (authentication). Both properties are inspected by an extremely simple lenseless reader.

Keywords: intaglio recognition, banknote quality inspection, finger pattern visualization, 3DAS, random authentication patterns

1. INTAGLIO SCANNING AND RECOGNITION DEVICE

Intaglio printing is a public security feature which is characterized by its tactile relief. This relief is brought about on the one hand by the thickness of the intaglio ink deposited on the paper from the recessed engraved parts of the steel plate, on the other hand it results from the enormous pressure exerted during the printing process, which permanently embosses the paper. The use of intaglio printing is primarily restricted to security printers and its characteristic appearance and tactility therefore provide an effective first line security feature on valuable documents.

The presence of the particular features of intaglio may be inspected with great speed and reliability in second line as well, with the use of the **I**ntaglio **S**canning **A**nd **R**ecognition **D**evice (ISARD). The ISARD was invented and developed by TNO Institute of Applied Physics in the late sixties in behalf of the National Bank of the Netherlands.[1-3]

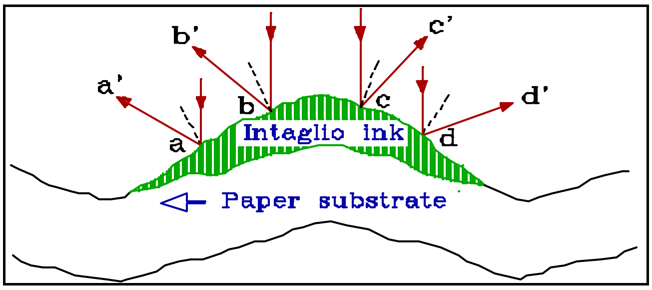


Figure 1 -ISARD, principle of operation

Its operation is based on the optical detection of the intaglio relief. Figure 1 illustrates the principle of operation of the ISARD. It shows a cross section of a thin intaglio line on a paper substrate. The intaglio ink surface is somewhat glossy and thus more or less specularly reflects the impinging light, while the paper substrate in between the intaglio lines diffusely reflects the light. Thus the reflected signal from the intaglio ink is much stronger than that of the paper. As figure 1 further shows, the cross section of an intaglio line is somewhat convex so that the light beam reflected from the ink blot tends to sweep over a certain angle (from aa', via bb', and cc', to dd') while the banknote is transported.

This angular sweep is detected by the optical system illustrated in figure 2. A cylindrical lens focuses a laser light line on the surface of the document which contains a distinct pattern of fine intaglio lines to allow intaglio detection by the ISARD. Both photodiodes alternately pick up the light sweep and thus produce two signals that show a distinctive phase difference. It will be appreciated that lithography type of printing and the images produced by colour printers, which are essentially flat, will fail to produce this characteristic optical behaviour. Signal processing reveals the eventual absence or atypical distortion of the sweep in the case of any printing deviating from intaglio. Suspect banknotes are sorted out for further inspection and thus their recirculation is precluded.

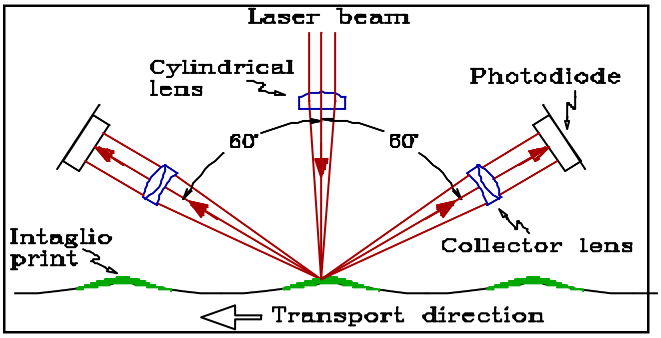
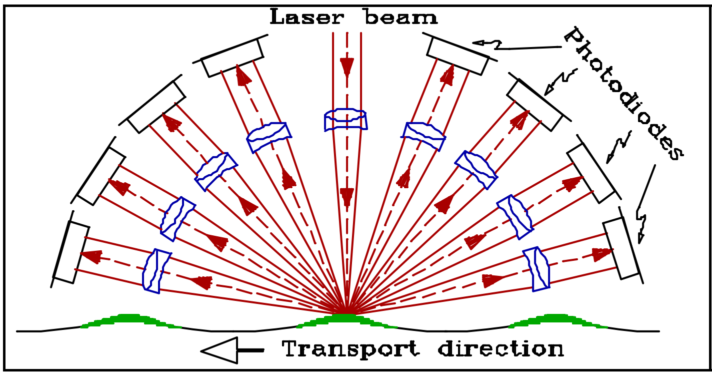


Figure 2 -ISARD, Optical set-up.

On line detection and recognition of very fine intaglio printing, up to 40 banknotes per second has been achieved. ISARD's have been installed on banknote transports at the National Bank of the Netherlands since 1970 as well as at the National Bank of Belgium since 1975. Various updates of the ISARD have since been designed. The ISARD inspects the complete circulation of banknotes in both countries and reliably rejects counterfeits, thus preventing their reissue.



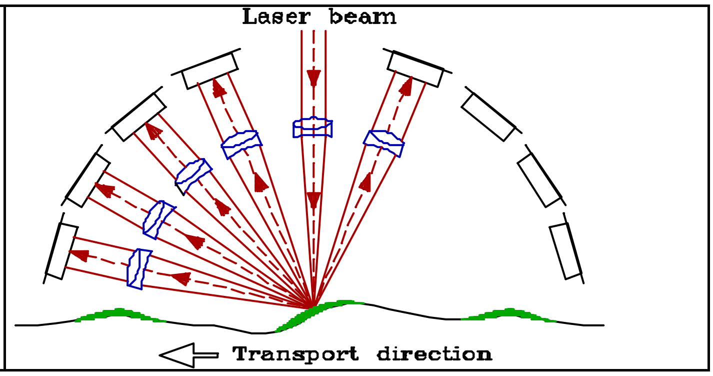


Figure 3 – ISARD+, optical set-up

Figure 4 – ISARD+, effect of wrinkles

An improved version of the ISARD had been recently proposed[4] that has two advantages over the current equipment. This new version, called ISARD+, solves the following difficulties:

1. The current version requires parallel intaglio lines for optimal detection of intaglio printing.
2. Wrinkles in the paper substrate of banknotes have an unfavourable effect on the ISARD performance as these tend to deflect the reflected light outside the angular photo detector range.

The optical principle of the ISARD+ is given in figure 3. The application of a focal point rather than a focal line allows the scanning of any banknote without a specifically designed ISARD intaglio feature. Multiple photo detectors warrant the detection of the reflected beam irrespective of the orientation of intaglio lines or the presence of wrinkles that deflect the reflected beam outside the normal range (figure 4).

2. BANKNOTE QUALITY INSPECTION

In behalf of the National Bank of the Netherlands, TNO Institute of Applied Physics has developed and manufactured equipment that automatically inspects the quality of banknotes on banknote transports. An important objective of automatic banknote fitness inspection is to maintain the volume of recirculated banknotes in a good condition. Maintaining banknote quality within strict standards guarantees that security features remain in good condition and can be more adequately inspected by the general public as well as bank tellers. Taking the enormous amounts of recirculated banknotes into consideration, it is no longer possible to sort them by hand.

The inspection equipment developed at the time for the clean-dirty inspection of banknotes is called **B**anknote **F**itness **I**nspection **S**ystem (BFIS).[5] Recently an advanced optical inspection system for assessing the quality of banknotes, returned from recirculation, has been proposed: AQuaRIS (**A**utomatic **Qua**lity for **R**ecirculation **I**nspection **S**ystem).[6] Both the existing system and a newly proposed system will be briefly discussed below.

2.1 Banknote Fitness Inspection System

The BFIS has been installed at the banknote transports of the National Bank of the Netherlands in 1980. The optical set-up is schematically illustrated in Figure 5. The banknote plane is illuminated with a thin white light line. This light line is detected by a CCD line scan camera in specular reflection while the banknote is transported. The sampled banknote image is divided into 2x2 mm pixels and inspected with respect to general dirtiness as well as the presence of dog's ears, holes, tape (front) and writing (front).

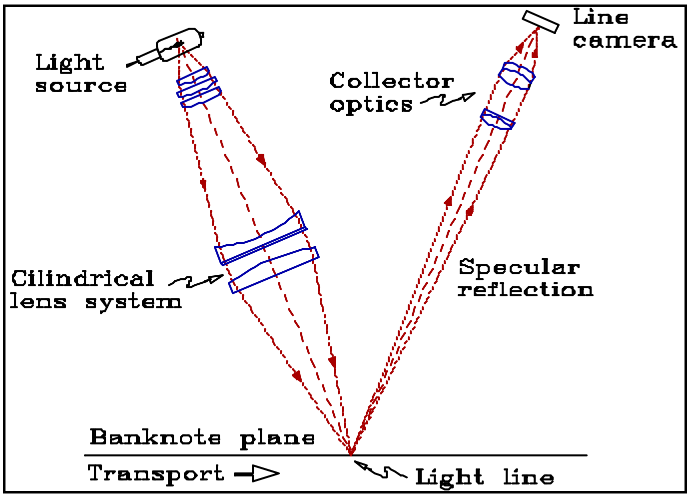


Figure 3 -Optical set-up of the current BFIS.

The overall dirtiness of the banknote is measured but specific areas of the banknote, depending on the denomination, are selected for separate inspection. An example is the unprinted watermark area, which is, amongst others, inspected for the presence of writing. The inspection rate on the present banknote transport is 15 banknotes per second.
A problem that has recently become manifest for the BFIS is the application of a new type of security devices on banknotes. There is an increasing, international tendency to apply optically variable devices (OVDs) to banknotes to expand their resistance against modern types of counterfeit, for example using DTP equipment. Such OVDs may vary from simple metallic foil prints to advanced diffractive features like holograms, pixelgrams, kinegrams or interference features like optically variable ink or thin interference film devices.[7] Such features generally have a specular reflection that significantly surpasses that of banknote paper and common printing inks. For example, the recent issue of the Dutch one hundred guilder note "little owl" has been provided with a gold foil as well as pearl lustre ink printing. Many national banks have by now provided banknotes with OVDs and it goes without saying that the current BFIS is not fit for inspection of such highly reflective features, because the great difference in signal between reflection from and paper and the reflection from highly reflective foils results in a too large dynamic range.

2.2 Automatic Quality for Recirculation Inspection System

An **A**utomatic **Qua**lity for **R**ecirculation **I**nspection **S**ystem (AQuaRIS), that copes with these OVD-type features, has therefore recently been proposed.[6] The AQuaRIS is based on the insight, that the optical properties of an object can only be completely assessed, if at least its transmission, its specular reflection, its absorption and its diffuse reflection are known. These four properties completely characterize the passive optical properties of matter. Active interaction of the object with light, like fluorescence, photochromism, etc., is left out of consideration here. Such a more complete assessment of the optical properties of the banknote requires the independent measurement of its transmission, as well as its specular- and diffuse reflection.

The optical principle of the AQuaRIS is given in figure 6. The measuring system has been extended with two extra line camera systems in order to meet the above requirements. It is expected that the AQuaRIS will allow banknote quality inspection that correlates to a high degree with human banknote teller inspection. To achieve this, the banknotes will be subjected to various visual and machine sorting cycles. Figure 7 serves to explain the connection between these cycles. New banknotes are brought into public circulation. On return from circulation, an initial sample is taken for visual sorting, by various experienced banktellers, into banknotes qualified and unqualified for recirculation.
These two batches of banknotes are fed to the learning module of the AquaRIS in order to teach it the difference between qualified and unqualified banknotes. The learning module considers many possible combinations of the parameters transmission, specular- and diffuse reflection and derives optimum sorting criteria from them, for the banknote in general and specific banknote areas like the watermark area and the various areas containing highly reflective features like pearl lustre printing, OVDs, etc. The inspection system subsequently sorts banknotes returning from circulation -using the established initial sorting criteria- into qualified for recirculation and unqualified (to be destroyed). From these machine selections samples are taken for visual review by experienced

bank tellers. The banknotes considered qualified by the inspection system are visually sorted into unqualified (Q/U: false accepts) and qualified (Q/Q: correctly sorted). Likewise the banknotes considered unqualified by the system are sorted into U/U (correctly sorted) and U/Q (false rejects). The batches flagged Q/U, Q/Q, U/U and U/Q are again presented to the learning module for re-examination and, as a result, refined sorting criteria will be established. This process is repeated until significant changes in sorting behaviour no longer appear. The machine sorting criteria may be altered on instigation of the management by a renewed visual review governed by new instructions for the bank tellers qualified/unqualified decision.

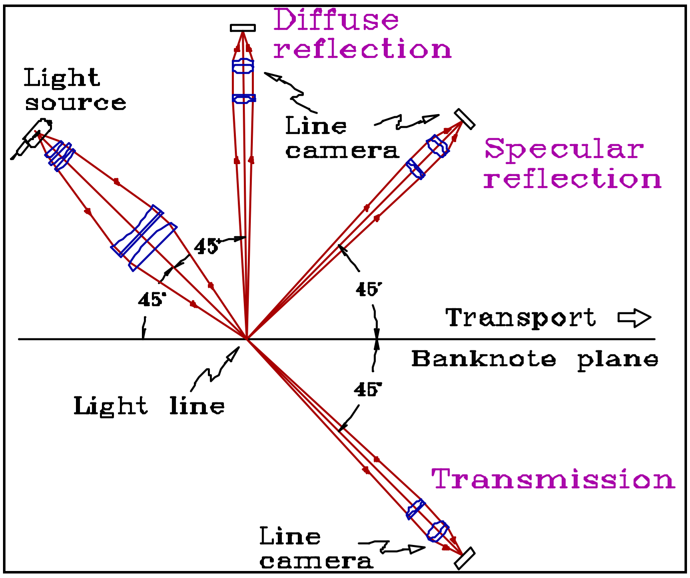


Figure 4 -Optical set-up of the AQuaRIS.

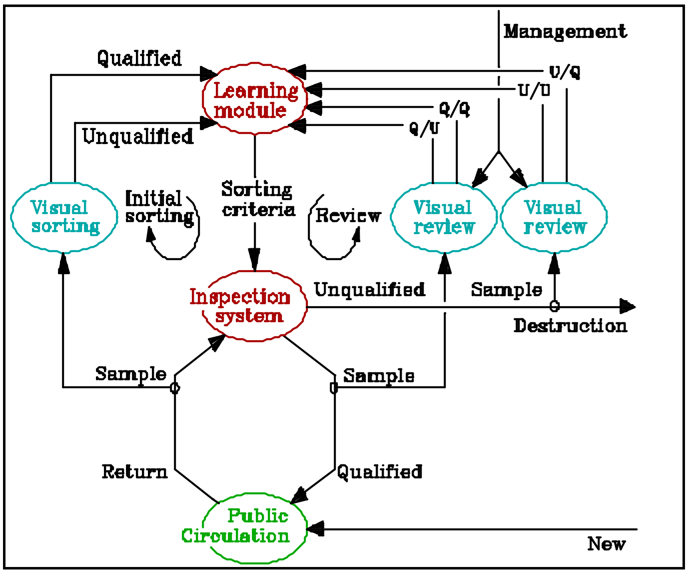


Figure 5 -AQuaRIS circulation scheme

3. AN UNUSUAL FINGER PATTERN SCANNER

A recent Dutch invention[8] describes a finger pattern reader based on the application of the compact disk scanning stylus or so called compact disk light pen. TNO Institute of Applied Physics has performed the feasibility study and has been involved in initial experiments and realization of the optical principle in 1992. The Frencken Group[9], The Netherlands is currently undertaking to develop a prototype of the system. This study involved two interesting optical principles that will be briefly discussed in the following sections: the combination of an elastomer finger relief sensor and a CD light pen scanner.

3.1 Elastomeric Visualization of Finger Patterns

A well known and frequently employed method of visualizing a finger ridge pattern is that of frustrated total internal reflection in a glass prism, as illustrated in figure 8.

Although this method has the advantage of simplicity, it is considered to have major drawbacks. Dry fingers reportedly make insufficient optical contact with the glass surface so that finger ridges are only partially visualized. Sweaty fingers, on the other hand, make too much optical contact, so that the spaces between ridges tend to become filled with matching fluid and the optical resolution between the finger ridges is partially lost. In both cases, which appear to occur relatively frequently, a poor image of the finger ridge pattern results. Therefore this method is considered unfit for general use. Moreover, using this method of direct contact of the finger with the optics, the contact plane easily becomes filthy, which makes regular cleansing necessary. These disadvantages have stimulated various inventors to circumvent the principle of frustrated internal reflection.

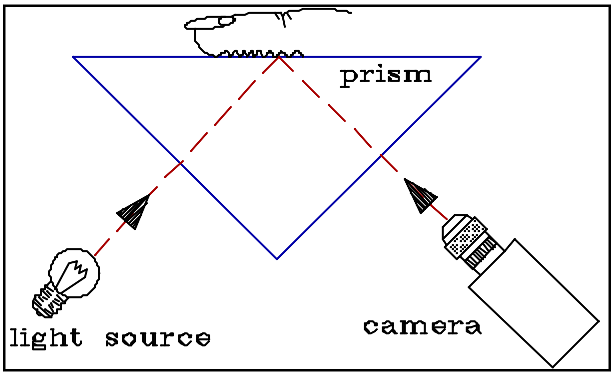


Figure 6 -Visualization of the finger ridge pattern by frustrated total internal reflection in a prism.

The alternative proposed, involves visualization of the finger relief using an elastomeric layer, covered with a thin reflective film. Surprisingly, research proved that extensive patent literature has been published on this subject.[10-28] The principle of the optical system is sketched in figure 9.

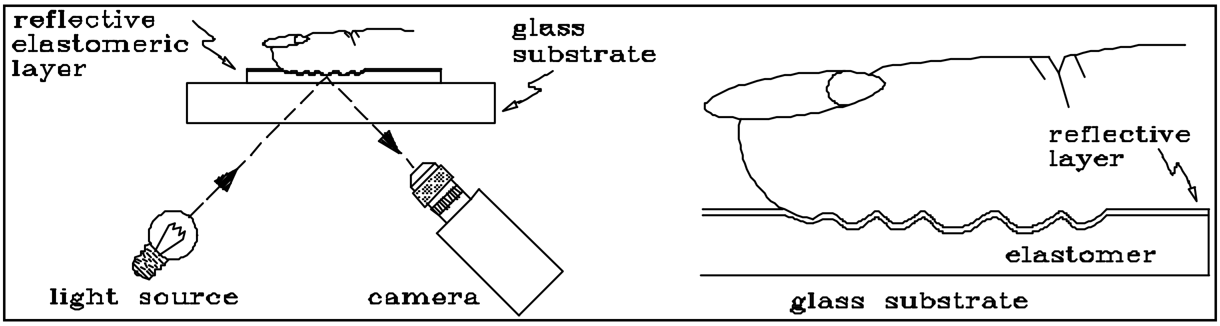


Figure 7 -Visualization of the finger ridge pattern via a reflective elastomeric layer.

On mechanical contact, the finger ridge relief pattern locally deforms the elastomer layer and with it the thin reflective film. On removal of the fingertip, the elastomer immediately resumes its original smooth surface. The camera captures the light reflected by the thin reflective film, except at the locations where the finger ridges cause local deformations of this film. This results in a high contrast image of dark finger ridges against a bright background. This image is independent of the state of humidity of the finger-tip. Moreover, smudging of the contact surface is no problem, because a complete optical separation exists between the finger surface and the detection system. Therefore, this elastomer method may have advantages over the classic total reflection method. The elastomer layer has a thickness of a few tens of millimeters and, for example, consist of a silicon or polyurethane. In an attractive variant, the reflective layer is again covered with a thin protective elastomer. Thus the reflective layer is sandwiched between two elastomeric layers. This second elastomeric layer not only prevents deterioration of the reflective layer, but by its thickness also acts as a high spatial frequency cut-off filter. Fine, irrelevant details of the finger ridges are eliminated by it, while a high contrast image of the finger ridges remains intact. This elastomeric fingerprint visualization system may be an interesting enhancement of existing finger pattern readers. A drawback may be the possible vulnerability to damage of the deformable elastomer. Furthermore it remains to be seen if the manufacture of this compound reflective layer can be successfully realized commercially.

3.2 Application of a Compact Disk Light Pen

It was conceived that the benefits of the reflective elastomer layer could be advantageously combined with a compact disk scanning system, the so called compact disc light pen, which is commercially available at very low cost. The optical principle of this combination is given in figure 10. The CD light pen scanning movement of ±0.5 mm is enlarged 20x by a microscope objective, in order to to cover the complete area of the relevant finger ridge pattern.

During the scan the angle of the laser beam varies. The field lens, with a focal length equal to the tube length of the microscope, serves to refract the scanning beam perpendicular to the reflective layer, so that the scanning beam will be precisely retro-reflected to the optical detection system of the CD light pen. In the figure the field lens is presented separate from the substrate of the elastomeric layer. It is advantageous however to attach the elastomeric layer directly to the flat top surface of the plano-convex field lens. The ±0.5 mm stroke of the light pen provides the x-movement of the scanning system. The focus error signal or the automatic focus signal of the CD light pen may provide the information on the presence of the finger ridge relief. The necessary y-scan has to be provided by additional mechanical means. Various solutions for the y-scan are currently being investigated by the Frencken Group. A surface of X=16 by Y=20 mm will be scanned, where the scanning movement has a resolution of 0,058 mm. This is sufficient to reconstruct the essentials of the finger line pattern. Conceivably the finger pattern will be sufficiently classified by the exact shape of a limited number of finger ridges and not by the mutual position of typica like forks and endpoints. Because of this, a considerable smaller skin surface may suffice to identify the finger ridge pattern, resulting in a relatively small template. The system will be interactive, that is, the light pen may be directed via the template code to any desired skin area. Because of the low cost of the various system components it is believed that this finger pattern scanner may have certain commercial advantages.

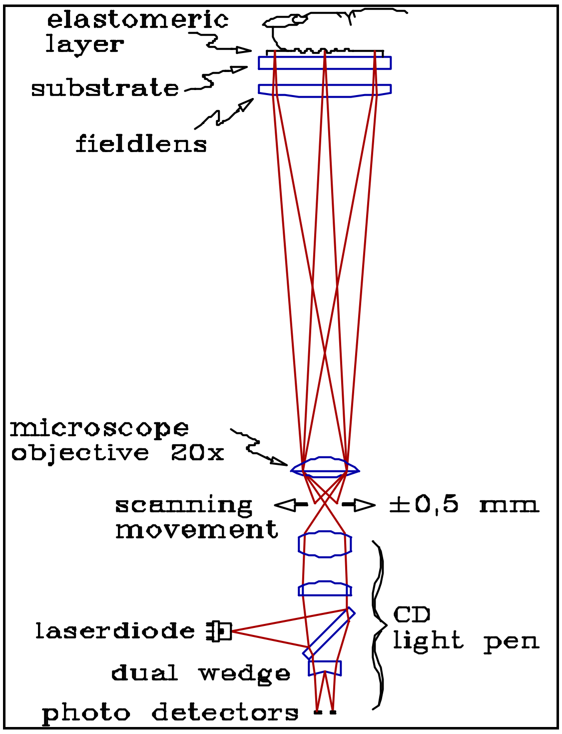


Figure 8 -A CD Light Pen finger ridge scanning system.

4. A 3D-STRUCTURE AUTHENTICATION SYSTEM (3DAS)

4.1 Optical Aspects of 3DAS

Another recent Dutch invention[29] makes use of a three-dimensional random arrangement of extruded nonwoven polymer fibres, of 40µm diameter, being arranged in a sheet of about 0.3 mm thickness. The system is called **3D**imensional structure **A**uthentication **S**ystem, **3DAS**, and it is described extensively in literature[30-33].

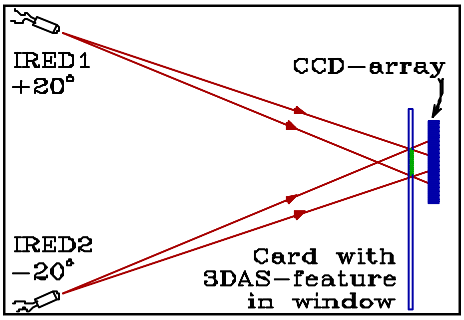


Figure 9 -3DAS reader optical set-up

A small area of this nonwoven (e.g. 0.3 x 3 x 3 mm^2) mounted in an ID-card or product label, serves as a unique identifier, while its 3D properties provide high resistance against photographic or other replication techniques. A low-cost, simple optical reader has been developed to record the pattern and its 3D-properties.[32] The optical principle of the reader is schematically illustrated in figure 11. All imaging optics have been eliminated, which is an enormous advantage from the perspective of cost, simplicity of optical alignment and robustness. Two shadow images of the nonwoven are successively projected on a two-dimensional CCD-array by two infrared emitting diodes (IREDs) at two different angles of illumination. As the IRED emitting surface is small, a sufficiently sharp shadow image can be obtained at distances between the object and the CCD array even up to 10 millimeters. Alternate switching of both IREDs yields two separate parallax images.

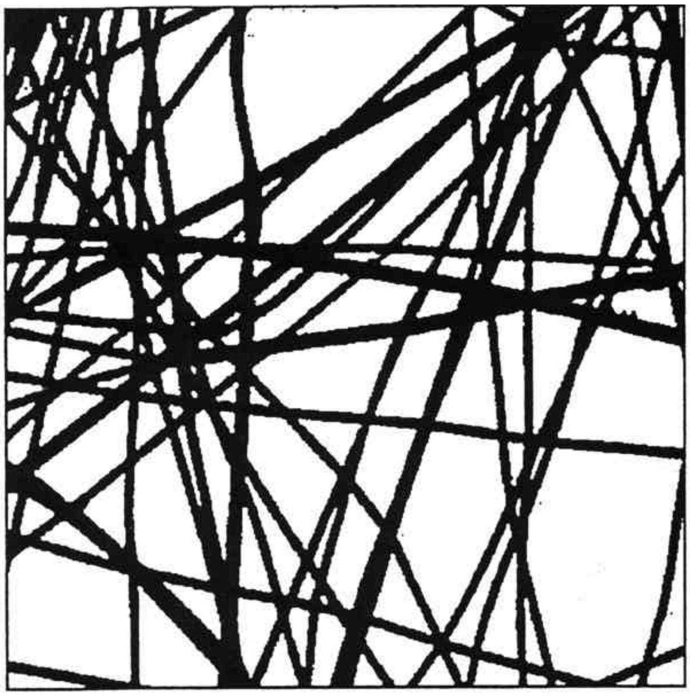


Figure 10 - CCD-recording of specimen at +20°

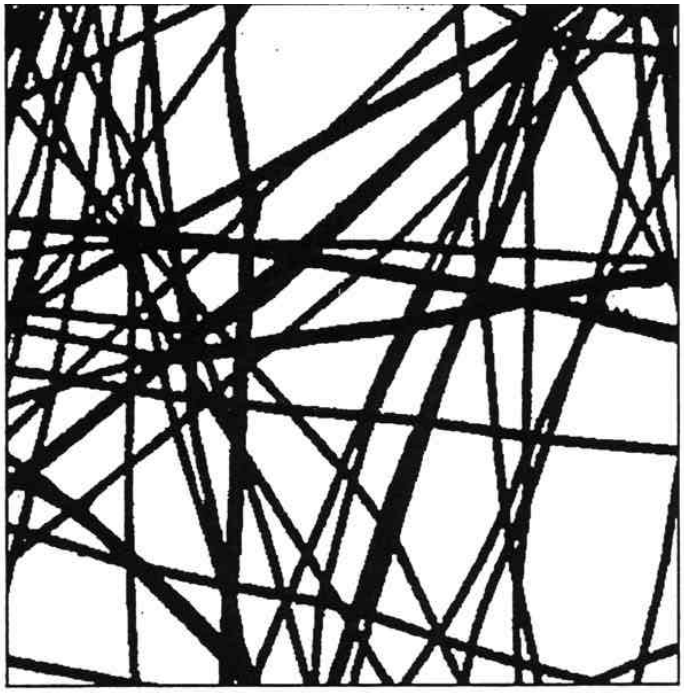


Figure 11 - CCD-recording of specimen at -20°

The parallax between both images is a measure of the three-dimensional properties of the nonwoven. This parallax is demonstrated by the small dissimilarities between figures 12 and 13 (approx. 20x enlarged). From both parallax images an identification and authentication template are computed, each comprising in the order of a few tens of bytes. The identification template is based on the unique structure of the pattern, while the authentication template is based on the 3D properties of the nonwoven. At enrolment both templates are either stored in the main computer database or in the memory of a microcontroller chip.

Figure 14 illustrates the 3DAS procedure for identification (random properties of the fibres) and authentication (three-dimensionality of the fibres). The physical 3DAS feature is presented to the 3DAS-reader, possibly but not necessarily combined with a personal password (e.g. PIN-code) or a biometric identification (e.g. hand geometry, finger pattern). The stereo-images recorded by the optical system then are processed to yield an identification template and a verification template. These templates are compared with the enrolled templates in the database. Only if the presented identification template and authentication template correlate with the enrolled templates, the input label is accepted and access to the system is allowed. Alternatively, both enrolled templates may be recorded on a memory chip on the card itself for comparison.

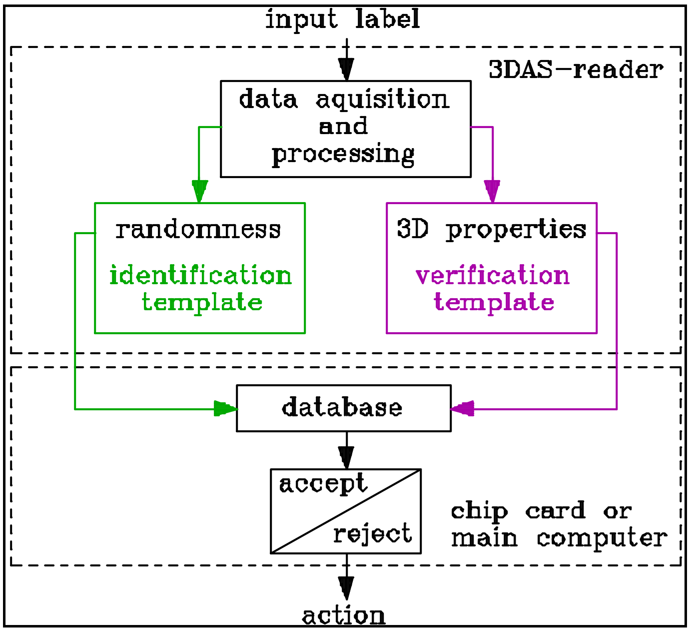


Figure 12 -functional scheme of 3DAS operations.

4.2 Security Aspects of 3DAS

Including the 3DAS-structure in cards provides high security access keys to security systems like safes, rooms, buildings, security territories or data files. The 3DAS microstructure is also 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 such as a pin code. Apart from operating stand alone, the 3DAS system may be supplementary to magnetic stripe cards, memory chip cards and smart cards, as a security enhancing card authentication method. This has the advantage that a cheap 3DAS access key takes over the security function from the chip, so that a cheap memory chip may suffice instead of a smart chip. The 3DAS templates can also be recorded on the memory chip for verification and authentication, so that replacement of the chip is no longer possible without the fraud being discovered. A combined 3DAS-chip reader will be developed.

Three basic procedures exist to verify the identity of a person:
1. Something a person knows (passwords, PIN-codes).
2. Something a person possesses (keys, cards).
3. A personal (biometric) habit or attribute (voice, signature or hand shape, fingerprint).

Low security access requires merely one of these three procedures. Both first procedures have the disadvantage that, what a person knows or possesses, may (even without being noticed) become the knowledge or possession of someone else in numerous ways.
Biometric identification supposedly does not have this disadvantage and therefore would offer a better security. However, as biometric machine identification is still in its childhood, either procedure 1 or 2, or their combination, are most frequently applied. Surprisingly, passwords and PIN-codes appear to be difficult to remember, so that the application of physical keys or cards is compulsory for public applications (e.g. POS/ATM-access, health care). However, physical attributes are frequently lost and must be replaced. Low cost, high security keys, like the 3DAS-key card therefore may have an advantage over more or less advanced but expensive keys.

5. DISCUSSION

First line inspection is limited to the human senses. The main advantage of first line inspection is the low cost, excellent and multiple performance potential, and world wide distribution of the human senses. A few pertinent disadvantages of first line inspection are of a psychological nature: (1) the human tendency to become slack when performing dreary tasks, and (2) human forgetfulness. As a result, valuable documents like credit- and ID-cards, cheques, banknotes, etcetera, are rarely inspected properly, if people know at all what features to look for. First line inspection therefore involves a certain insecurity. The application of machine inspection, by definition, is a second line approach to security.
Machine inspection on the other hand has the disadvantage of high cost, which on its turn tends to inhibit the general distribution of machine inspection systems. Another drawback involves the difficulties encountered in putting up generally accepted standards for machine inspection systems. A pertinent advantage though is that machines do not get forgetful, negligent or tired and may perform complex but one-sided tasks with great accuracy and high speed. Accordingly, high security is a characteristic of most machine inspection techniques.
In view of the alarming, world wide escalation of fraud, it may be expected that the application of machine inspection techniques will gain ground. We will also see the number of different inspection techniques increase as well as the integration of different inspection techniques in a single machine. Biometric systems may very soon become important players in this field.

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