Consiglio Nazionale delle Ricerche

Test procedures for the automatic inspection of finished, plain weave, uniform coloured flat and denim fabric

Esprit project 21089
High Performance System for Textile Evaluation

Luciano Azzarelli, Massimo Chimenti, Ovidio Salvetti, Eugenio Mandelli

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Summary

Introduction

In the frame of Task 1.5 of the Project, IEI has defined the main criteria to be followed for a proper design of a general system for textile inspection and consequently for its testing (see Deliverable 2, Performance and test criteria).

After the development of a prototype system and in view of the execution of the first factory experiments (Task 3.2), IEI has synthesised and analysed further information in order to define the real performances of the system to be realised in the framework of the project and to prepare suitable tests.

From one end, Legler has given a detailed description of the materials to be inspected (chapter 1) and of the criteria of visual inspection (chapter 2) and has defined a list of requirements (chapter 3), that is the result of the relevant skill of the company in the textile manufacturing and quality control and also the result of long term relationships with major world-leader garment making companies.

On the other end, on the basis of the performed market analysis, the most significant few systems and the different solutions adopted, even if information is not yet complete, have been individuated (chapter 4).

The specifications given in chapter 3 refer to an ideal, fully automatic and highly complex system: indeed, we feel that such a system, apart from the difficulties of its realisation, will not respect to the performance/costs ratio that is one of the general constraints of the project. Therefore, in accordance with the real performances of existing systems for quality textile control, technical requirements are defined (chapter 4) that allow a certain degree of interaction with the system in order to obtain the required classification of defects and of fabric aspect.

Some experiments and evaluations have been carried out at IEI laboratory to better understand the requirements and constraints of the system and to partially evaluate the desired performances (results of these activities are being reported into the Hipertex Web-Site under construction at IEI); this activities constitute also a guideline for the definition of test criteria.

1. Fabric inspection at Legler plants

Quality control of fabric (fabric inspection) performed by trained inspectors at Legler plants includes three types of activity:

- Defect detection, identification and grading
- Fabric aspect control
- Shade control

1.1. Defect detection, identification and grading

Denim or uniform coloured flat fabrics are normally inspected at different speed, ranging between 25 and 35 m/min. Under the operational point of view, defect detection is composed of several steps:

a) the detection and identification of the anomaly on fabric
b) the classification of the anomaly
c) the evaluation of the gravity of the anomaly (grading)
d) the marking of the defect
e) the assessment of the quality.

Detection and identification

During the detection and identification phases, the machine speed can be adapted to the fabric quality and condition (anyway, a default speed is defined). According to existing rules detection and identification has to be carried out with running fabric. The rest of the machine is allowed only in case of strict necessity, in particular when the detection or identification is doubtful.

Classification

A morphological classification of the defects is performed.

Grading

The evaluation of the defect (numeric grading) used at Legler follows the world wide known rules of the "Demerit Point System" (DPS) also called as "Four Point System". The ranges adopted at Legler have been defined following the specification of the Italian Association of Denim fabric producers; Legler's definition is as follows (see also Tables 1 and 2):

- From 0.25 mm to 75 mm (flat fabric) 1 point
  From 0.5 mm to 75 mm (denim fabric) 1 point
- More than 75 mm and up to 150 mm 2 points
- More than 150 mm and up to 230 mm 3 points
- More than 230 mm 4 points.

In order to be able to satisfy the manufacturer or customer specifications for grading, each defect must identified and measured giving thus its shape and dimensions.

Marking

Marking of defects is realised by applying adhesive labels on one selvage or by signing defects with marks of chalk directly on the flaw: in this case, the running of fabric has to be stopped for each mark.

Assessment of quality

The length of fabric ranges between 50 and 400 metres depending upon the level of automation of the garment making company, while the maximum number of DP depends from the supplied quality and it ranges, for denim fabric, between 20 to 30 DP per 100 square metres.

The Italian Association of Denim fabric producers mentioned above uses the following rules:

Denim fabric realised with ring yarns:

Average in the shipment: 20 DP / 100 m^2
Maximum for each piece: 30 DP / 100 m^2

Denim fabric produced with open-end yarns:

Average in the shipment: 15 DP / 100 m^2
Maximum for each piece: 25 DP / 100 m^2

1.2. Fabric aspect control

Three degrees of aspect can be defined. They are:

- **Well**, when the fabric is without or with a limited number of defects and the surface is uniform; in this case, fabric is of good quality and it can be dispatched to the customer.
- **Bad**, when the considered portion of fabric includes severe defects or it is considerably not uniform. Depending from the number and density of severe defects the portion of fabric can be removed or not from the piece, the defective area is anyway covered with a bonus in the price.
- **Unwell**, when the considered portion of fabric is fitted with a large number of small anomalies, each one of them small enough to be evaluated as a non-defect, or the surface of fabric is slightly irregular. In this case, the piece of fabric is tagged with a particular flag and code corresponding to the revealed problem, but it is anyway dispatched to the customer, who makes the final evaluation of the quality of the material.

1.3. Shade control

During the quality control on finished fabrics human inspector operates the following activities:

- instrumental measurement of colour differences between the middle of the inspected sample and a reference (sorting);
- visual and instrumental evaluation of the colour consistency from the top and the end of the inspected fabric piece (tailing);

- visual and instrumental evaluation of the colour difference between the centre and the lateral sides of the fabric piece (shading).

When fabric inspection is running, the inspector periodically checks for colour consistency and when he feels that the shade is changing over the visual tolerances, a new sample is taken from the fabric is transmitted for the instrumental check.

2. End user specifications

This chapter defines the types and sizes of fabrics to be inspected and reports the classifications of fabric defects and fabric aspect assessment used by Legler.

2.1. Fabric types

Two types of cloth are to be taken in consideration: flat and denim fabric.

Flat fabric

The colour of the surface of flat fabric is constant and uniform; in general, face and rear sides of the flat fabric have the same colour; the aspect of the surface of finished flat fabric depends on chemical and mechanical processes.
All the possible types of fabric structures (e.g. Twill, Canvas, Satin, Panama, Reps, Diagonal, Honeycomb and Piquet) should be processed by the system.
The density of threads in the weave is a fundamental parameter for quality inspection since the minimum dimension of the flaws is correlated with the density of the threads .As table 1 shows, threads density varies from 19.2 up to 52.5 in warp and from 14 up to 50 in weft.

Weaving structure	Weight category	Number of threads/cm			
		Warp		Weft	
		max	min	max	min
Twill 3/1	heavy	42.2	19.2	25.0	14.0
Twill 2/1	medium	48.8	22.5	25.0	16.0
Twill 2/1	light	26.4	46.0	19.0	40.0
Canvas	heavy	42.8	25.0	44.0	14.0
Canvas	medium	42.8	23.7	24.0	15.0
Canvas	light	52.5	27.5	40.0	16.0
Diagonal	heavy	42.8	34.5	23.0	16.0
Diagonal	medium	34.5	34.5	20.0	20.0
Diagonal	light	44.5	30.0	50.0	22.0

Table 1. Threads density in flat fabric

Denim fabric

Denim fabric is the result of the weaving combination of dyed warp threads with natural white weft threads. The use of two different types of yarns determines the well known typical colour and aspect of denim that is different when you consider the face or the backside.
The difference in colour identifies denim against the other flat fabrics; in fact, all the other technological characteristics are identical in the denim and in the corresponding structures of flat fabric. Under this point of view, it can be said that denim fabric is a subset of flat fabric. As table 2 shows, thread density in denim

varies from 21 up to 40 threads/cm in warp and from 13 up to 22 threads/cm in weft.

Weaving structure	Weight category	Number of threads/cm			
		Warp		Weft	
		max	min	max	min
Twill 3/1	heavy	26.9	21.0	19.0	13.6
Twill 2/1	medium	40.0	22.5	22.0	13.0
Canvas	heavy	24.9	24.9	16.0	16.0

Table 2. Threads density in denim fabric

2.2. Fabric sizes

Fabric sizes refer to the transversal and length-wise dimension of fabric as well as to its thickness. In our application, the maximum total width of fabric (transversal size) is established at 160 cm for both denim and flat fabrics; maximum longitudinal sizes are 1000 - 1500 m (denim fabrics) and 6.000 m (flat fabrics).

2.3. Fabric defects

Referring to the general catalogue of defects adopted at Legler for the purposes of finished fabric inspection, two separate sets of defects for denim and flat fabric are defined.
Tables 3 - 5 lists the flaws recurrent on flat fabric, according to a morphological classification based on visual recognition. The flaws have been grouped into three classes:

- Flaws lying in the warp direction (Table 3)
- Flaws lying in the weft direction (Table 4)
- Flaws with random shape [area flaws] (Table 5)

3	Slub in warp
4	Coarse end
5	Wrong number in end
6	Dirty or soiled end
7	Foreign fibre in warp
8	Double end
9	Missing end
10	Broken end
11	Slack end
12	Tight end
40	Reediness

Table 3. Flaws lying in the direction of the warp (flat fabrics)

13	Filling slub
14	Coarse pick
15	Wrong number in weft
16	Dirty or soiled pick
17	Foreign fibre in weft
18	Double pick
19	Missing pick
20	Broken pick
21	Slack pick / Snarls / Loopy filling
22	Tight pick
23	Filling floats
24	Jerk-in
25	Loom waste
26	Wild filling
27	Wrong warping
28	Thick place / Uneven filling
29	Reed misdraw
30	Harness misdraw
31	Harness balk
32	Harness breakdown
33	Loom stop / Starting bar

Table 4. Flaws lying in the direction of the weft (flat fabrics)

1	Dead or immature cotton
2	Neps
34	Knot
35	Hard size
36	Tangle
37	Hole
38	Cut / Tear
39	Burned place
41	Oil spot
42	Water spot / Stain
43	Dirt stain
44	Crease
45	Sanforize undulation
46	Bruise / Temple bruise
47	Broken selvage
48	Rolled selvage
49	Irregular cloth structure
50	Irregular width
51	Irregular raising
52	Irregular shearing

Table 5. Flaws with random shape (flat fabrics)

Tables 6 - 8 list the flaws recurrent on denim fabric, according to the previous classification; table 9 list the subset of the most important and recurrent flaws on denim fabrics, agreed with QC responsible of Legler.

3	Slub in warp
4	Coarse end
5	Wrong number in end
6	Dirty or soiled end
7	Foreign fibre in warp
8	Double end
9	Missing end
10	Broken end
11	Slack end
12	Tight end
40	Reediness

Table 6. Flaws lying in the direction of the warp (denim fabrics)

13	Filling slub
14	Coarse pick
15	Wrong number in weft
16	Dirty or soiled pick
17	Foreign fibre in weft
18	Double pick
19	Missing pick
20	Broken pick
21	Slack pick / Snarls / Loopy filling
22	Tight pick
23	Filling floats
24	Jerk-in
25	Loom waste
26	Wild filling
27	Wrong warping
28	Thick place / Uneven filling
29	Reed misdraw
30	Harness misdraw
31	Harness balk
32	Harness breakdown
33	Loom stop / Starting bar

Table 7. Flaws lying in the direction of the weft (denim fabrics)

1	Dead or immature cotton
2	Neps
34	Knot
35	Hard size
36	Tangle
37	Hole
38	Cut / Tear
39	Mechanical bump
41	Oil spot
42	Water spot / Stain
43	Dirt stain
44	Crease
45	Sanfor waves
46	Bruise / Temple bruise
47	Broken selvage
48	Rolled selvage
49	Colour band
50	Irregular width
51	Thick denim cloth
52	Open denim cloth

Table 8. Flaws with random shape (denim fabrics)

Warp oriented	Coarse end Wrong yarn number in warp Slub in warp Double end Missing end Foreign fibre in warp Slack end Broken end Tight end
Weft oriented	Loom waste Wild filling Filling floats Filling slub Coarse pick Double pick Missing pick Broken pick Slack pick Snarls Harness balk Harness breakdown Thick place Loom stop
Small & large areas	Hole Knot in warp / Knot in weft Cut Tear Hard size Colour band Water spot Oil spot Sanfor waves Tangle Crease Mechanical bump

Table 9. Subset of denim flaws statistically revealed and to be detected from an industrial automatic inspection unit

2.4. Fabric aspect

Fabric aspect can be identical on the two sides or can be completely different. Normally, the back or reverse side does not need to be inspected and does not influence the commercial evaluation of fabrics.
The automatic inspection unit should be able to detect the conditions that determine the unwell aspect. Two fundamental conditions must exist for the occurrence of the unwell aspect:

- the existence of anomalies
- the density of the anomalies.

The quantity of the anomalies revealed in a predefined area defines the density of the anomalies. In order to give a correct rule, we must also take care of the typical dimension of the detected anomaly; for example, the defect called "dead cotton" is composed of several light dots smaller than one square millimetre, while the defect called "filling slub" can be half millimetre wide but several millimetre long.

2.5. Colour measurements

Colour measurements are carried out using dedicated instruments (colorimeters and spectrophotometers) and the result of the measure is a set of values which define the spatial position of that colour in the selected standard colour space (e.g. CIELab , HUNTERLab , etc.). Colour tolerances define the boundary over which commercially acceptable colour differences become rejected.
For example, in CIELab colour space, colours are classified using three units:

L (Luminosity)
C (Chrome)
H (Hue)

while colour differences are presented giving four values:

ΔL (difference in Luminosity)
ΔC (difference in Chrome)
ΔH (difference in Hue)
ΔE (a mathematical formula that integrates the differences in Luminosity, Chrome and Hue)

We can define two sets of tolerances (Light source: D65, Observer: 10°):

	ΔE	ΔH	ΔL	ΔC
sorting and tailing	1.20	0.60	0.80	0.80
shading	0.60	0.30	0.40	0.40

3. General requirements for automatic inspection

The following requirements are based on the desired features of automatic systems for textile inspection both at Legler plants and at other fabric maker's plants.

Fabric presentation

Fabric shall be inspected full width, face side only. Fabric must be inspected in all its extension, thus avoiding that the initial or final parts of the piece of fabric remain not inspected.
Positioning tolerance can be established as ± 3 cm.

Inspection speed

Normally, fabric is running at constant speed: the target speed is 60 m/min for flat and denim fabric, and the typical range of machine speed is between 10 m/min and 60 m/min.
At the beginning and the end of a piece, fabric is running at variable speed: in these cases, in order to inspect the full piece, an automatic inspection unit should be able to synchronise image acquisition and processing to the actual fabric speed.

Operational time

Operational time should be 24 hours per day and 365 days per year.
Maintenance pauses are acceptable if total efficiency rate is not less than 90% of the theoretical working time of the unit.

Inspection accuracy and tolerance in defect classification

Fabric inspection can be performed by using a three steps flaw classification approach, based on anomaly detection, macro-classification and micro-classification of defects (see par. 5).
The unit must be able to detect the entire set of defects specified for flat and denim fabrics, with a rate of success not less than 95%, that is the average rate of success of the human inspector. The unit has to be able to macro-classify the defects, grouping them in the three categories presented in Tables 3, 4, 5 (flat fabrics) and 6, 7, 8 (denim fabrics): also in this case, the rate of success cannot be less than 95%. Finally, the unit has to be able to micro-classify the defects, with the same rate of success.
For each defect, the unit has to supply the following morphological information:

- the longitudinal position of the flaw
- the transversal position of the flaw
- the dimension of the rectangle that includes the flaw
- the approximate actual area of the flaw
- a set of other characteristic parameters such as average, luminosity, type of flaw contour, etc. which could be used for the classification of identified flaws.

False detection of defects is admitted in a percent up to 0,1% of the real defect detection.

Output of the inspection

The automatic inspection unit must be able to provide all the necessary information for the assessment of the inspected fabric piece, like customer and producer maps.
The unit must be able to control a marking unit, which will be better identified during the dedicated analysis to be carried out in a later stage of the project. According to the actual requirements a permanent mark should be put in the immediate proximity of the flaw.
The final system should be able to control the operation of the marking unit even when this equipment is installed far from the image acquisition location.

Location of the unit

The automatic inspection machine can be installed in-line or off-line to the production process.
When the unit operates in-line, it means that the unit is installed as section of a production machine and that the production machine moves the fabric. Supplementary equipment to help the relaxed passage of the cloth in the inspection section is allowed.
Two possible in-line installations can be foreseen:

- the unit is located at the end of the last finishing machine, i.e. typically the shrinking machine
- the unit is located before the packaging machine.

In the first case, fabric speed depends only from the requirements of the production machine, provided that the speed range for the automatic inspection is respected. Typical range of speed in the shrinking machine is between 30 and 50 m/min.
At Legler, as well as at many other middle-large companies, fabric exits the shrinking machine rolled up on wide rolls (diameter of about 200 cm). Between the last drying section and the rolling-up section, it is a scray unit, that is a sort of cradle where the cloth can be stored during the replacement of the giant roll, without stopping the shrinking machine. The inspection unit can be installed just before the scray, thus maintaining the same constant speed of the main production sections.
A particular advantage of this in-line application is that the fabric lies between 2 and 8 hours before the cutting and packaging phase because technological tests have to be carried through on the finished fabric. In this time, a post-analysis of the inspection data could take place.
This type of location is nowadays very popular in the installations of competitors' equipment dedicated to the denim fabric. A careful analysis carried out by Legler's experts showed that in-line installation on the last production machine is the most advantageous location and will become even more convenient when the price of the unit will become less expensive.
When the inspection unit is installed together with the packaging machine, a post-analysis of the inspection data is impossible, but on the other hand, the fabric speed can be managed by the inspection unit, thus giving priority to the needs of the quality inspection against packaging operation. Nevertheless, it is to note that cutting and packaging are operations that need frequent stoppages of the fabric piece, while automatic inspection needs for a continuous and regular movement of the fabric; a compromise of the two requirements could be difficult to reach.

Off-line inspection means that the automatic unit is a stand-alone equipment, without any connection with the production machines, located between the shrinking machine and the packaging machine. This type of location presents many advantages and few disadvantages, which all together propose the off-line implementation as the most adapted for the first approach to the automatic inspection problems.
Main advantages are:

- the possibility of inspecting the fabric at the maximum speed of the automatic unit, thus having less inspection unit installed;
- the possibility of driving the speed of the unit in close co-ordination with the computation needs, i.e. slowing down the speed when the resolution necessary is very high or stopping the inspection when a large number of flaws is detected;
- the possibility of being benefited by the delay in packaging for technological tests, when the automatic inspection takes place immediately after the shrinking operation;
- the avoiding of stopping the inspection unit when the production machine is in maintenance or out of service.

Main disadvantages are:

- the necessity of implementing a fabric moving equipment for each automatic inspection unit, with higher installation cost in comparison with in-line installations;
- the necessity of personnel dedicated to the inspection units;
- a further rolling-down and rolling-up phase, which could be dangerous for the fabric technological characteristic.

Field parameters

The automatic inspection unit must be adapted to the installation in the textile industrial environment. It implies a set of characteristics to be respected.
Some of them are related with electrical and mechanical characteristics, such as:

- power supply aligned with the standard requirements for the country of installation,
- the respect of the CE norm for the protection of the users,
- the capability of operating in an environment with low EMI interference,
- the robustness of the mechanical components enabled to the mechanical tension of fabric,
- the possibility of operating in environments affected by low structural vibrations.

Other requirements originate from the flexible nature of the fabric:

- the capability of monitoring the elongation or the narrowing of the fabric at the entrance and at the exit stage of the unit;
- the capability of inspecting the running fabric without strong longitudinal and transversal tension so that the natural characteristics of fabric are not damaged;

- the capability of operating with small waves and light vibration of the fabric;
- the capability of detecting and taking care of sudden variations of the fabric width and of slight lateral translations (± 3 cm).

Further environmental conditions are:

- atmosphere with high dust content;
- presence of natural light in the inspection zone;
- exclusion of physical and chemical emission dangerous for the user health.

Auto-diagnosis and easy maintenance

The unit has to be able to detect and signal the out-of-service conditions, such as the sudden break of the illumination media, as well as it has to implement on-line diagnosis.
The unit should perform also off-line diagnosis of malfunctioning, almost every week during the weekend pause; the output of this auto-test should be produced in form of written protocol.
The robustness of the components is a sine-qua-non condition for the industrial application of the inspection unit. We refer in particular to the consumable components, whose working life must be not less than 1000 hours.
The engineering of the unit will implement all the necessary tools for a fast and easy maintenance of the unit; i.e. replacement of consumables has to be possible from the technical staff of the customer, when opportunely trained in the domain.

Fault tolerance characteristics

A hard question to reply concerns the implementation of a back up unit capable of continuing the automatic inspection when the main computing hardware fails. A complete analysis of the problem should take care of two significant arguments:

- the supplementary cost of the unit owing the doubling of the computer
- the possible consequences of the break of the unit.

Under the premises that the unit implements auto-diagnostic routines for the detection of malfunctioning of each electronic component, we come to the conclusion that each malfunctioning of the system immediately produces the stoppage of the inspection process.
This is not however a dramatic situation because:

- the automatic inspection can be replaced by human inspection for a short period
- the purchase of the automatic inspection equipment has to be supported with the supply of an adequate number of spare parts and with a fast service from the supplier.

If technical consequences can have a low impact, we have to consider now the economical aspects, which are of non-secondary importance owing to the relatively high price of the inspection unit.

Taking the hypothesis that the commercial price of one unit ranges between ECU 150.000 and ECU 250.000 and that the computing hardware represents the 30% of the price, a back-up unit cannot be more expensive than 50 - 60% of the main one. In order to avoid a significant increase of the commercial price, particularly addressed to the SME, the back up unit, in any case, has to be offered as optional part of the simpler configuration.
The number of break-downs and the standardisation of components, together with their market availability, will also play an important role in the decision of equipping the system with a back-up unit, because the low price and fast purchase of standard electronic components can push the user to avoid an immediate surplus on the purchase cost when the number of system break-down is estimated near zero.

Commercial price

While the cost of the inspection unit only depends from the adopted technology, the commercial price should take care of several different parameters, the most important the real capability of the system to replace the human inspection. In this domain the ratio performance / price must be maximised and over the ratio of the existing marketable systems.
The daily practice give us, on the contrary, several examples of application where the automatic inspection unit was bought not to replace the inspector but only to help him and to guarantee an higher probability of success in defect detection.
The market situation however is today influenced by a monopolistic condition where one supplier dominates the market for a lot of reasons, particularly for the weakness of the competitors' offer.
Market prices of the different models of inspection unit reflect this situation. All they range over ECU 250.000 and are not in the possibility of SMEs.
Legler's analysis on the economical benefits produced by the installation of automatic inspection units considers the total replacement of the personnel dedicated to the inspection of flat and denim fabrics. Automatic inspection systems are placed at the end of the shrinking machine, thus having the maximum economical benefit from the personnel saving.
The following data summarises the conclusion of the analysis.

Total production in metres:	FLAT	DENIM
	14.800.000	19.300.000
# of automatic inspection unit:	FLAT	DENIM
	2	2

Actual number of personnel	74	
Future number of personnel	45	
Saving of personnel	29	
Total yearly saving in ECU	about 680.000	
Company pay-back period in years	1	2
Cost saving for the pay-back period in ECU	680.000	1.360.000
Estimated minimum price per unit in ECU	**170.000**	
Estimated maximum price per unit in ECU		**340.000**

4. State-of-the-art of textile inspection systems

In order to have an overview of the performances of systems available for the textile quality control, a state-of-the-art research has been done. At the moment, only few industrial systems are available on the market, while Universities and centres of research, mainly in USA, are developing some prototype systems under research projects.

4.1. Industrial systems

Elbit Vision System Ltd.

EVS is an Israeli leading group in the development of automatic inspection systems for the quality improvement in textile applications.

The I-TEX system makes use of unique image understanding algorithms (trying to imitate human visual system) to detect the defects. The system is able to detect different kind of defects (spinning, weaving, dyeing, finishing and coating) small up to 0.5 mm on any single-colour fabric, wide up to 330 cm and at speeds that reach 100 meters per minute.

For denim and flat fabric the performances are lower. In fact, the I-TEX 200 for denim, installed in-line with Sanfor line, can inspect fabric wide up to 160 cm and at a maximum speed of 50 m/min, with a width tolerance of ± 3 cm and same positioning tolerance. The I-TEX 200 for flat uniform coloured finished fabrics has a maximum inspection speed of 60 m/min, a maximum fabric width of 190 cm and width and positioning tolerance of ± 3cm.

The I-TEX 100 for grey and natural coloured fabrics has the same features of the I-TEX 200 for flat, except for the speed that can reach 90 m/min. The defects classification is performed by an off-line workstation (the Video Album): only morphological features (e.g. vertical, horizontal, spot) are extracted, while the kind of defect (e.g. missing peak, oil spot, slack end, etc.) is not revealed. The workstation let the operator see all the frames containing defects for reviewing and analysing; information as type, severity, location and size is provided for each defect. Moreover, the Video Album allows presenting specific subsets of defects and viewing them in different scales. The presence of an off-line workstation means that a real-time interaction between man and machine is not possible. All the systems can be integrated with an in-line system that measures shade variation in textiles during normal fabric running (Shade Variation Analyser - SVA). The system utilises calibrated traversing sensor and proprietary signal processing algorithms. The SVA is modular and can be accommodate to any fabric width. It is designed even to operate as a stand-alone unit.

<u>System features</u>

Acquisition:	not available
Processing:	image understanding algorithms
Defects analysis:	off-line
Defects classification:	macroscopic
Defects marking:	features storing
Producer:	Elbit Vision System Ltd., New Industrial Park P.O. Box 140, Yoqneam, ISRAEL

Systronics Inc.

Systronic inspection systems are installed in many industries: non-woven, metal, rubber, plastic film, textile and paper. These systems utilise line scan technology coupled with various lighting techniques to optimise the fabric inspection. The system can detect all the usual imperfections such as holes, foreign material, streaks, voids blotches and other defects. According to the present information, this system seems able to inspect only fabric of small size: a deep research about this and other technical features is in progress.

Once the defects are detected, they can be marked directly or an alarm can be triggered to alert the operator, so that real-time interaction is possible. This option is settable by a touch-screen user interface (controlled in a Windows environment) provided with the system. The interface let the operator access also other information, such as defect maps, class graphs, trend graphs and roll reports for further statistical analysis. All information can be printed, stored or networked to a host computer.

<u>System features</u>

Acquisition:	line scanning
Processing:	not available
Defects analysis:	on-line and off-line
Defects classification:	not available
Defects marking:	acoustic alarm or features storing
Producer:	Systronics Inc, 6400 Atlantic Boulevard Suite 100, Norcross, GA 30071

Nova technologies

Nova provides system integration services for high technology control and automated visual inspection systems. The Nova Web site is actually under construction so that more information is not yet available. In order to build up our knowledge about these systems, we are looking for a direct contact.

4.2. Research systems (prototypes)

Alpha system

A prototype system has been developed by ISMV - Image Science and Machine Vision group - under the Computer-Aided Fabric Evaluation (CAFE) project.

The system utilises an algorithm based on the wavelet transform to process the high quality images acquired with either by light reflection or transmission. Relevant attributes of the fabric under inspection are compared with parameters learned from a reference fabric, so that a portion of the fabric containing defects is determined. Defects are then localised and characterised through the extraction of their main features. These features are then also available for further analysis and archiving.

All the functions are performed entirely on a PC platform equipped with an off-the-shelf, DSP-based board.

The system accomplishes on-loom real-time inspection of the material under construction. Tests in an effective environment have given really good results.

System features

Acquisition:	not available
Processing:	wavelet transform
Defects analysis:	on-line
Defects classification:	not available
Defects marking:	features storing
Producer:	ISMV - Image Science and Machine Vision group

WeaveScan:

An automated on-line inspection system, developed by researchers at the Georgia Institute of Technology, has been successfully operated on a loom at the company's Southern Phenix plant, since July 1996. A West Virginia maker of textile equipment (Appalachian Electronic Instruments, Inc.) has licensed the technology with plans to produce a commercial system.

The Georgia Tech system automatically identifies defects as the fabric comes off the loom, allowing the manufacturer to immediately correct process problems, improving the quality of the manufacturing process and not just determining what quality exist in the finished products. A special lighting arrangement and a set of high-speed cameras is used to scan the fabric, while a computer analyses the information provided by the vision system to identify anomalous patterns and determine whether they should be considered defects.

Weavescan uses the new Motorola ColdFire microprocessor coupled with DSP Texas Instrument's TMS320C5X to control the image capture and processing. Digital signal processors offer a cost-effective, fast parallel processing capability to reduce defect recognition times by orders of magnitude. The system extract signatures from the images that are characteristic of the type of defect that might be present; a new wavelet/neural network approach is used for this signature extraction, along with fuzzy logic decision support systems. Moreover, the software integrates learning and optimisation tools that avoid false alarm and improve the recognition accuracy. Utilising these advanced Imaging Technology, the fabric can be scanned at speeds up to 180 inches per minute, and using the specified cost-effective hardware the system will have a low cost (<4000 $ for Plain Weave system).

System features

Acquisition:	not available
Processing:	wavelet / neural network + fuzzy logic
Defects analysis:	on-line
Defects classification:	not available
Defects marking:	features storing
Producer:	Georgia Institute of Technology, Atlanta, GA 30332-0828

5. Technical requirements for Hipertex system

The Hipertex system should execute three types of actions:

- defect detection and characterisation
- fabric aspect control
- shade control

In addition, auxiliary activities (such as labelling of defects or post processing activities) should be carried on by the system to produce rolls of fabric, ready to be delivered to the final customer.

The first two activities should imply the use of different and current approaches of image analysis. In fact, some kinds of surface defects, like, for example, those determined by the presence of foreign substances, can produce large variations of the contrast of the image: thus, the acquired image can be processed by using some measurements techniques of the photometric values of the pixels, such as thresholding or histogramming. On the contrary, other kinds of defects, like, for examples, doubling or lacking picks, modify the structure of the textile, without affecting the image contrast: in this case, the image can by analysed by means of techniques based on frequency analysis.

Some of the defects looks very similar and the surface aspect is not defined in a unique way: this means that in some cases specific approaches should be followed in order to solve ill-posed problems.

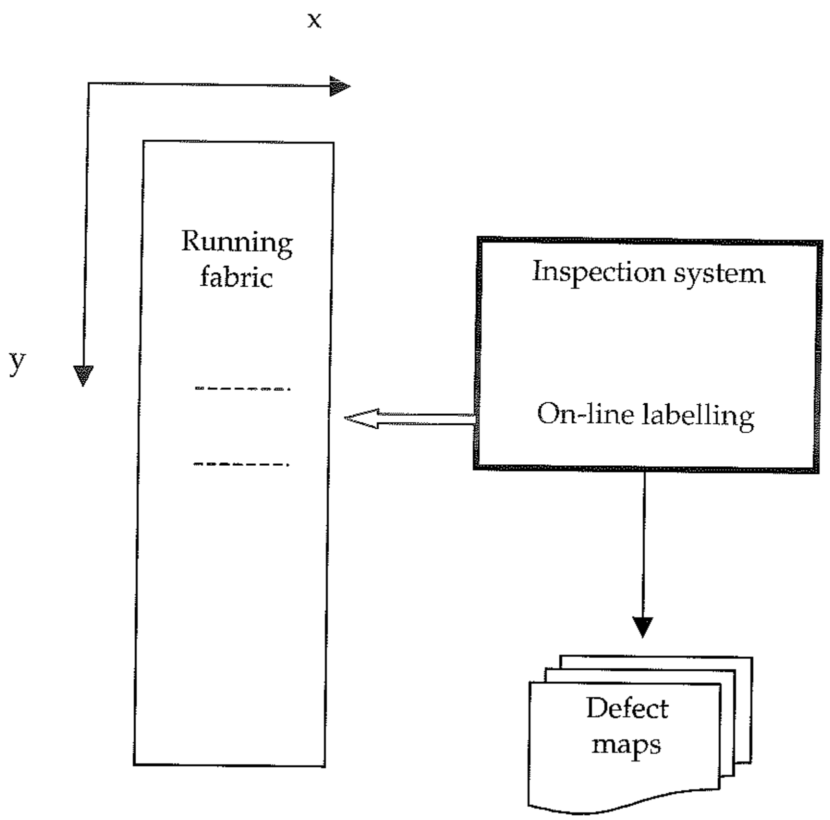

Figure 1. Automatic detection, classification and labelling of flaws areas.

The performances of the system should be partially reduced with respect to those offered by an ideal system, as evidenced in chapter. 3, but should be better or at least equal to those offered by other systems available on the market (see chapter 4).

The Hipertex system should execute the above mentioned operations by a two-phase approach (see figure 1).

In the first phase, regions of the fabric containing flaws are detected during inspection; these regions can be marked or labelled by the system either in on-line or in off-line conditions.

In the second phase, at the end of fabric inspection or in a parallel post-processing phase, only the image data pertaining to flaw regions are analysed in order to achieve a fine classification of defects.

Following this approach, two kinds of maps can be obtained: customer maps, containing locations and dimensions of the defects, useful for grading of fabrics and cutting operations; producer maps, containing also the fine coding of defects, useful for statistics and for the control of production machines or processes.

6. General test criteria

In order to evaluate the efficiency, accuracy and reliability of the system, we propose to introduce testing criteria based on a comparison with the statistically significant results of visual inspections, performed in two ways:

- automatic mode, in which the operator, placed at a constant distance from the textile, looks at the fabric running at a constant speed;
- interactive mode, in which the operator can stop the fabric and inspect it in different conditions.

Hence, we state a hierarchy of testing phases, which allow evaluating the system with an increasing complexity of the required tasks.

To this end, and based on the technical partners' request, a Black Box Testing (BBT) approach has been defined: this test is based on analysis of requirements and system specification and the system is simply viewed as a mapping of actions from an input space to an output space; a detailed knowledge of the hardware and software implementation of the system is not required.

BBT implies:

- Running the system with a controlled set of inputs (test data)
- Observing the run-time effect that the inputs have on the system
- Examining the system outputs to determine their acceptability

BBT is performed according to:

- Functional testing, to check the correctness of the algorithms
- System testing, to check the validity of the system
- User testing, to verify if the system is well suited for the user's requirements
- Robustness testing, to check for possible crashes of the system

Tests can be performed following two complementary approaches: static and dynamic conditions. In the first case, single images of fabric are digitised when fabric is still or during fabric movement at constant speed: the image analysis can be then performed without particular time constraints. In the second case, on the contrary, images are acquired when fabric is running at constant speed and each computational process is applied in real-time.

According to the above-described concepts, the following test criteria are individuated.

6.1. Functional testing

This phase tests the correctness of the software in order to verify if developed algorithms are able to detect a set of predefined defects on different types of fabrics, to evaluate the aspect of the fabric and to monitor its shade.

Defect detection

The analysis of acquired images can be performed following a three level approach (see figure 2):

I. detection of regions with anomalies (possible defects);
II. coarse (or macro) classification of defects (weft oriented, warp oriented, random shape);
III. fine (or micro) classification, according to the morphological classification reported in tables 3-8.

Fabric aspect control

The system unit should be able to detect the conditions that determine the well, unwell or bad aspect of the inspected fabric. For this purposes, the system has to determine the number and density of defects with dimensions between 0.25 mm and 75 mm (see Demerit Point System, par. 1.1), in regions whose dimensions depend on the type of finished fabric and that are to be still exactly defined.
The test performed for this function could require the detection of the above mentioned parameters and their location in each acquired strip of fabric and over more adjacent strips.

Shade control

The measurements performed by means of the colorimetric unit of the system will be compared to those obtained using the reference instrument of the end user, in order to evaluate the accordance between the two instrumental systems. The test should consist in the collection of discrete or continuous measurements performed in the middle and at both edges of the fabric.

In all kinds of tests, each sample of fabric has to be inspected several times, in order to determine the repeatability of the system outputs; the results have to be compared to the assessments resulting from visual inspections or from colour measurements, in order to evaluate the accuracy of the system.

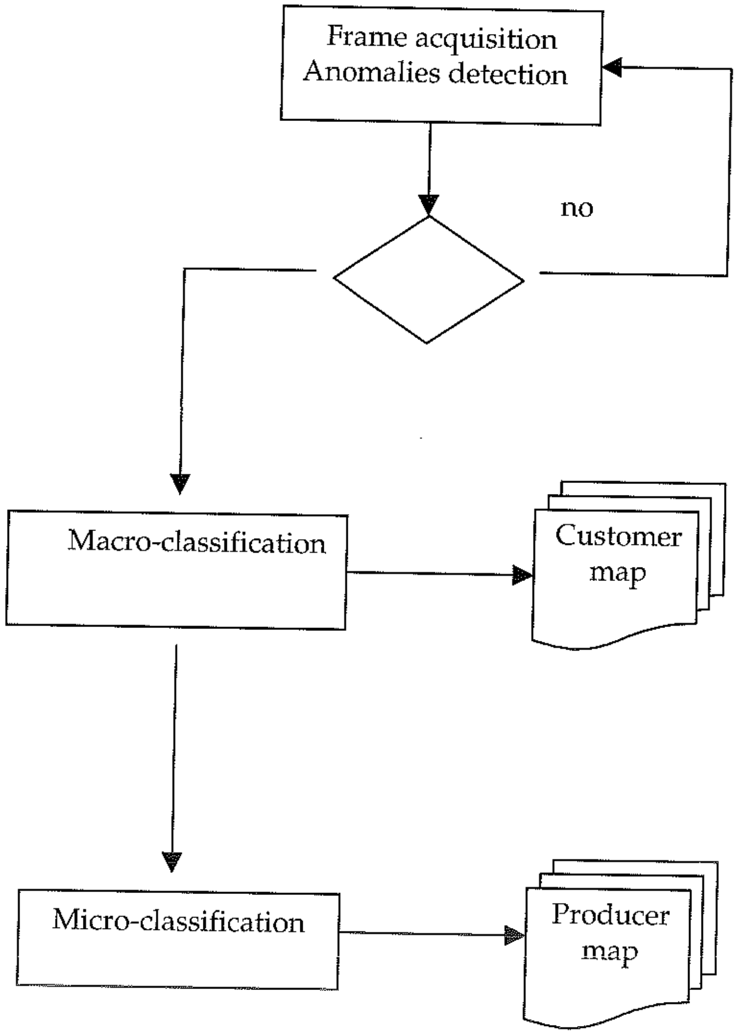

Figure 2. Anomalies detection and defects classification.

6.2. User testing

This step is performed to verify if the system is well suited for the user's requirements from its point of view. Three types of tests are to be executed:

- *Performance testing*: the system should work with a fabric running at a speed of 60 m/min. and should be able to classify correctly all the defects.
- *Cost testing*: compute the cost of all the components of the system, add the costs for use and maintenance and verify that the global costs are acceptable.
- *Serviceable testing*: the system should be easily usable by the user; when the system detects anomalous conditions it should be able to assist the user to solve the problem; the presence of specialised technicians should be limited.

6.3. System testing

This step tests the validity of the system, considering its efficiency and its competitiveness with respect to other existing systems.
The first kind of test verify if the system is able to fulfil its complete task in the requested time with an acceptable global cost; the second kind of test consists in a comparison between the system and all the other systems on the market considering the following features:

- Hardware and Software solutions
- Global system cost
- Global system reliability
- Capacity of up-grading

Furthermore, three different tests can be identified in accordance with the three main functions performed by the system: image acquisition, image analysis, output of results.

Image acquisition

Static test

In this case, a small sample of fabric is inspected several times, using the different input channels of the system: this way, the functionality of each channel and the uniformity of their responses are tested.

Dynamic test

In this case, pieces of full width fabrics running at predefined constant speed are inspected: this way, the overall response of the system, and in particular its functionality at the fixed speed is tested.

Image analysis

A test should be performed in order to evaluate the modularity vs. adaptability of the system. In particular, the system should function properly using a pre-selected number of adjacent input channels so that different width of fabric could be inspected.

Output of results

Apart from the production of synthesis maps regarding the overall evaluation of a piece, as previously mentioned, a test should check the proper functioning of a marking device and should evaluate the management of a temporary image archive useful for detailed post-analysis; in addition, a test should also be done for evaluating the management of a permanent data archive containing the statistics relative to the inspected rolls.

6.4. Robustness testing

This test checks the response of the system to possible crashes.
Two different tests should be carried on:

- *Stress testing*: in case of environment modification (e.g. light intensity, anomalous movements of rolling fabric) the system should continue to work correctly or alternatively it should signal when the working conditions are not appropriated; the system should work without any problems in the requested duty time.
- *Recovery testing*: the system should be capable of recovering and resume processing within a specified time.

7. Test procedure for the prototype system

The prototype system to be used in the first factory tests will have reduced performances with respect to the final system; in particular, the prototype will acquire only a fraction of the full fabric, it will not be able to control in real time the labelling or marking of defected areas, it will perform only the first and second levels of defect classification and it will not have the capability to perform some statistical analyses of the results or the present output data in the requested form: anyway, due to the modular structure of the designed system, most of the expected final performances will be shown by the prototype system.

For what concerns defect classification, the sensibility and the accuracy of the prototype system should be measured making use of the result of an accurate inspection performed by Legler operators; the expected rate of success in flaw detection should be 95%, in accordance with the user requirements stated before.

Two sets of reference samples of flat and denim fabrics, collected by Legler, will be used during tests of the system prototype; each sample contains at least one kind of defects; the samples will be sewed together in order to form two reference rolls, one for flat and one for denim fabrics, giving priority to the flaws, as shown in the following tables.

Table 10 reports the available examples of flaws recurrent in flat fabrics; Table 11 reports the available examples of flaws recurrent in denim fabrics: not all kinds of defects are presently at disposal. Table 12 lists the defects included in the roll composed of reference denim samples, while Table 13 lists the defects included in the roll composed of reference flat samples.

The test on fault detection will be carried out on fabric running on a dedicated inspection table available at Legler; the fabric speed will be agreed with the partner.

We feel that, in order to collect a proper amount of data for the successive formal evaluations, the following sequence of tests should be executed.

T0	T1	description	N	T0	T1	description	N
1	C	Dead or immature cotton		27	B	Wrong warping	
2	C	Neps	1	28	B	Thick place / Uneven filling	
3	A	Slub in warp	6	29	B	Reed misdraw	
4	A	Coarse end		30	B	Harness misdraw	1
5	A	Wrong number in end		31	B	Harness balk	
6	A	Dirty or soiled end		32	B	Harness breakdown	1
7	A	Foreign fibre in warp	5	33	B	Loom stop / Starting bar	8
8	A	Double end	1	34	C	Knot	6
9	A	Missing end	3	35	C	Hard size	1
10	A	Broken end	7	36	C	Tangle	6
11	A	Slack end	6	37	C	Hole	11
12	A	Tight end	4	38	C	Cut / Tears	2
13	B	Filling slub	11	39	C	Burned place	
14	B	Coarse pick		40	C	Reediness	
15	B	Wrong number in weft	2	41	C	Oil spot	4
16	B	Dirty or soiled pick		42	C	Water spot / Stain	5
17	B	Foreign fibre in weft		43	C	Dirt stain	
18	B	Double pick	5	44	C	Crease	6
19	B	Missing pick	8	45	C	Sanforize undulation	
20	B	Broken pick	2	46	C	Bruise / Temple bruise	
21	B	Slack pick / Snarls / Loopy filling		47	C	Broken selvedge	
22	B	Tight pick	2	48	C	Rolled selvedge	
23	B	Filling floats		49	C	Irregular cloth structure	1
24	B	Jerk-in	2	50	C	Irregular width	
25	B	Loom waste	11	51	C	Irregular raising	
26		Wild filling		52	C	Irregular shearing	
				53		Colour band	14

T0: micro-classification;
T1: macro-classification: A = warp oriented, B = weft oriented, C = area defects;
N: number of samples.

Table 10. List of flaws recurrent in flat fabrics

T0	T1	description	N	T0	T1	description	N
1	C	Dead or immature cotton		27	B	Wrong warping	
2	C	Neps		28	B	Thick place/ Uneven filling	5
3	A	Slub in warp	3	29	B	Reed misdraw	
4	A	Coarse end	6	30	B	Harness misdraw	
5	A	Wrong number in end		31	B	Harness balk	2
6	A	Dirty or soiled end		32	B	Harness breakdown	2
7	A	Foreign fibre in warp	6	33	B	Loom stop / Starting bar	6
8	A	Double end	2	34	C	Knot	9
9	A	Missing end	4	35	C	Hard size	3
10	A	Broken end	4	36	C	Tangle	4
11	A	Slack end	5	37	C	Hole	3
12	A	Tight end	2	38	C	Cut / Tears	2
13	B	Filling slub	6	39	C	Mechanical bump	2
14	B	Coarse pick	2	40	C	Reediness	
15	B	Wrong number in weft		41	C	Oil spot	7
16	B	Dirty or soiled pick		42	C	Water spot / Stain	2
17	B	Foreign fibre in weft		43	C	Dirt stain	2
18	B	Double pick	4	44	C	Crease	4
19	B	Missing pick	6	45	C	Sanforize undulation	6
20	B	Broken pick	4	46	C	Bruise / Temple bruise	
21	B	Slack pick / Snarls / Loopy filling	5	47	C	Broken selvedge	
22	B	Tight pick		48	C	Rolled selvedge	
23	B	Filling floats	3	49	C	Colour band	
24	B	Jerk-in		50	C	Irregular width	
25	B	Loom waste	4	51	C	Thick denim cloth	
26	B	Wild filling		52	C	Open denim cloth	

T0: micro-classification;
T1: macro-classification: A = warp oriented, B = weft oriented, C = area defects;
N: number of samples.

Table 11. List of flaws recurrent in denim fabrics

Piece n°	Defect n°	m-c	Description	Suppl. flaw n°	m-c	Description
1	25 a	B	Loom Waste	41	C	Oil spot
2	25 b	B	Loom Waste	41	C	Oil spot
3	25 c	B	Loom Waste	21	B	Slack pick (dropped)
4	23 a	B	Filling floats	34	C	Knot in warp
5	23 b	B	Filling floats			
6	23 c	B	Filling floats			
7	37 a 37 b	C C	Hole Hole			
8	34 a	C	Knot in warp	25	B	Loom waste
9	34 b	C	Knot in warp			
10	34c	C	Knot in warp	11	A	Slack end
11	34 d	C	Knot in warp			
12	34 e	C	Knot in warp	10	A	Broken end
12	34 f	C	Knot in warp			
13	34 g	C	Knot in warp	4 4	A A	Coarse end Coarse end
14	7 a 7 b	A A	Foreign fibre in warp Foreign fibre in warp			
15	7 c	A	Foreign fibre in warp			
16	10 a	A	Broken end	36	C	Tangle
16 a	38 a	C	Cut / Tear			
16 b	38 b	C	Cut / Tear			
17	4 a	A	Coarse end			
18	4 b	A	Coarse end			
19	4 c	A	Coarse end	3	A	Slub in warp
20	4 d	A	Coarse end	7	A	Foreign fibre in warp
21	13 a	B	Filling slub			
22	13 b	B	Filling slub			
23	13 c	B	Filling slub			
24	13 d	B	Filling slub			
25	13 e	B	Filling slub			
26	13 f	B	Filling slub			

Table 12a. List of faults included in the denim roll samples

27	14 a	B	Coarse pick	7	A	Foreign fibre in warp
28	14 b	B	Coarse pick			
29	12 a	A	Tight end			
30	12 b	A	Tight end			
31	18 a	B	Double pick	33	B	Loom stop
32	18 b	B	Double pick	44	C	Crease
32	18 c	B	Double pick			
33	18 d	B	Double pick			
34	21 a	B	Slack pick (dropped)			
35	21 b	B	Slack pick (dropped)			
36	21 c	B	Slack pick (dropped)			
37	21 d	B	Slack pick (dropped)			
38	3 a	A	Slub in warp			
39	3 b	A	Slub in warp			
40	31 a	B	Harness balk			
41	31 b	B	Harness balk			
42	8 a	A	Double end	10	A	Broken end
43	8 b	A	Double end			
44	11 a	A	Slack end	34	C	Knot in warp
45	11 b	A	Slack end	10	A	Broken end
46	11 c	A	Slack end			
47	9 a	A	Missing end			
48	9 b	A	Missing end			
49	9 c	A	Missing end			
50	32 a	B	Harness breakdown			
51	32 b	B	Harness breakdown			
52	19 a	B	Missing pick			
53	19 b	B	Missing pick	20	B	Broken pick
54	19 c	B	Missing pick	20	B	Broken pick
55	19 d	B	Missing pick	20	B	Broken pick

Table 12b. List of faults included in the denim roll samples

56	28 a	B	Thick place	19	B	Missing pick
57	28 b	B	Thick place			
58	28 c	B	Thick place			
59	28 d	B	Thick place	9	A	Missing end
60	28 e	B	Thick place			
61	33 a	B	Loom stop	41	C	Oil spot
62	33 b	B	Loom stop	20	B	Broken pick
63	33 c	B	Loom stop			
64	33 d	B	Loom stop			
65	35 a	C	Hard size	11	A	Slack end
66	35 b	C	Hard size			
67	35 c	C	Hard size	45	C	Sanforize undulation
68	41	C	Chemical (Oil?) spot			
69	42 b	C	Water spot			
70	42 c	C	Water spot			
71	45 a	C	Sanforize undulation			
72	45 b	C	Sanforize undulation			
73	45 c	C	Sanforize undulation			
73a	45 d	C	Sanforize undulation			
73a	45 e	C	Sanforize undulation			
74	36 a	C	Tangle			
75	36 b	C	Tangle			
76	36 c	C	Tangle	33	B	Loom stop
77	41 a	C	Oil spot			
77	41 b	C	Oil spot			
78	41 c	C	Oil spot			
79	43 a	C	Finishing spot (Dust)			
79	43 b	C	Finishing spot (Dust)	37	C	Hole
80	44 a	C	Crease			
80	44 b	C	Crease			
81	44 c	C	Crease			
82	39 a	C	Mechanical bump			
83	39 b	C	Mechanical bump			

Table 12c. List of faults included in the denim roll samples

Piece n°	Defect n°	m-c	Description
1	2	C	Neppy
2	7	A	Foreign fiber in warp
	7	A	Foreign fiber in warp
3	7	A	Foreign fiber in warp
	13	B	Filling slub
	34	C	Knot
4	9	A	Missing end
	10	A	Broken end
	34	C	Knot
	10	A	Broken end
	23	B	Filling floats
	11	A	Slack end
	34	C	Knot
5	9	A	Missing end
	10	A	Broken end
6	41	C	Oil spot (light)
	10	A	Broken end
7	11	A	Slack end
	xx	B	Foreign fiber in weft
8	10	A	Broken end
	11	A	Slack end
	10	A	Broken end
	11	A	Slack end
	25	B	Loom waste
9	23	B	Filling floats
	13	B	Filling slub
10	13	B	Filling slub
	25	B	Loom waste
11	28	B	Chopped filling ?
	25	B	Loom waste
	7	A	Foreign fiber in warp
12	18	B	Double pick
	26	B	Wild filling
13	18	B	Double pick
	33	B	Loom stop
14	18	B	Double pick
	11	A	Slack end
15	19	B	Missing pick
16	19	B	Missing pick
17	18	B	Double pick
18	22	B	Tight pick
19	24	B	Jerk in
	24	B	Jerk in

Table 13a. List of faults included in the flat roll samples

20	25	B	Loom waste
21	26	B	Wild filling
22	27	A	Wrong warping
	10	A	Broken end
23	30	B	Harness misdraw
	32	B	Harness breakdown
	32	B	Harness breakdown
24	33	B	Loom stop
	10	A	Broken end
	9	A	Missing end
	41	C	Oil spot
25	33	B	Loom stop
	10	A	Broken end
26	33	B	Loom stop
27	36	C	Tangle
28	36	C	Tangle
	36	C	Tangle
29	37	C	Hole
	37		Hole
30	38	C	Cut / Tears
31	37	C	Hole
32	38	C	Cut / Tears
33	41	C	Oil spot
	41	C	Oil spot
34	41	C	Oil spot
35	42	C	Water spot
36	44	C	Crease
37	43	C	Color stain
38	42	C	Water spot
39	44	C	Crease
40	44	C	Color band
41	43	C	Color stain
42	37	C	Holes
	47	C	Broken selvage
43	XX	C	Sanforize pucker

Table 13b. List of faults included in the flat roll samples

7.1. Static test

This kind of test implies the analysis of single images, acquired either when fabric is still or it is running; the inspection camera can be shifted in order to acquire any interesting area within the full width of the fabric.
The prototype system will be opportunely tuned for each type of fabric, then several acquisitions of the same area will be performed, in order to obtain a statistically significant set of values; the obtained results, that is anomaly detection and macro-classification, will be reported for successive evaluation.

7.2. Dynamic tests

This kind of test implies the analysis of continuous sequences of images, acquired with fabrics running at constant, predefined speeds. In order to verify the system performances, these tests are split in two parts.

Short length specimens

In order to fully analyse the response of the system, it would be necessary to store onto the system memory all the acquired frames of raw data, together with the output images, showing the position of the anomalies detected during the automatic inspection of fabrics.
If the length of the inspected fabric is limited at 1-2 m, a quantity of about 10 MB data per test is obtained, so that it is possible to store it either easily on the hard disk or in the memory of the system.
This test allows to determine if the acquisition rate of images satisfies the required specification, so that the fabric is fully inspected in adjacent regions without interruptions; this test permits also to evaluate the efficiency and accuracy of the system.

Full length fabrics

In this case, the digitised raw images will not be stored and only the final outputs of the system will be considered to determine its sensibility, repeatability and accuracy.
The system should be able to signal all the anomalies and to macro-classify all the defects already examined during the learning phase; in particular, the system should detect area defects, independently from their number, shape, colour and position, and linear defects, independently from their number, length, connectivity, colour, orientation and position.
Several inspections of the same rolls should be made in order to evaluate the repeatability of defect detection and the accuracy of the system, both with respect to successful results and false positive detection, according to the specifications previously mentioned. For this purpose, it should be also quite opportune to compare the results obtained by the system and by different visual operators when inspecting unknown pieces of fabrics.

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