SYNTHESIS REPORT

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PROJECT COORDINATOR : Universiteit Gent - Department of Textiles

PARTNERS : BIC Carpets nv
Lano nv
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Balta Industries nv
Brintons Carpets Ltd
Interface Heuga
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Herforder Teppichfabrik
Novalis Fibre
Van Besouw BV Tapijt
Vorwerk & Co Teppichwerke KG
Anker Teppichfabrik
Teppich-Werk Neumunster
DLW aktiengesellschaft
Deutsches Teppich-Forschungsinstitut
Pulsarr Industrial Research BV

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PROJECT FUNDED BY THE COMMISSION OF THE EUROPEAN COMMUNITIES UNDER THE BRITE/EURAM/CRAFT PROGRAMME
Automatic Assessment of Carpet Wear

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1. ABSTRACT

For many years an objective way of replacing the rather subjective assessment by a group of experts of the change of appearance of carpets has been looked for.

Image analysis and digital image processing seem to be very suitable methods. Experiments often gave nice results, but the number of carpets tested was too small in order to put forward a method valid at all times.

TFI and the Department of Textiles of the University of Ghent joined their efforts in 1991. At the end of 1993 both centres, which had already put a great deal of energy into image analysis and carpet assessment, received financial support from the European Commission to carry out a large-scale research project in cooperation with a great deal of the European carpet manufacturers.

2. INTRODUCTION

For many years now various laboratories have been looking for away to make an objective evaluation of the change of appearance of carpets subjected to a wear test.

So far, change of appearance has been assessed by a group of experts, in accordance with the regulations laid down in many national and international standards. This method is generally accepted and yet everyone is convinced that this technique is not free of some subjectivity.

The last few years laboratories have mainly focussed on the use of image analysis and digital image processing in order to obtain the desired result. By means of a configuration consisting of a camera, a frame grabber, a set of lamps arranged in a special way and a powerful PC, the
appropriate algorithms are looked for to calculate suitable numerical data from a digitised image.

From these data (also referred to as image parameters), a judgement must be made in relation to the change of appearance of the carpet. This can be clarified schematically as follows:

Many investigations have shed some light on this matter during the last decade. Time and time again a parameter was found that changed significantly as the tested carpet was worn. However, this parameter often turned out to be of little or no significance for another type of carpet. It is even so that a parameter, which seems promising for e.g. a cut-pile carpet with very fine pin point effect, becomes totally unsuitable for a slightly coarser pin point type.

The solution to the problem is much more complex indeed. It is our considered opinion that a combination of image parameters has to be looked for that may not cause any significant change on their own but give a clearer assessment of the wear of a whole range of carpet types when considered together.
Drawing a judgement from the combination of parameters is quite complex too. Hence, more advanced techniques have to be turned to in order to reach the goal. In this light, neural networks seemed to be the appropriate tool.

The following chapters will first describe which set-up was used in the research. Also, the methods available to generate the required image parameters from an image will be dealt with. Finally, an explanation will be given of how a neural network was used to link numerical data of image parameters to the appearance change of carpet.

3. RESEARCH WORK

3.1. Project tasks and time schedule

Task 1: Gathering of test material
Task 2: Accelerated wear of samples
Task 3: Assessment by panel of human assessors
Task 4a: Development of parameter set for cut pile carpets
Task 4b: Development of parameter set for loop pile carpets
Task 4c: Development of parameter set for patterned carpets
Task 5: Training of the neural network
Task 6: Development of a user-friendly system

3.2. Task 2: Accelerated wear tests

Since the assessment procedure for change of appearance gives a note from 1 to 5 (over half notes) it was decided to try to obtain different samples with 5 distinct wear levels.

The wear test were made according to the standard Vetterman drum test (German standard DIN 54 323) and the Hexapod Tumbler Test (British standard BS 6659). The wear levels had to be modified since the basic test only foresee to do the test at 2 levels. Hence the following test scheme

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>0 cycles Vetterman</td>
<td>or</td>
</tr>
<tr>
<td>2000 cycles Vetterman</td>
<td>or</td>
</tr>
<tr>
<td>5000 cycles Vetterman</td>
<td>or</td>
</tr>
<tr>
<td>12000 cycles Vetterman</td>
<td>or</td>
</tr>
<tr>
<td>22000 cycles Vetterman</td>
<td>or</td>
</tr>
</tbody>
</table>

These number of cycles represent the different levels used in EN and ISO standardisation work.

Depending on the construction and the quality of the yarn used the resulting change of appearance did not always cover the complete range from 1 to 5. Because the neural network
needs to see results over the complete range, the wear testing was personalised depending on the quality of the carpets supplied.

The remaining wear tests were conducted as follows:
First:
- 5000 cycles Vetterman or 4000 cycles Hexapod
- **22000 cycles** Vetterman or 12000 cycles Hexapod

and then depending on a first rough figure, 3 other wear intensity levels were applied, chosen from the following list:
- 1000 cycles Vetterman
- 3000 cycles Vetterman
- 4000 cycles Vetterman
- 14000 cycles Vetterman
- 40000 cycles Vetterman
- 60000 cycles Vetterman

### 3.3. Task 3: Assessment of worn samples

Approximately 6 months after the start of the project, over 200 carpet samples had been assessed, mainly uni-coloured cut pile carpets. The first results of the neural nets and the parameters showed that the standard assessment procedure that had been used at that date was not sensitive enough. The data obtained by the image analysis techniques are of a continuous nature, whereas the assessment by a group of experts, be it according to the EN, DIN or ISO methods gives only up to 9 discrete values.

Where the assessors panel sometimes sees that there are differences between the worn samples, the grading system from 1 to 5, eventually for half grades, does not always allow them to express this difference in numbers. The rating going from 5 to 1, over half-grades, is not sensitive enough to make a distinction between these products, whereas the parameters obtained by the image-analysis techniques do detect differences.

Furthermore, there was the problem of which assessment procedure (EN1471, ISO 9405 or DIN 54328) to choose.

The assessment procedure used in the research was somewhat different from the standardised procedures described in the EN, ISO and DIN standards. With this method we tried to combine the data obtained by EN, ISO and DIN assessment procedures in one assessment session. The reason was simple:

1) we don't know exactly what the CCD camera sees: the best change, or the worst change or something intermediate.
2) we avoided a triple assessment procedure. From the data gathered it is easy to calculate the rating that would have been obtained by one of the other test methods. Time and tests will show which method is the best.
<table>
<thead>
<tr>
<th>Method</th>
<th>Parameter</th>
<th>To be reported</th>
</tr>
</thead>
</table>
| EN 1471 | Colour | rating in worst direction *
| Appearance | - average of rating in worst direction and best direction * 
| | - if colour grade < 2-3 then aspect + 1/2 grade |
| 1S0 9405 | Colour | rating in worst direction *
| Appearance | rating in worst direction *
| DIN 54328 | Colour | rating in worst direction *
| Appearance | - average of rating in worst direction and best direction *
| | - if colour grade < 3 and if colour most important parameter then aspect + 1/2 grade |
| Project | Colour | rating in worst direction *
| | - rating in best direction *
| Appearance | - rating in worst direction *
| | - rating in best direction *
| | - most important parameter

* the median of all assessors is calculated

At the first 6-monthly meeting in June, it was decided to go for the European assessment procedure described in the European standard EN 1471 and to work not only with the median but also with the average of the assessors' result. This decision proved to be the right one because the ISO technical committee TC 38/SC12 - "Textile Floorcoverings" decided in 1995 to adapt the EN assessment procedure.

At the same time, for research's sake, we amended this procedure in that sense that we assessed up to a quarter of a grade, reporting at the same time all the wear phenomena observed during the assessment, i.e. apparition and appearance of fizzing, felting, flattening, shading, etc...

3.4. Task 4: Development of parameter sets

Task 4 is subdivided in 3 sub-tasks. This subdivision is based on the main groups of product types, namely cut pile plain carpets, loop pile (plain) carpets and patterned carpets.

A first series of images taken by DTFI and the university of Ghent showed that there were some technical problems to be solved first before the work on the identification of the parameters could be started.

In the previous small scale research projects on this topic, the range of products was much smaller. Therefore, the importance of some technical issues, such as the calibration of the

* Sometimes a carpet's appearance changes depending on the angle you look at it. Therefore the assessment procedure asks the assessors to average the appearance change of a specimen over all the angles it was looked at.
camera only became clear when comparison between laboratories of the data obtained from the first images was started.

The issues to be solved concerned:
- hardware compatibility
- the size of the images
- the position of the lighting device and the sample
- calibration of the camera

These topics are discussed under task 6.

At the beginning of the project the carpets were divided into three main groups:
- cut pile plain carpets
- loop pile (plain) carpets
- patterned carpets

These groups were subdivided as follows:

- **group 1- cut pile plain carpets**
  - subgroup 1.1 soft velour carpets
  - subgroup 1.2 normal velour carpets
  - subgroup 1.3 velour carpets with pin point effect
  - subgroup 1.4 saxony carpets
  - subgroup 1.5 frisé carpets
  - subgroup 1.6 chunky (= coarse) frisé carpets

- **group 2- loop pile (plain) carpets**
  - subgroup 2.1 fine loop carpets
  - subgroup 2.2 medium loop carpets
  - subgroup 2.3 coarse loop carpets

- **group 3- patterned carpets**
  - subgroup 3.1 cross-over carpets
  - subgroup 3.2 fine pattern and medium pattern carpets
  - subgroup 3.3 coarse pattern carpets

This subdivision was made based on the surface and the appearance behaviour of the products.

Previous small scale work had shown that following parameters could be of interest (for grey scale images):
- colour shift
- colour standard deviation
- Fourier power spectra
- statistical matrices

The principle is very easy: to look for parameters that change uniformly with wear. In practice it was not so easy to do because of the influence of the colour and the structure of the specimens.

Since it was not obvious in which direction to look, all possible parameters were calculated for every image. This required a new software protocol on how to store the images and the corresponding data.
As explained before some parameters such as colour change with wear. The problem is that the degree of change is influenced by the original colour and structure of the carpets samples. Therefore the efforts were directed at finding a procedure to rescale the known parameters in a specific way to obtain a set of universal parameters.

a) ordinary statistical analysis of the colour

When a colour image is recorded and digitised, a group of image points is obtained. These points are all characterised by two place coordinates and three intensity figures. The place coordinates determine the physical place where the pixel is situated in the image. The three intensities together give an indication of the colour of this spot in the image. In general one can say that an image is built of three colours, viz. red, green and blue (fig. 3.4.1.1). Every pixel has a red intensity, green intensity and blue intensity.

It is often stated that the intensity of a black and white picture is the mean of the three colour intensities. Previous research at DTFI showed that it is not always correct. Nevertheless, it was already found that this mean intensity turns out to be a good parameter for the determination of the wear.

The research confirmed these findings to a certain extent. However, it must be noted that sufficient attention must be paid to the way in which this mean is calculated. A first method consists in calculating a ‘mean intensity’ for every pixel by making a mean of the three colour intensities (R+G+B)/3 for each pixel separately. The general intensity is thus the mean of these separate mean intensities (fig. 3.4.1.2).

A second method consists in calculating first the mean red, green and blue intensities for the entire image. After that, these three means are averaged in their turn into the result aimed at. (fig 3.4.1.3).

The latter method was chosen, since rounding off errors can be drastically reduced by first making three separate distributions and average these afterwards. Moreover, the second method offers a much clearer view of what happens and provides more information.

It is clear that the intensities, i.e. red, green and blue intensities as well as the mean intensity always have a tendency to rise due to wear (fig. 3.4.1.4.). Hence, these are fairly suitable parameters to interpret the change of appearance of carpets. However, the degree of rising is not uniform for all carpet colours. For two carpets with two different colours but equal structures, the rise of intensity will not be proportional (fig. 3.4.1.5.). Hence, it is difficult to draw a conclusion from these changes of intensity without the use of more complex techniques.

From the three distribution curves, three standard deviations can be calculated (δr, δg, δb) as well as the mean of these three values (δ=δr+δb+δg/3). The standard deviation is the direct results of the influence of the “shadows” between the tufts. However, it is found that standard deviations thus obtained do not always provide really useful information. Better results are obtained if the various distribution curves are “resealed”. Before calculating a deviation, every pixel is given new intensities according to the following formula:
newmeanR = 3 * (100*meanR)/(meanR+meanG+meanB)
newmeanG = 3 * (100*meanG)/(meanR+meanG+meanB)
newmeanB = 3 * (100*meanB)/(meanR+meanG+meanB)

The mean intensities, calculated according to the second method mentioned above, are always reduced to 100 and the distribution curve is changed in terms of the imposed shift of this mean. The standard deviations resulting from these resealed distributions, are better parameters. (fig. 3.4.1.6. and fig. 3.4.1.7.).

It is also a feature of these distributions that they decrease as wear increases. This applies both to resealed and non-rescaled distributions. However, since deviations and means are often used concurrently, both deviations, i.e. resealed and non-rescaled, keep their usefulness. An example of the deviation change is shown in fig. 3.4.1.8.

Starting from the resealed distribution curves, more statistical features of these distributions were calculated. The third moment of the distribution for example seemed to be a promising instrument, but was finally abandoned.

The research work also lead to the following conclusions on the use of the colour change and the standard deviation:

1) because the human assessors look at the carpet from different sides at an angle of 45° there are several (=6) images to be looked at (cfr. task 6);

Schematically, averaging can be done as follows:

```plaintext
angle of incidence of light 0°

angle of incidence of light 45°
production // light

angle of incidence of light 45°
production perp. to light

intensities
```

image 1: RGB
image 2: RGB
image 3: RGB
image 4: RGB
image 5: RGB
image 6: RGB
(resealing)

angle of incidence of light 0°

angle of incidence of light 45°

production // light

production perp. to light

standard deviations

2) Secondly, the shape of the distribution curves seems to be typical of the carpet type taken into the image. So it could be possible to use the properties of this distribution, bundled in typical figures, for carpet type recognition.

b) statistical matrices

These calculation methods include the drawing up of a number of matrices, that give an idea in various ways of the probability of occurrence of colour combinations in an image. An image can also be considered as a group of pixels, for which the colour distribution is arranged over the pixels in a certain way. This is in contrast to the Fourier techniques, where an image is considered to be a set of objects that can re-occur periodically.

A number of matrices are described in literature. The following two matrices have been used during the research.

1. SILDM or Spatial Intensity Level Dependence Method. This matrix gives the probability for two pixels, that lie on a distance “d” in direction a versus one another, to have an intensity combination (I1, I2).

2. ILDM or Intensity Level Difference Matrix. This matrix gives the probability for two pixels, that lie on a distance “d” of one another to present an intensity difference AI.

Since a colour image consists of a red, green and blue image, six matrices were actually calculated during the research.
From each matrix, certain parameters can be calculated. This can be done by looking for the characteristics that describe the occurrence of the pattern in the matrix. These parameters change with increasing wear of the carpets in image. This is because the wear affects the figures occurring in the matrix. A number of these parameters show a monotonously rising or falling course, which reflects the power of these methods.

Again the degree of change of these parameters often depends on the colour of the carpet that is considered. This is the same problem that occurred with the simple statistical parameters in the paragraph above. Again the consequence is that interpreting these changes does not give satisfactory results in an easy way.

A second remark that ought to be made is that the chosen distance “d” has an important effect on the parameters. By varying this “d”, the parameters show a periodic course. This periodic course seems to correlate well with the texture of the carpet taken up in the picture. The period to be found in the “d”-parameter curve, is a measure for the periodicity texture in the image. The periodic wave movement decreases in amplitude with rising wear and the period changes. This can mainly be seen in the case of loop piles, which show a much clearer periodicity in their texture. The change of the curve can be explained by the fading out and disappearance of the texture in the carpet appearance.

Thirdly, it must be pointed out that not only the image parameters individually, but also combinations of them can be used as powerful tools for the characterisation of the images. Sometimes certain impurities and interference on two parameters cancel out one another.

The colour of the sample itself also serves as a parameter for the neural network. It allows the network to determine the importance of the parameters: the “same” absolute colour change will be felt to be more disturbing for a blue carpet than for a dark brown carpet.

The statistical matrices were tried for the all types of carpets, at first for the plain cut pile carpets, then for the other types. They seemed interesting but the characteristic “d”-factor proved very difficult to determine. Even for the same machine setting, there are several processes during the production that can have an influence on the distance between and the appearance of the tufts. The heating, wetting and crushing all lead to variations of the “d” factor between and within the carpets. Without a correctly defined/calculated “d”-value, the other information from the statistical matrices can only be used with certain restrictions. Therefore the statistical matrices finally had to be abandoned for the training of the neural network.

c) Fourier techniques

These arithmetic techniques will show whether there are elements in the image that re-occur periodically. Via a Fast Fourier Transformation (FFT) an image of a carpet is converted into a Fourier image, that is a representation of a two-dimensional function. This image generally looks like a field in which there is a central peak (highlighted zone in the middle of the image), with a number of additional peaks and noise signal for the rest. The place of the
peak indicates the frequency of the periodicity, the height of the peaks gives information on the colour of the repeating element.

Parameters can be calculated from this Fourier spectrum in various ways. During this research two different approaches were used. First, parameters were calculated that relate to the general Fourier transformation, such as average height of the Fourier surface. Later on, a Fourier curve was calculated based on the radial averaging of the Fourier image. This method too gave nice results.

The most promising parameter turned out to be the Mean of the Fourier Power Spectrum, calculated for R, G and B (fig. 3.4.1.9). Again the irregularity within and between carpet specimens made the other information of the Fourier Power spectrum hard to use, even tough they seemed rather promising when tested on small scale.

3.5. Task 5: Training of neural networks

This task was also foreseen to consist of three sub-tasks, being the training of neural networks for the cut pile carpets, the loop pile carpets and the patterned carpets. The training of the networks and the choice of the set of parameters was closely interlined.

It became soon clear that some of the carpet groups could be taken together into one network. Less easy was the finding of a correct way to rescale the chosen input parameters.

The neural network that was used during the research is of the back-propagation type. The back-propagation network compares the results it produces with the expected values. Subsequently it adapts the way it calculates its results to obtain as much correlation with the expected results as possible. A Kohonen neural network organises all the data it gets independent of the expected results. It just makes an algorithm that groups the results in a predetermined range. Since the parameters obtained from the carpets are not very uniform, because of the inherent non-uniformity of the surface, this is a dangerous path to follow. Although it would produce an objective network completely free of any human influence, the results are much more difficult to interpret, especially when it is not clear yet which parameters to use. Therefore the back-propagation networks were used. This type of networks allows to keep an eye on the direction the network is following in its training phase.

A neural network is an advanced software system that makes a link between the values of a number of input parameters and a number of generated outputs. In order to organise itself in such away and adjust its ‘weights’ so as to obtain a suitable input - output connection, the neural network must go through a learning phase.
In every node of layer 1 the inputs are combined in different ways chosen by the network. The resulting value is rescaled. The data is then combined with the data of the other nodes of layer 1 to make a set of nodes in layer 2. Again every node is a combination of the data of the previous layer. Finally all the nodes of layer 2 are combined, after rescaling, to make one or more output data. By modifying the number of layers and nodes per layer, we can make the network as complex as we want.

During the learning phase the network processes a given number of sets of input values, of which it knows which output it must generate for this set. It calculates by means of a set of weights (at first completely at random) an output, starting from a set of image parameters. It compares its calculated value to what it should give as output. Depending on the difference, it will adjust its weights. In order to be able to set its weights optimally, it must repeatedly go through these sets a number of times. The number of times that it goes through the input data, is called the number of learning cycles of the network.
After the learning phase, it will be able to provide an output in a proper way for input sets it has never seen before. If the network has had too few learning cycles, the weights will not be sufficiently adjusted at that point. If it has had too many learning cycles, the weights will be set in such a way that it has no more space for new data, i.e. the system becomes too rigid to allow new products.

Hence, the choice of the number of learning cycles is important. However, sufficient care must be taken too for the choice of input parameters. If the network learns parameters whose changes are not significant for the result aimed at, no good results can be expected.

What did that mean for the research? An “over”-complete set of parameters were calculated from recorded images for a whole range of carpet sets. Out of this set, the parameters which showed the best monotonous change were retained. Each carpet was also assessed by a group of experts and received a EN quotation for the change of appearance.

These parameters were used as input values for different neural networks. There were several networks trained, to try to eliminate superfluous information or false influences. The weight factors of the final networks can be found in annex 1.

4. RESULTS

4.1. Parameters for plain cut pile carpets

At the midterm meeting one set of parameters for all the plain cut pile carpets was presented, namely:

- a combination of mean intensity and standard deviation
- Mean intensity of Fourier Power Spectrum
- Mean of intensity level difference matrix
- reference intensity of unworn carpet

Further research showed that the results were improved if for different subgroups, a different set of parameters was used.

Finally we ended up with 3 sets of parameters for the calculation of the change of appearance

one set for subgroup 1.1: soft velour carpets
one set for subgroups 1.2,1.3,1.4: normal velour carpets, velour carpets with pin point effect and saxony carpets
one set for subgroups 1.5,1.6: soft frisé carpets and chunky frisé carpets

The parameters used in these set were taken from the following list:

- colour Shift
- colour deviation shift
- grey level ratio
- intensity
- black carpet (yes/no)
- saturation
- Fourier mean
- black carpet (yes/no)
- carpet type

4.2. Parameters for plain loop pile carpets

At the midterm meeting one set of parameters for all the plain loop pile carpets was presented, namely:
- a combination of mean intensity and standard deviation
  - Mean intensity of Fourier Power Spectrum
  - Peak intensity vs. mean intensity ratio of Fourier Power Spectrum
  - Mean of intensity level difference matrix
  - reference intensity of unworn carpet

It was clear that the same techniques and parameters could be calculated for the loop pile carpets. The results indicated that the mean value of the image, calculated as described above, is a good parameter. Also the parameters of the Fourier technique were more promising than for the cut pile carpets. This is because the repetition of tufts is much more obvious for loop pile carpets than for cut piles. The statistical matrices were only abandoned at the end. Several attempts were made to find away to determine the “d”-value from the image parameters. No adequate solution was found so finally the statistical matrices were abandoned.

A very simple trick helped solving the problem momentarily. Simply stating if the specimen is a fine loop, medium loop or coarse loop carpet, helps the neural network to organise the data. Nevertheless the computer program will record which type of loop was chosen so that in case of dispute the size of the loops can always be controlled afterwards.

Finally we ended up with a similar set of parameters for the calculation of the change of appearance

set for plain loop pile carpets
- colour shift
- colour deviation shift
- grey level ratio
- Fourier mean
- loop type (“fine”, “medium”, “coarse”)

4.3. Parameters for patterned carpets

As stated before, the patterned carpets were divided into 3 subgroups:

subgroup 3.1 cross-over carpets
subgroup 3.2 fine pattern and medium pattern carpets
subgroup 3.3 coarse pattern carpets
The division was made based on the size and the repeat of the pattern elements. The cross-over carpets have a small, "regular" and very frequent pattern, whereas in the second subgroup the pattern elements only come back 2 to 4 times. The third subgroup holds the very large pattern with no or very small repeat.

The parameter set for subgroup 3 was not fully determined partly because of the limited number of colours available for the same pattern. That makes it very difficult to obtain the amount of comparable data necessary to train a neural network. Also the expertise of Pulsarr in the field of image analysis proved insufficient to solve the problem of pattern recognition.

However, based on the research work and on the experience of the labs, it seems logical to conclude that basically the same parameters apply as for plain cut pile carpets. Also for the human assessors the carpet surface mainly consists of several differently coloured surfaces. Information on the pattern deformation can be obtained from the ratio of the uni coloured surfaces before and after wear.

This operation required a completely new software module prepared by Pulsarr. This module splits an image into several smaller images each holding 1 colour. The program works as follows: it divides the complete image in blocks of a predetermined size; the software then determines the colour for every block of pixels and extracts the blocks with "same" colour to form separate images. The size of the block determines the quality of the pattern separation. If the blocks are too big, the resolution of the separation is bad, to fine and the program gets confused due to the effect of the colour of the shadows of the tufts.

Simply splitting the image in its RGB components does not suffice since individual colours react differently to wear. Furthermore every colour consists of a certain percentage of red, green and blue. This means that one part of the pattern can fade lightly, hence locally only a
slightly different RGB value, whereas other parts of the pattern completely change. Splitting the image into RGB images before and after wear give completely different split images.

For the other types of patterned carpets, the parameters of the loop pile carpets finally proved to be of the most interest. Apparently there is no need for all the information needed for the plain cut pile carpets. The more information the human eye has to process the less important the details become. The cross-over and the fine pattern carpets have a lot of different colours spread over small surfaces, whereas on a uni surface the eye (brain) is less distracted by additional information. That is also why very heavy patterned carpets have very little or no complaints because they “hide” the change of appearance.

Finally we ended up with 3 sets of parameters for the calculation of the change of appearance:
- one set for cross-over carpets
- one set for fine and medium pattern carpets
- one set for coarse pattern carpets

The parameters used in these set were taken from the following list
- colour shift
- colour deviation shift
- grey level ratio
- Fourier mean
- intensity
- saturation
- carpet type
- geometrical information of uni-coloured surfaces (still under research)

4.4. Neural networks for plain cut pile carpets

The training of the network evolved in several stages. At first the data were fed to one single network (cfr. midterm report). The data from task 3 was entered with the set of parameters defined at that moment and trained at different number of learn cycles. The first results showed a “bad” influence generated by the dark carpets. The camera simply did not see enough to obtain distinct data for the different wear levels. At that time it was decided to leave out the black carpets until a suitable solution for their processing could be found.

The initial results also indicated that the number of learning cycles was best chosen at about 8000.

Following results for 160 specimens were obtained:

- 55% : no difference between computer and humans
- 36/40 : ≤ 0.5 note between computer and humans
- 09% : > 1 note difference computer and humans
Subsequently the image parameters were reprocessed and rescaled. Additionally a solution was found for the dark carpets: by enhancing the signal electronically the quality of the data could be improved. Thirdly a new set of parameters was added to take into account the surface structure of the new carpet: “visible structure: yes/no” and “if visible structure, pin-point effect: yes/no”.

Following results for 225 specimens were obtained:

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>52%</td>
<td>no difference between computer and humans</td>
</tr>
<tr>
<td>37%</td>
<td>≤ 0.5 note between computer and humans</td>
</tr>
<tr>
<td>11%</td>
<td>&gt; 1 note difference computer and humans</td>
</tr>
</tbody>
</table>

Basically the same result was obtained, but with a lower number of training cycles and with more specimens.

Finally by splitting the data and train networks for every of the 3 subgroups of products it was found that the results could be improved while the number of learning cycles decreased to 500.

This gave following global results for 445 specimens (including the black carpets):

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>53.3%</td>
<td>no difference between computer and humans</td>
</tr>
<tr>
<td>32.4%</td>
<td>≤ 0.25 note between computer and humans</td>
</tr>
<tr>
<td>9.9%</td>
<td>≤ 0.5 note between computer and humans</td>
</tr>
<tr>
<td>3.1%</td>
<td>≤ 1 note between computer and humans</td>
</tr>
<tr>
<td>1.4%</td>
<td>&gt; 1 note difference computer and humans</td>
</tr>
</tbody>
</table>

Per subgroup the results look as follows:

**subgroup soft velour carpets**

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>63.2%</td>
<td>no difference between computer and humans</td>
</tr>
<tr>
<td>25.3%</td>
<td>≤ 0.25 note between computer and humans</td>
</tr>
<tr>
<td>6.3%</td>
<td>≤ 0.5 note between computer and humans</td>
</tr>
<tr>
<td>5.2%</td>
<td>≤ 1 note between computer and humans</td>
</tr>
<tr>
<td>1%</td>
<td>&gt; 1 note difference computer and humans</td>
</tr>
</tbody>
</table>

**subgroup normal velour carpets**

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>no difference between computer and humans</td>
</tr>
<tr>
<td>36.4%</td>
<td>≤ 0.25 note between computer and humans</td>
</tr>
<tr>
<td>8.9%</td>
<td>≤ 0.5 note between computer and humans</td>
</tr>
<tr>
<td>2.8%</td>
<td>≤ 1 note between computer and humans</td>
</tr>
<tr>
<td>1.8%</td>
<td>&gt; 1 note difference computer and humans</td>
</tr>
</tbody>
</table>

See figure 3.5.1.1. for an excerpt of the results.

**subgroup saxony carpets**

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>no difference between computer and humans</td>
</tr>
<tr>
<td>36.4%</td>
<td>≤ 0.25 note between computer and humans</td>
</tr>
<tr>
<td>8.9%</td>
<td>≤ 0.5 note between computer and humans</td>
</tr>
<tr>
<td>2.8%</td>
<td>≤ 1 note between computer and humans</td>
</tr>
<tr>
<td>1.8%</td>
<td>&gt; 1 note difference computer and humans</td>
</tr>
</tbody>
</table>
See figure 3.5.1.2. for an excerpt of the results.

**subgroup  frisé carpets**

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>52.8%</td>
<td>no difference between computer and humans</td>
</tr>
<tr>
<td>25.7%</td>
<td>≤ 0.25 note between computer and humans</td>
</tr>
<tr>
<td>18.6%</td>
<td>≤ 0.5 note between computer and humans</td>
</tr>
<tr>
<td>1.4%</td>
<td>≤ 1 note between computer and humans</td>
</tr>
<tr>
<td>1.4%</td>
<td>&gt; 1 note difference computer and humans</td>
</tr>
</tbody>
</table>

See figure 3.5.1.3. for an excerpt of the results.

4.5. **Neural networks for plain loop pile carpets**

The first networks consisted of 2 layers with 10 nodes each. The number of learn cycles was set at 8000 cycles after a series of preliminary tests.

The network gave following results for 130 samples:

- 47% : no difference between computer and humans
- 27% : ≤ 0.5 note between computer and humans
- 26% : > 1 note difference computer and humans

Further research work lead to a new neural net. By adding the type of loop (fine, medium or coarse) and by modifying the parameters (resealing, other parameters), the results were improved to read:

- 43.5% : no difference between computer and humans
- 35% : ≤ 0.25 note between computer and humans
- 17.4% : ≤ 0.5 note between computer and humans
- 4.5% : ≤ 1 note between computer and humans
- 0% : > 1 note difference computer and humans

See figure 3.5.2.1 for an excerpt of the results.

These values were achieved at a reduced number of cycles :3000. Similar results were repeatedly achieved when the number of specimens was increased to 400. At the same the network was split into different networks.

The final results read:

- 66.2% : no difference between computer and humans
- 32.7% : ≤ 0.25 note between computer and humans
- 1.1% : ≤ 0.5 note between computer and humans
- 1% : ≤ 1 note between computer and humans
- 0% : > 1 note difference computer and humans
4.6. Neural networks for patterned carpets

The neural network were only looked once it was clear which parameters were successful for plain cut pile and loop pile carpets. Small repeating patterns in cross-over carpets show similar wear behaviour as loop pile carpets. Hence it was reasonable to expect the neural network to require similar parameters.

The first results showed following results for 40 carpets:

- 22.5: no difference between computer and humans
- 40: ≤ 0.25 note between computer and humans
- 35: ≤ 0.5 note between computer and humans
- 2.5: ≤ 1 note between computer and humans
- 0%: > 1 note difference computer and humans

By adding information on the difference between the data from the different sample/lamp positions the results for 200 carpets trained at only 500 cycles read:

- 16.7%: no difference between computer and humans
- 60.7%: ≤ 0.25 note between computer and humans
- 17.4%: ≤ 0.5 note between computer and humans
- 5.2%: ≤ 1 note between computer and humans
- 0%: > 1 note difference computer and humans

See figure 3.5.3 for an excerpt of the results.

Especially for the patterned carpets it was important to keep the number of learn cycles as low as possible. The reason for this is very simple: patterns come in all kind of colour combination and shapes. The more learning cycles, the better the result for the learn file data, the more difficult to assess completely new patterns.

Unfortunately the research work for the coarse pattern was not finished on time. A lot of time was spent trying to develop automatic pattern recognition algorithms, without success however. Where the trained human assessor does not need to see exactly the same pattern on the reference sample and on the worn sample, this is imperative for the computer system.

Where for research purposes, it could be possible to work with manual pattern recognition mechanisms, this is totally unacceptable for use in quality control testing as required by the carpet manufacturers. Misuse or abuse could again lead to unacceptable differences between labs.

However the complexity of the patterns proved of a completely different type as the one Pulsarr is used dealing with. The issue is not so much to detect and isolate a part of a pattern but to assess the influence of the pattern change on the assessment note. The know-how Pulsarr could bring in, is aimed at the detection of similarities between objects, e.g. for the food industry.
Nevertheless the know-how of Pulsarr proved helpful to help detect the differences between the images. The problem was how to use the information on the difference between the images. The results of the neural networks trained with this data showed a lot of inconsistencies. Therefore the input of DTFI and the University of Ghent had to be increased because only the following working method proved useful in the end.

Since time was limited, the work under task 2 and 3 was modified. Instead of doing all the wear tests on different specimens and then take record images of the different specimens with the vision system, all subsequent tests needed to be done on one single specimen. First the unworn specimen was recorded. Then the “reference” specimen was worn at the required wear level and the image was recorded again. This way the vision system always gets to see the “same” image, hence the same pattern. This was only the first step. Because of the size of the pixels (13,7 10-3 MM*) it is virtually impossible to position the specimen so that exactly the same pixel on the new and the worn specimen coincide. The simple fact of pushing the sample more or less against the sides of the sample holder causes the image to shift a few pixels. Since we use the same specimen to do the tests on, the shifting can only occur over a small distance. Therefore an additional software algorithms had to be written that shifts the image over several pixels in all directions to determine how the position of the image was altered.

The pattern separation algorithm provided by Pulsarr proved useful for the characterisation of the unworn reference specimen. The idea is to separate certain areas with the “same” colour and to individually compare the surface changes of only these parts by means of the parameters of the plain cut or loop pile carpets.

The next problem in line was the colour change of the worn samples and the deformation of the edges caused by wear. When the surface structure (or the edges for that matter) and/or the colour of the uni-coloured areas change to much, the software has difficulties to decide which areas and what data to compare. This is particularly problematic because most of the image analysis parameters are calculated as a difference between worn and unworn specimens. We first hoped that the software would be powerful enough to deal with this problem but the test results proved differently. Therefore following approach was tried: “try, for the unworn specimen, to define the uni-coloured areas by means of geometrical parameters. The software then looks on the worn specimen for similar areas.

This procedure can only work when the same “images” are compared. Unfortunately this approach was only decided on at a very late stage in the project. The direct consequence was that not all patterned carpets could be tested. A first test was done on the fine and medium patterned.

The results of a series of 50 specimens showed:

10% : ≤ 0.25 note between computer and humans
66,7% : ≤ 0.5 note between computer and humans
20% : ≤ 1 note between computer and humans
The dead-line did not leave us enough time to train the neural network in full with the latest parameters.

4.7, Task 6: Development of a user-friendly system

A SONY 3CCD colour camera, powered by a stable 12 Volt direct current source, takes an image of a carpet specimen. This carpet is put on a specimen holder. The light comes from a pair of fluorescent tubes shedding a light of 5400 K at an intensity of 2000 lux on the carpet surface. The lighting angle can be varied between 90° and 45°. The direction of the carpet sample can be changed to perpendicular or parallel to the direction of the tubes. The analogue image signal is sent to a framegrabber, manufactured by the Leutron Vision AG company. This is a hardware card, integrated a PC, that digitises the image and sends it to the video monitor. The resolution of the camera is chosen at 768x512 pixels.

The first idea was to put the calculation algorithms for the image analysis parameters into hardware modules.

Because of the price evolution of personal computers and for reasons of flexibility (future upgrades) it was decided by the consortium to go for a software based system rather than a hardware based system. The software is divided into several modules:
- one module to take the images;
- a second module to calculate all the necessary parameters;
- a third module to calculate the change of appearance;
- a fourth module that takes care of the user-friendly environment.

During the first months of the research a test protocol was prepared. This protocol was also used to check the calibration of the existing laboratory versions of the equipment. Following this procedure should guarantee to obtain repeatable results on other machines used by other operators. Following issues had to be solved before the software modules could be prepared.

**Calibration**

A first series of images taken by DTFI and the university of Ghent showed that there were some technical problems to be solved first before the work on the identification of the parameters could be started.

In the previous small scale research projects on this topic, the range of products was much smaller. Therefore, the importance of some technical issues, such as the calibration of the camera only became clear when the comparison between laboratories of the data obtained from the first images was started.

As explained earlier the system uses a 3 CCD camera. This camera has a separate CCD chip for red (R), green (G) and blue (B). The different cameras seem to have CCD chips with a slightly different sensitivity for the RGB components. Since the software looks at
these RGB components of the image separately, differences in the sensitivity of the individual CCD chips could give incorrect information. Based on their previous experiences DTFI developed a calibration procedure.

When the first series of images were taken, the importance of all of these issues was not clear yet. It is only because there are so many different products to be tested that the importance of these parameters became obvious.

As a direct consequence the data obtained for the uni-coloured carpets after processing the RGB images, were useful but some of the parameters did not come out as clearly as expected.

So, the first series of images had to be processed again. This cleared the way for most of the colours, except the very dark shades (see task 5). There the problem was that, without changing the light intensity, the exposure time or the opening of the diaphragm, the camera simply doesn’t see enough. Changing the intensity of the incident light caused problems at certain wear levels, where the wear action causes enhanced reflection. Changing the exposure time is an impractical thing to do. Changing the opening of the diaphragm gives a different depth of sharpness and requires a different calibration procedure. At a later stage it proved possible to enhance the signal electronically to obtain workable data.

At the same time, the repeatability of the recording was monitored. We tested e.g. if the data change when the lamps have been switched on for half an hour, for one hour, etc... We found that a minimum warm-up of 1.5 hours was needed to get a constant reading.

Hardware

Before the start of the project the different laboratories used different framegrabbers. These were all replaced by the same device to facilitate programming. Since Pulsarr is a dealer for Leutron framegrabber cards, a Leutron products was chosen. However since the software is divided into several “independent” modules, it is easy to change for another framegrabber card at any time. This will only require the first module to be modified.

Size of the images

The surface of the carpet looked at, was another problem that had to be solved. There were some discussions whether we should take the same absolute image size or modify the size of the surface looked to obtain the same resolution for the tufts. It was to decided to opt for the same absolute image size to start with.

The position of the lighting device and the sample

The EN and DIN grading systems look at the average change of appearance. If you detect a noticeable difference in the appearance of the sample when you look at it from different angles, you have to take the average of the best and the worst rating (see task 3). The ISO method look at the worst rating only.
From a practical point of view it is impossible at this time to take a continuous series of images and try and find the best and the worst view. Every single image takes up more than 1 MB of memory. On the other hand we don’t know yet what the 3 CCD camera sees exactly, so we can but take a series of frames under different angles.

Another important parameter is the position of the lamps vis-à-vis of the sample. A setting of 90° provides a high amount of incident light, but gives no shades to the tufts, a setting at a very low angle gives just the opposite. The latter setting gives difficulties with dark colours, the former with the light colours.

The first series of images were taken with the lamps at a 45° angle as a compromise between contrast and clearness. Results showed that for a fair amount of samples this works, but that the really dark and light coloured samples still gave problems. As a consequence following work scheme was adopted:
- a set of 3 frames, lamps 90°, carpet length-wise
- a set of 2 frames, lamps 45°, carpet length-wise
- 1 frame, lamps 45°, carpet perpendicular to previous position.

In order to be sure that these conditions are met DTFI developed a specimen holder that can pivot over an 90° angle and slides over a set distance.

**White balance**

A special calibration procedure was setup to check the uniformity of the white balance over the surface of the image. A different white balance between the worn and the unworn specimen can make the data unusable. To check the uniformity of the level of the white balance a sheet of special white paper is used. To check the absolute value of the white level, a ceramic white plate is used. This plate is also used in colour matching systems, so the availability is not an issue.

At regular intervals cross-checks were made to check to validity of the results, the test-protocol and of the calibration procedure.

5. CONCLUSION

Basically we can say that apart from the complex patterned carpets, where the information is not available yet, the neural networks give in more than 90% of the cases less than 0.5 note difference with the human assessors. The participating carpet manufactures expressed their satisfaction with these results since the differences between different international labs have been found to be 0.5 to 0.8 note in general. That is more important than what the computer finds. Even if the system is not perfect yet, they are pleased with it because it clearly shows that in the very near future a objective assessment system will become available. Most of the parameter set for the patterned carpets has been determined except for some of the geometrical data used to describe the pattern shape. It is expected that these parameters will be available
shortly. The subsequent training of the neural nets with these parameters will indicate if this is correct.

At the same time a prototype was developed with a computer program in a Microsoft Windows environment. The handling of the specimens and recording of the images was set out in a protocol, as was the calibration procedure for the equipment.

6. ACKNOWLEDGEMENTS

The research work was possible thanks to the financial and logistic help of the European community and the participating industrial partners.

Project title: automatic assessment of carpet wear
Project n°: CR 1070
Contract n°: BRE2-CT93-0632

7. ANNEXE

Contains graphics and figures.
Fig. 3.4.1.1.

- Red surface
- Green surface
- Blue surface
- Combination of red, green, and blue surface

Full colour image

Red image

Green image

Blue image
Fig 3.4.1.2.

\[ I = \frac{(R + G + B)}{3} \]

\[ \bar{M} = \sum I \]
\[ \bar{R} = \Sigma R \]

\[ \bar{G} = \Sigma G \]

\[ \bar{B} = \Sigma B \]

\[ \bar{M} = (\bar{R} + \bar{G} + \bar{B}) / 3 \]

Fig. 3.4.1.3.
colour light green

![Graph showing the relationship between CEN note and intensity for different color channels (R, G, B) with a mean line.](image-url)
B1; colour blue

Fig 3A.1.5.
relative mean intensity

Fig 3.4.1.7.
Fig. 3.5.1.2,

- CEN Ratings
- Neural Networks
- Difference between CEN ratings and Neural network
CEN Ratings

Neural Networks

Difference between CEN values and Neural Network
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97 101 105 109 113 117 121 125 129 133 137 141 145 149 153 157 161 165 169

- CEN Notes
- Neural Network
- Difference between CEN and Neural Network