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**Part 1:**

Linen can be described as the main product of a textile company that produces various products from clothes to the carpets and used for many areas in our life. Through many years, development in technology has led firms to implement technology in the production industry and production processes. Each new feasible technology led companies to improve efficiency by one more step while reducing costs and lead times. Use of machine-vision technology in textile manufacturing processes is just another advancement since the conventional way is visual inspection that relying on human efforts to inspect the linen, fabrics, weaves and etc. which is actually not reliable all the time due to human factors. To ensure a sustainable quality control process, companies shift to monitor processing techniques by algorithmic tools. Compared to conventional methods, defect detection rate is much faster and more reliable.

When it comes to the textile industry, since the production process is standardized, one of the most important quality control factors is the regularization in the texture of the product. The control of this factor can be made by observation of the controller. As it is said at the beginning, the competitiveness of the market and the trend of the use of technology would propose better solutions for these areas. Therefore, studies have been conducted to make control of the process to be automated. The factor of having regular texture is, therefore, controlled by the image processing and relational statistical control approaches.

**Part 2:**

Process monitoring is gaining utmost importance. Image processing is widely used in process monitoring nowadays. In the second part of the project. We researched the literature regarding the process monitoring to have a greater understanding of the process. We found out that there are many different ways to detect problematic tissue.

Discrete Wavelet Transform is one of the many techniques. It provides a time-frequency representation of a signal. It passes signals through different filters, low pass filter and high pass filter. Discrete wavelet transform transforms a discrete time signal to a discrete wavelet representation.

The second filter is called Lee Filter. The main working principle of this filter is checking local statistics of the current pixel. If the variance of an area is low, it will do the smoothing. If the variance is high then it will not perform the smoothing.

Gaussian filter is yet another filter the overcome the same problem. It uses Gaussian function. Gaussian filter changes the input by convolving with the function. It is used to blur the image and reduce the noise. Gaussian filter offers a solution to detect the edges.

Wiener filter is used for image processing as well. It yields better results than linear filtering since it is an adaptive filter. This filter preserves the edges and patterns of the image. The main goal of the Wiener filter is detecting and filtering out the noise that causes corruption in a signal.

Different types of Fourier Transformation are widely used in the image processing field. Fourier Series is named after Jean Baptiste Joseph Fourier. He found out that any periodic function can be written as sines and cosines of different frequencies. Fourier Transformation transforms time domain to frequency domain. It can be used for sound or image. In the frequency spectrum, a noise that has a pattern can be eliminated easily.

During our researches, we found out that Principal Component Analysis is also used in image processing. As we learnt in our lecture PCA is used to reduce observations into a lower-dimensional space while keeping the variance information as much as possible. It is mainly used to recognize patterns. Generally, PCA is followed by another algorithm. After PCA reduces the noise and dimension, the following algorithm works more efficiently. Local Pixel Grouping may follow the PCA to denoise the image even more. After the procedure Inverse PCA is applied to the output.

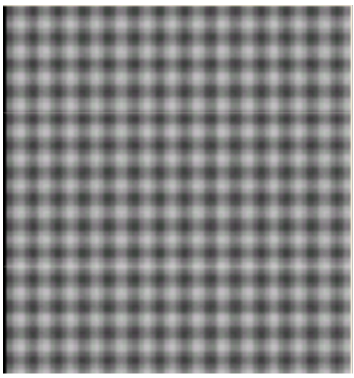
Neural Networks can be used to detect problematic tissues but first, a huge training data is needed. By using Supervised learning, a detection system can be built up. In our project, we do not have a training data. We only have 20 images. So, it is not possible to have a supervised learning model. Unsupervised image processing might be applied to our images in our case but it requires computational power and knowledge to build up.

After investigating and applying many filters and algorithms, we chose the Gabor filter to do further analysis. It satisfies the conditions were looking for. Gabor filter is elaborated deeply in the following part.

**Part 3:**

In the third part of the term Project, aim is to come up with a statistic that can identify irregularities in each image. It is important to distinguish irregular from regular. The term "irregular" has to depend on the context where the "regular" is defined. In our case, dataset consists 20 different linen images where each of them has its own pattern. Besides having different patterns, directions also differs from each other. At the same time, each image in the database has defects in its own way. Some of them has cross patterns, some of them has marks and lines etc.

With this context behind it, we are asked to come up with a statistic filtering method to make texture segmentation for distinguishing these defects or irregularities from the original pattern in that specific linen image. “An image texture is a set of metrics calculated in image processing designed to quantify the perceived texture of an image. Image texture gives us information about the spatial arrangement of color or intensities in an image or selected region of an image “(Wikipedia "Image texture") . There are many types of textures. Textures can be classified into 3 types: synthetic, natural and stochastic. In our case, all images in the database have synthetic textures.


Synthetic


Natural


Stochastic

“Texture segmentation is the process of partitioning an image into regions with different textures containing similar group of pixels”(Madasu & Yarlagadda 2007). For that reason, an academic literature search has been done and various filters are tested. Gabor filter is chosen for further examination.

“In image processing, a Gabor filter, named after Dennis Gabor, is a linear filter used for texture analysis, which means that it basically analyzes whether there are any specific frequency content in the image in specific directions in a localized region around the point or region of analysis. Frequency and orientation representations of Gabor filters are claimed by many contemporary vision scientists to be similar to those of the human visual system. They have been found to be particularly appropriate for texture representation and discrimination. In the spatial domain, a 2D Gabor filter is a Gaussian kernel function modulated by a sinusoidal plane wave”(Wikipedia "Gabor filter").

Gabor function has 2 different parts. Real and imaginary part represents orthogonal directions of the filter.

$$g(x, y; \lambda, \theta, \psi, \sigma, \gamma) = \exp\left(-\frac{x'^2 + \gamma^2 y'^2}{2\sigma^2}\right) \cos\left(2\pi\frac{x'}{\lambda} + \psi\right)$$

*Real component*

$$g(x, y; \lambda, \theta, \psi, \sigma, \gamma) = \exp\left(-\frac{x'^2 + \gamma^2 y'^2}{2\sigma^2}\right) \sin\left(2\pi\frac{x'}{\lambda} + \psi\right)$$

*Imaginary component*

$\lambda$: The wavelength of the sinusoidal factor
$\Theta$: The orientation of the normal to the parallel stripes of a Gabor function
φ: The phase offset
$\boldsymbol{\sigma}$: Standart deviation of the Gaussian envelope
$\boldsymbol{\gamma}$: Spatial aspect ratio

Statistical programming language R is chosen for image processing purposes. There is a function called *gabor.filter* in *wvtool* package. This function has several parameters. Lambda is the wavelength of the cosine part of Gabor filter kernel in pixel. Real number greater than 2 can be used. However, lamda=2 should not be used with phase offset (phi) = -90 or 90. Theta is the orientation of parallel stips of Gabor function in degree. Bw is the half response spatial frequency bandwidth of a Gabor filter. This relates to the ratio sigma/lamda, where sigma is the standard phase offset of the cosine part of Gabor filter kernel in degree. Asp is elliptcity of the

Gabor function. Choosing right values for these parameters is very crucial for finding the irregularities in each photo.

Therefore, first the texture's slope is determined in order to define **theta (**if the texture is starting at left upper corner and finishing at right lower corner theta is selected to be **135º**). **Lambda** value is selected with respect to the wavelength of the cosine part at the kernel. **Bandwidth** is determined to be low for more frequent patterns horizontally. **Phi** is selected with respect to the phase offset(which refers to patterns wave location at the starting edges). Lastly **Asp** is determined to be 1 when texture is constructed from circle shaped stitches and adjusted with respect to the elliptical orientation of needlework.

After defining parameters gabor filter transforms the picture to a homogeneous surface by removing patterns and points out the defects. So that the pixel value difference between normal and defect gets larger. The second benefit of the filter is that the 262144 pixel values are now can be handled as a sample from a greater population. For the sake of simplicity data is normalized before quality control application. 3-sigma limits control chart is selected and sample mean and sample standard deviation are the estimators for population parameters. 20 control charts are constructed for 20 different fabric images and the pixels out of limits are labeled as defective.

**Part 5:**

Since production process monitoring mainly aims an accurate analysis of the texture with minimized error and random noise explanations, attaining right threshold values becomes extremely important for correct analysis. It is a significant decision since otherwise natural regularities of the texture might have perceived as irregularity or vice versa. Type 1 and Type 2 error rates depends on correct selection of parameters. Ultimately, false alarm rates should be minimized and hit rates should be high regarding the utilization of the texture segmentation. To accurately process texture segmentation, we've moved on with Gabor Filter since the filter is specifically designed for texture analysis and a good fit. Also it works similarly with the perception process of human visual system according to some authors. After filtering the image by using gabor filter function, a statistical process control(SPC) is implemented since the defects and other patterns become obviously visible and subsequently multiple control charts are analyzed. Heuristical selection of parameter value set and its drawbacks are discussed in the following paragraph.

Our approach is based on one solution set and one filter method which is namely gabor.filter in wvtool package. This filter uses a well-defined function. So, this function has 5 arguments and the values of the parameters are determined manually in a heuristical way which actually may result in different outcomes and conclusions in a different parameter set. Optimal result is not guaranteed. In addition different packages and filter methods might have been used to get better results. However, optimization models such as neural network models may have been developed to detect directions, patterns or set of values that are closer to optimality. In addition, as mentioned in Part 3 above, the selection process of the parameters is done manually which makes the approach non-autonomous and very slow. Hence, heuristic models and methods may have been implemented to help determining process and make the process autonomous instead of manually choosing.

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