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"Continuous thread density control by intelligent low-cost sensor system and integrated machine control"

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"Continuous thread density control by intelligent low-cost sensor system and integrated machine control"

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Abstract

The development of an integrated solution for the continuous, automated control of the product geometry in continuous processes during the manufacturing of textiles and other flexible goods on the basis of fast on-line measurement of geometric data of the product and appropriate control of machine parameters is described.

A prototype intelligent multi-sensor system based on a low-cost, geometry sensitive type of sensor for the fast on-line measurement of the thread density of the textiles at industrial process speeds was designed as a precompetitive development.

On the reasons of cost, measuring speed and performance, optical profilometry was chosen as the measuring principle. Sensors (based on the triangulation priciple) were specially manufactured for the application. Fast and reliable evaluation of the time dependent signal train recorded by the sensors was achieved by means of a software-based, mathematical frequency analysis.

To achieve the various tasks of signal recording and analysis of the isolated sensors in continuous mode and in real time a hardware concept of modular architecture was developed in order to divide the sensing, controlling and analysing tasks to individual components, which can act simultaneously.

The actual performance of the multisensory design was tested under industrial conditions, The experimental system yielded a very high accuracy for geometry recordings in the region of ± 2% under industrial conditions with machine speeds up to 140 meters per minute, with very fast analysing cycles appropriate for on-line measurements. No influence of fabric movement was detected at machine speeds. Samples with a rms-deviation in excess of 2 %, i.e. non-constant geometry with a danger not to meet tolerances, or too high or low mean values, i.e. failure to meet the customer specified set-value, could be identified.

In the frame of actual control experiments the controlling feedback was taken from a sensor placed at the machine's exit to the overfeed control. As could be clearly shown, arbitrary changes of the set values resulted in automatic reaction of the overfeed control. At ail times the effective mean number of threads per cm equalled the set values.

1. Introduction

The increasing need to keep certain quality standards can only be guaranteed by modem techniques for measurement and control. An important example in textile manufacturing and processing is the evenness of the geometry of textile goods characterized by the average number of threads per unit length (*thread density*), which prominently determines the textile's quality. Depending on the specific range of textile goods today an average textile finishing company has to meet a demand for guaranteed or even certificated geometry by its customers for more than 40% of all products, where a typical demand is to keep certain geometry parameters within ± 5 %. Marked deviations have to be corrected in costly after-treatments or have to be met by detractions from the product's prize. Annual costs for after-treatments and rejected articles caused by uneven product geometry sum up to several 100.000 ECU in a typical textile finishing SME.

A common method to evaluate a textile's geometry is - besides the overall width - the assessment of the fabric weight per area by means of β-ray attenuation measurements, a rather insensitive method. Present offerings by manufacturers of measuring equipment mostly comprise camera recording and image analysis, which form expensive and - with regard to the recording speed - limited solutions.

It was the scope of the work reported beret to develop an integrated solution for the continuous, automated control of the product geometry in continuous processes during the manufacturing of textiles and other flexible goods on the basis of fast on-line measurement of geometric data of the product. The multi-sensor system was to be based on a *new* type of sensor on the basis of optical profilometry [1 ,2,3] for the fast on-line measurement of the thread density of the textiles at industrial process speeds, a number of which have to be installed at various stages of the process. One of the most important factors for the given choice of sensor was the need of a low-cost system.

The signal processing part of this system had to be designed to be able to compare the signals of the various sensors and to deliver a control signal for an automated, continuous setup of relevant machine parameters, e.g. overfeed, in order to secure a constant product geometry. The scheme given in Figure 1 sketches the envisaged data flow and network structure.

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[1] K.-F. Elgert, W. Ringens, E. Schollmeyer, Melliand Textilber. 70 (1989) 575.

[2] Bekleidunsgtechnische Schriftenreihe Band 85, Forschungsgemeinschaft Bekleidung e, V., 1992.

[3] T. Bahners, W. Ringens und E. Schollmeyer, *On-line inspection of textile geometry by fast profiling*, Proceedings *Textile* Process *Controll* 2001, University of Manchester Institute of Science and Technology, 18-20 April 1995.

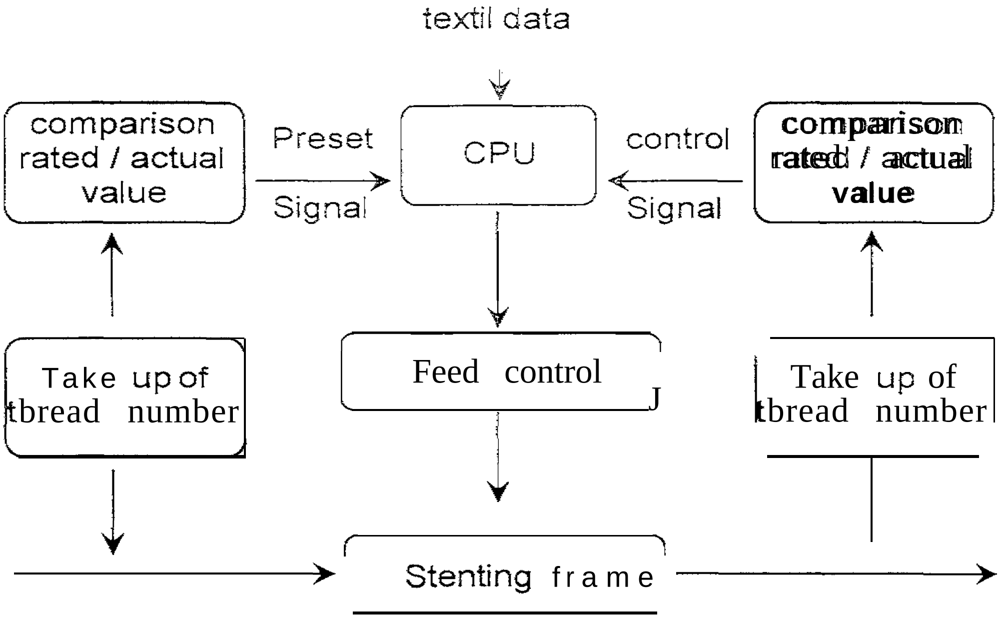

Figure 1: *Data flow of the envisaged multisensor control system.*

2. Technical description

2.1 Sensors

The envisaged multisensor-system consists triangulation sensors, whose signals serve to evaluate the textile geometry, velocity measuring units and - where applicable - s seam detector to indicate a change of textile specification.

Triangulation sensors are basically distance sensitive optical instruments, which by careful design allow for a sensitivity in the region of 0.05 millimetres and therefore the recording of surface profiles of textiles.

The basic principle is to illuminate the textile surface by a finely focussed laser beam of a spot size of 25 to 100 microns. Most technical surfaces - and practically all textiles - will reflect the incident light diffusely in all directions. In triangulation sensors only this part of the reflected light intensity, which is transmitted through a small and well-defined pinhole or the aperture of a focussing lens as shown in Figure 2, is finely focussed in an ‘observation plane', were a light sensitive detecting element as a photodiode can be placed.

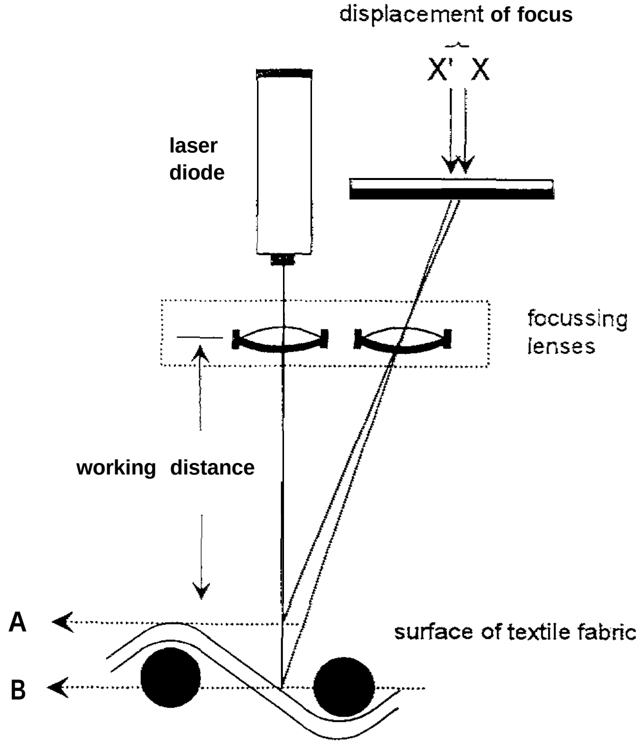

Figure 2: *Measuring principle of the triangulation technique.*

If the distance between the optical arrangement of the sensor and the illuminated surface changes as indicated by planes A and B in the diagram, the finely focussed spot on the detecting element will be displaced from point X to point X. If *position* sensitive elements as CCD-sensors or multi-electrode single chip modules (as in this case) are employed the displacement can be measured. There is a simple geometric correlation between the variation of sensor-surface distance (*working distance)* and the measurable displacement. Accordingly, the surface profile of the sample can be recorded, if sample or sensor are scanned with respect to each other.

The light source, the illuminating spot on the textile surface and the pinhole in this arrangement form a triangle as is clearly seen in Figure 2, hence the term 'triangulation'.

Sensors were specially manufactured to give an optimum signal characteristic with regard to the geometry of a range of representative textile articles.

The construction of the various textiles basically defines the necessary measuring range, i.e. maximum variation from the working distance, and - in correlation to electrical requirements to signal height - the sensitivity of the sensors, i.e. voltage vs. surface height variation, to record surface profiles properly (*'vertical resolution').* The demanded lateral or *'horizontal'* resolution of the profiling system is given again by the textile construction, but also by the industrial processing speed, Physically this horizontal resolution is defined by the spot size of the focussed illuminating laser und the maximum readout frequency.

To minimize the influence of colorations, stray light and/or illumination variations the choice of the wavelength of the laser and use of *position sensitive photodiodes* to the latest state of the art were important factors.

in order to characterize the resolution of the surface structure of the given textile samples profiles of various plain weave fabrics have been recorded. An example is given in Figure 3. The average thread number per cm taken from these profiles is in good agreement with the technological data of these samples. The recording error (deviation between actual and recorded number of threads) was found to be less than 1,7 % for these plain weave fabrics.

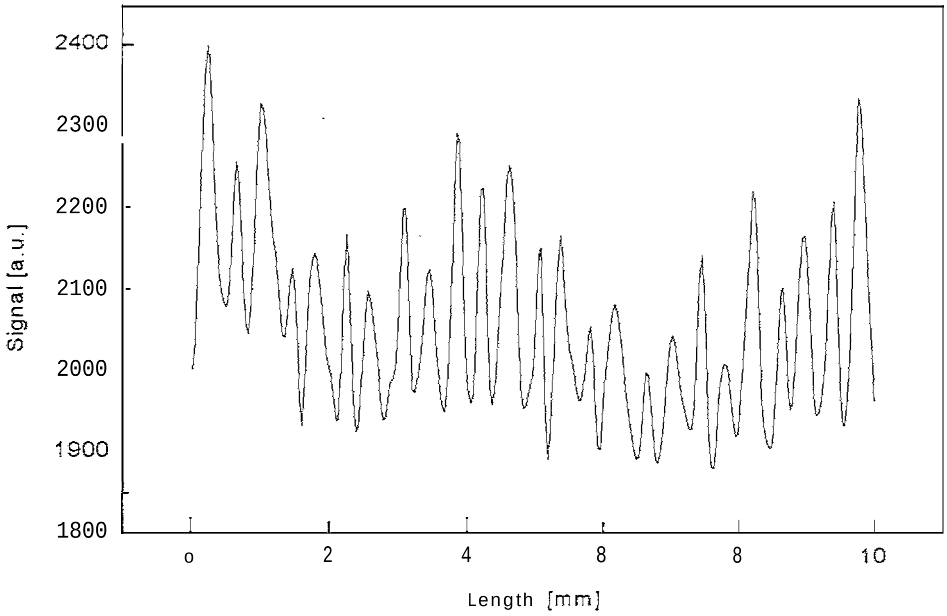

Figure 3: *Surface profile of a plain weave fabric taken on a laboratory stage.*

2.1 Signal analysis

One may identify the threads as distinctive peaks in the recorded profile, which occur at a rather regular frequency (cf. Figure 3). In a time-dependent signal the number of threads per unit length therefore can be taken from the time interval between peaks and the fabric speed or - rather more directly - from the frequency of peak occurance.

In the case of Figure 3 the signal comprises mainly one frequency f = 1/TD (TD = number of threads per unit length). In the case of more complex textiles the signal will be more developed, but it can always be considered as the sum of the frequencies, one of which will supply TD, while the others will be multiples or sub-multiples of 1/TD depending on the construction and construction parameters such as warp tension during the weaving process.

The textile density measuring system must ‘therefore be able to analyse the signal as a function of its frequencies and extract the one that corresponds to the number of threads directly. In theory, different approaches to the determination of the space frequencies of the textile, or its surface profile are possible:

One scheme is to calculate the thread density TD from the interval Δt between the occurance of two (thread indicating) peaks in the time-dependent signal and the scanning speed v. The *identification of the peaks* could be either done by a software-based analysis of the signal train or by comparing the signal with a threshold. In spite of being highly accurate and powerful even with complex profile structures, software-based analysis of the signal train proved to be far too time-consuming for an on-line signal analysis, while the *purely* electronic comparator technique proved inadequate to analyze more complex fabric structures.

A *frequency analysis* will - for a real textile - yield a spectrum of frequencies, which is characteristic for each type of fabric and will show prominent contributions by the frequency which is equivalent to the thread distance and its multitudes. The fast frequency analysis of the signal train can be done by frequency selective filtering (a hardware-solution rather similar to the well-known 'Lock-in'-technique) or by means of a mathematical frequency analysis (*Fast Fourier Transformation).* By applying FFT to this table, a second table supplying the information required will be produced. An example of the graphical representation of such a table is given in Figure 4. The peaks represent the presence of a signal of a particular frequency (negative frequencies only have mathematical significance).

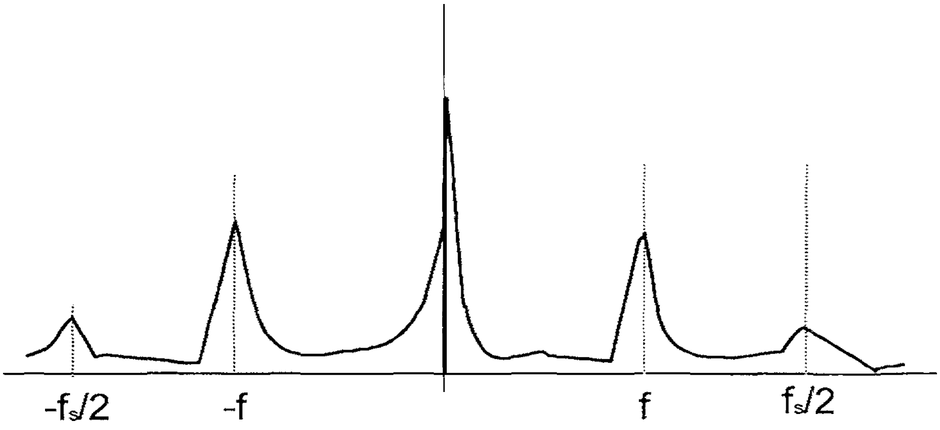

Figure 4: *FFT-spectrum of the profile of a plain weave textile (schematically).*

Since only one of the occuring frequencies represents the thread density, while the other represent harmonics or other geometric idiosyncrasies, e.g. yarn construction, a way had to be defined to dsicriminate ‘the relevant frequency. It should be noted, that the prominent thread density TD does not always correspond to the most prominent space frequency in the obtained FFT-spectrum, which might be given by TD/2 or 2·TD depending on conditions during the manufacturing process, i.e. weaving or knitting. An automatic search for TD using this criterion therefore will fail from time to time. Tests showed that it is most convenient to preset a rough *base value* for the thread number per unit length, in fact an order of magnitude, around which the search for a prominent frequency in the FFT-spectrum was executed. H should be noted that the base value for the sensor(s) at the machine’s exit represents the set value of the textile as specified by the customer.

2.3 Hardware and multisensor-network

To achieve the various tasks of signal recording and analysis in continuous mode and in real time a hardware concept of modular architecture was developed in order to divide the sensing, controlling and analysing tasks to individual components, which can act simultaneously.

H was of utmost importance to process the signal in a very short time. This was achieved by implementing the analysis software on a DSP (Digital Signal Processor), a particularly powerful microprocessor. The data exchange of this architecture is exemplified by the flow chart in **Figure 5.**

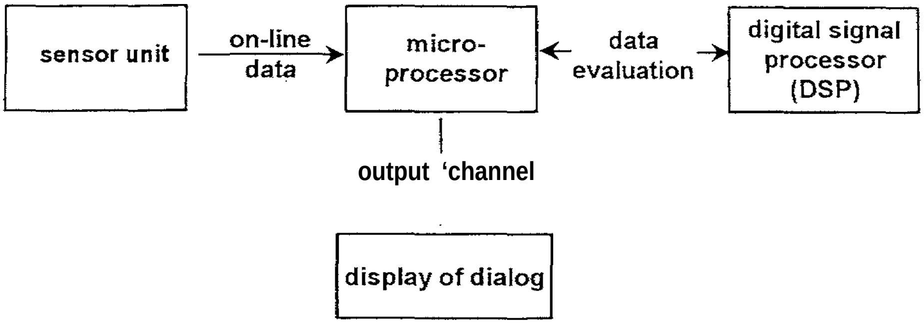

Figure 5: *Modular architecture of the individual thread counting modules.*

It should be pointed out, that this concept readily offers various possibilities of signal comparison, evaluation and generation of control signal by exchange or modification of sensor, DSP and/or dialog channel, Therefore aspects of multisensor architectures, i.e. the multisensory control system envisaged as the main aim of the project (cf. Fig. 1), as well as application of this system with others types of sensors as well as at other types of machinery are definitely incorporated in this basic layout, enhancing the perspectives of possible dissemination into other applications and branches.

A multisensor system with a potential for automatic process control could be easily set up by adding acquisition and DSP-boards for each sensor - therefore compatible to a varying number of sensor units - , where the individual microprocessor control units exchange data not any more with a display but with a suitable central signal processing uni, which served to

- compare the input thread number with a predetermined value,
- give rise to machine control signals for relevant machine parameters in order to achieve a correct processing result (preset),
- control the final geometry after passing the process,
- readjust machine control signals, if necessary, and
- deliver a documentation of the textile's geometry.

For central data procession, i.e. comparison, display, documentation, etc., a commercial control panel (*Bianco OP90* Operating Panel) was employed and a special control and display software developed.

2.3 installation at production machines for testing

For the purpose of extended tests under industrial conditions the multisensor-system was installed at stenting frames in the premises of the textile finishers.

At all experiments only one sensor was installed at the feed side of the stenting frame (cf. Figure 6) before the pinning area. The sensors were fixed directly to cross members of the machine frames at positions, where a rather calm run of the textile, free of flattering, was guaranteed.

Recordings of textile geometry at the delivery side (exit) of the stenting frame were mostly done in the midth of the textile wit the sensor installed to cross members of the winding device (Figure 23). it should be noted, that the fabric speed was recorded in this area by an indiviual velocity sensor for accuracy.

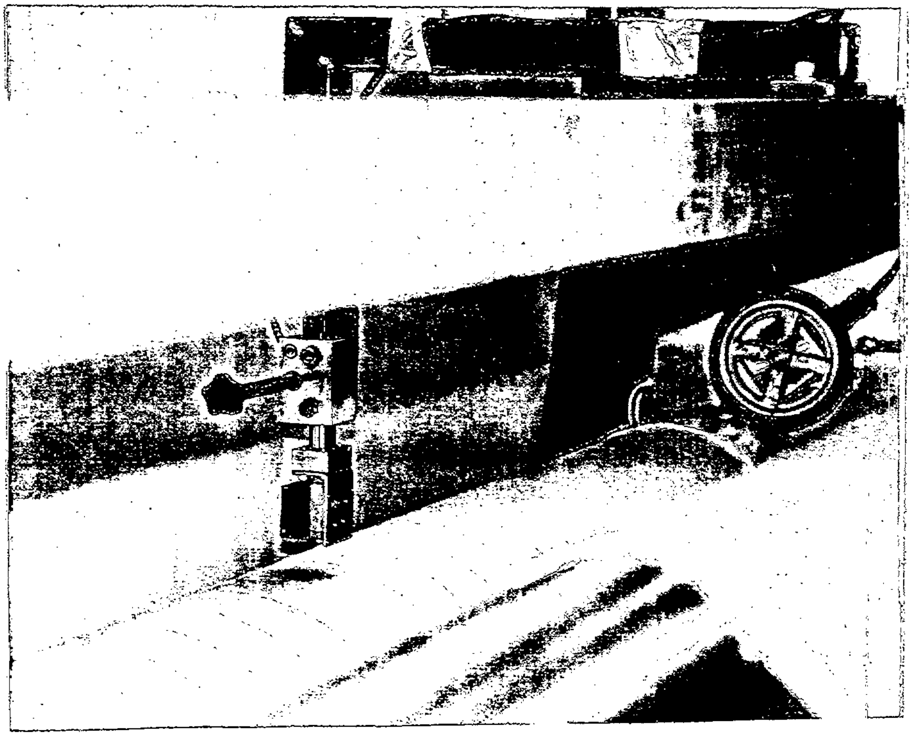

Figure 6: *Phonographic view of the sensor arrangement at the feed side of a stenting frame. The spoked rolling wheel for velocity measurement can be seen in the right side of the photograph, while the triangulation sensor is mounted above the textile.*

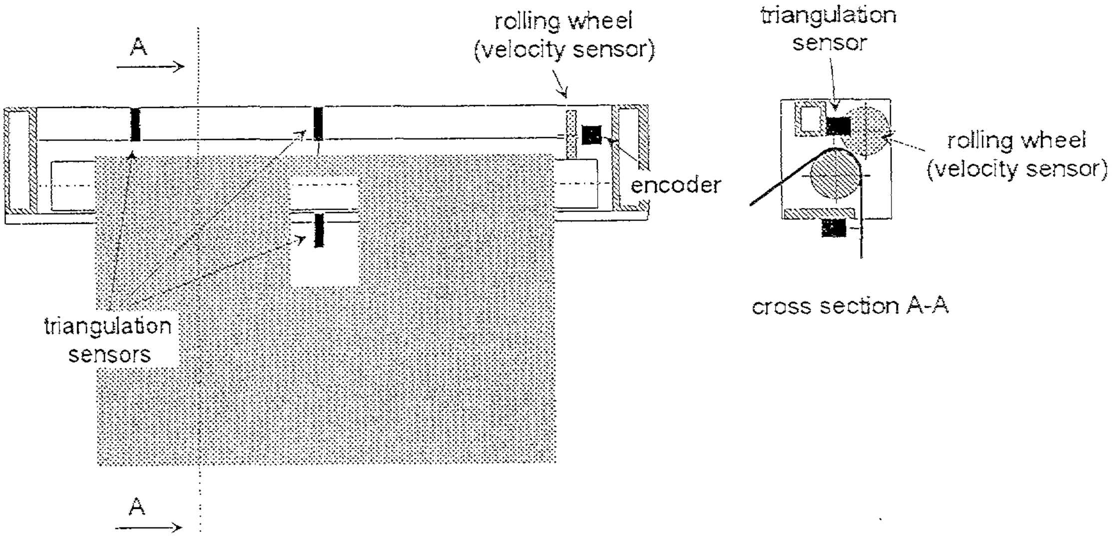

Figure 7: *Sensor arrangement for thread counting at the delivery side of the stenting frame in order to record the geometry of the treated textile.*

Over- or underfeed is defined by the variation of the electrically controlled speed of the individually driven upper drawing roller. In order to be able to conduct experiments with an automatic feed control a suitable modification to the original drive control of the upper drawing roller, where a DC-signal 0....10 V served to control a motor driven potentiometer and the drawing roller speed.

3. Results of industrial tests

The actual performance of the multisensory design was tested under industrial conditions. A first set of tests was executed using only one sensor at the machine's exit and served to check the ability of the layout of sensor and signal analysis to cope with the geometries of the various textile goods and the processing speeds at the plants.

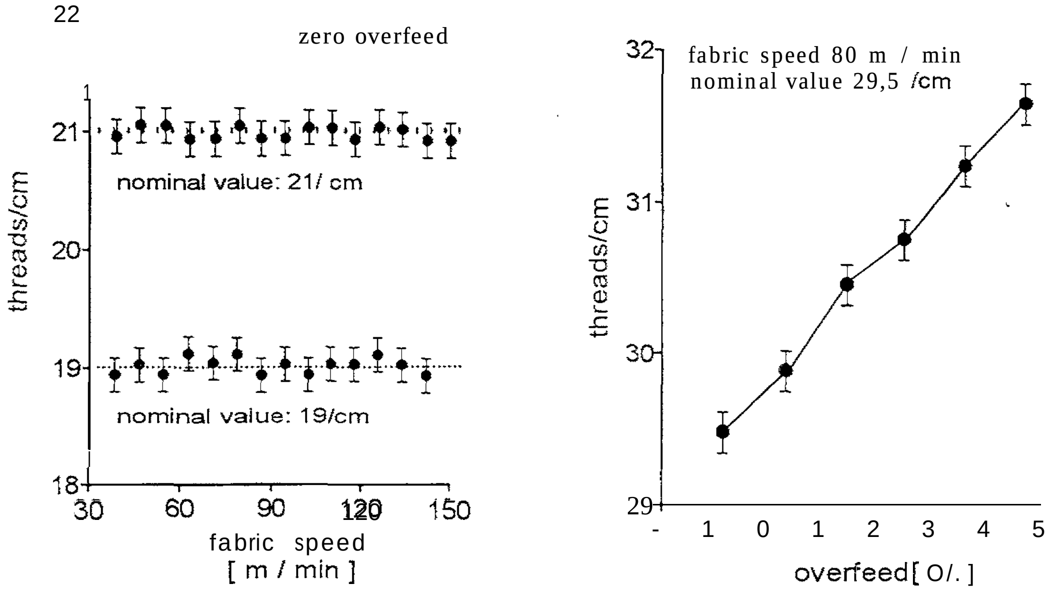

Figure 8: *On-line characterization of textile fabrics: Thread numbers per unit length were determined by fast frequency analysis of optically recorded* **surface** *profiles.*
Left: Measurements were executed with two types of fabric at various machine speeds and zero overfeed.
Right: Measurements were executed at constant machine speed but varied overfeed.

Figure 8 gives thread numbers per unit length for two types of plain weave fabrics with a nominal construction of 19 and 21 threads per centimetre respectively, which were determined as described from surface profiles taken by the optoelectronic sensor at various machine speeds. The data indicate a very high accuracy of this determination with a general deviation in the region of ± 0.1 thread per centimetre. No influence of fabric movement was detected at machine speeds up to speeds of 140 meters per minute. As is shown in Figure 8 this new type of on-line measurement of fabric geometry clearly mirrors the influence of a variation of machine parameters as the overfeed that is shown here.

Table 1: *On-line documentation of textile geometry* at a *production machine by fast optical profiling. Processing speeds were 30 and 60 m/min respectively. TD denotes the weft threads per centimetre, shaded values exceed the measuring accuracy of the system (± 2 %, cf. chapter 3. 1. 3).*

material	construction	TD, set value	TD, measured	± σ		set value - actual value	
		[/cm]	[/cm]	[/cm]	[%]	[/cm]	[%]
cabriolet soft top	mixture of twill and plain weave	23.0	22.3	0.9	4	- 0.7	- 3.1
		23.0	22.3	0.5	2.2	- 0.7	- 3.1
		23.0	22.5	0.7	3.1	- 0.5	- 2.2
airbag	plain weave	20.0	19.5	0.7	3.6	- 0.5	- 2.6
canvas	plain weave	25.0	24.6	0.8	3.3	- 0.4	- 1.6
		20.0	19.0	0.4	2.1	- 1.0	- 5.3
		20.0	20.0	0.8	4	-	-
	modified plain weave	38.0	37.6	0.8	2.1	- 0.4	- 1.1
		38.0	37.2	1.3	3.5	- 0.8	- 2.2
bandaging material	plain weave	17.0	16.4	0.6	3.7	- 0.6	- 3.7
		17.0	16.1	0.6	3.7	- 0.9	- 5.6
clothing material	plain weave	12.5	13.1	0.2	1.5	+ 0.6	4.6
		14	13.1	0.6	4.6	- 0.9	- 6.9
		14.6	13.7	0.6	4.4	- 0.9	- 6.6
		22	20.2	0.7	3.5	-1.8	- 8.9
		22	20.3	0.9	4.4	-1.7	- 8.4
chintz	plain weave	26	26.3	2.0	7.6	+ 0.3	1.1

Am overview of the recorded data from different textile articles in production is given in Table 1. While the combined processing speed of signal recording and analysis would allow for measurements every 0..5 (1.0) metre at these speeds, it was regarded as sufficient to take profiles, which are several centimetres long, only every 10 metres.

'With an average measuring accuracy of approximately ± 2 % samples with arms-deviation in excess of 2 %, i.e. non-constant geometry with a danger not to meet tolerances, or too high or low mean values, i.e. failure to meet the customer specified set-value, can be identified. The respective values of marked samples are shaded in Table 1.

A second set of experiments was carried out using two sensors at various position (again without controlling feedback) in order to evaluate the significance and reaction of the recorded signal and the hereof derived geometric information to machine settings. This served as a background to the actual control experiments.

Two examples of recordings are given in Figures 9 and 10, where sensors were positioned at the entry and the exit of the sterling frame, thus recording the geometry of the untreated and heat-treated article. The examples were chosen to exemplify the effects of different heat-treatments carried out in the stenting frame and the differing role of machine parameters such as overfeed and possible benefits from the developed sensor system.

The data given in Figure 9 were recorded during a *dying process,* were any effects to the geometry of the textile are basically unwanted. A rough inspection of the data would suggest that the mean number of threads per unit length is in fact unaffected, albeit with a marked rms-deviation. Due to the high resolution of the optical sensors and the connected signal analysis, it is revealed, that actually there is a slight decrease of threads per cm, possibly due to mechanical stress by transport elements. This could be corrected by means of the envisaged positive overfeed control. In spite of being in the order of the measuring resolution of ± 2%, the tendency is shown significantly enough to affect a reaction of an appropriate control feedback.

The data shown in Figure 10 were recorded during a *heat-setting process,* which serves to correct the textile geometry to a specified set value, The textile is affected by appropriate means of positive or negative stress input, e.g. overfeed or underfeed, and thermally fixed in the polymer structure. The data clearly mirror the effect of the manually set overfeed, which results in an increase of the mean number of threads from roughly 36/cm to 38/cm, an increase of roughly + 5%. Here, the geometric effect is significantly higher than the measuring accuracy.

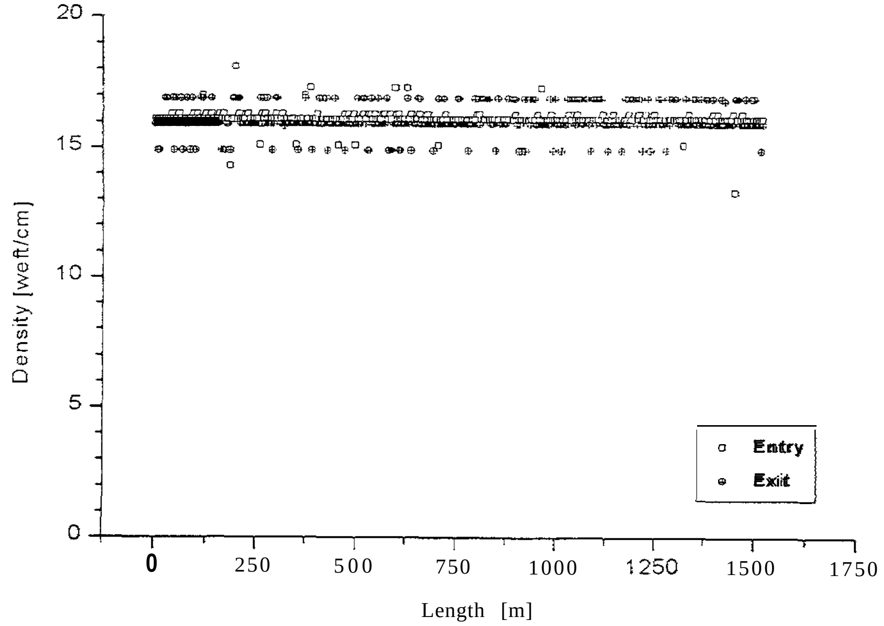

Figure 9: *On-line documentation of the textile geometry before and after a drying process. Processing speed 65 m/min, spun Rayon with a TD set value of 17/cm.*

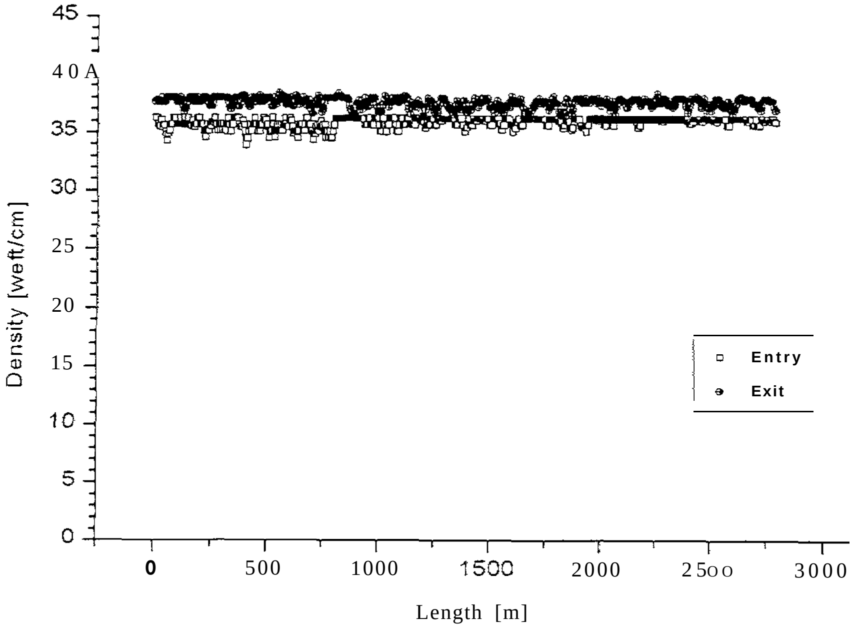

Figure 10: *On-line documentation of the textile geometry before and after a thermo-setting process. Processing speed 45 m/min, canvas with a TD set value of 38/cm.*

Using the heat-setting process as an example an actual control experiment was carried out. In the proceedings of this experiment the controlling feedback was taken from sensor 2 (placed at the machine's exit) to the overfeed control. A typical recording of a run is shown in Figure 11. The original set value of 38/cm resulted an overfeed of 4 %. As the material under investigation was very even originally - i.e., the controlling effect cannot be identified easily -, the set value was arbitrarily changed to 36/cm after processing 1850 metres of the textile and reset again after approx. 250 metres.

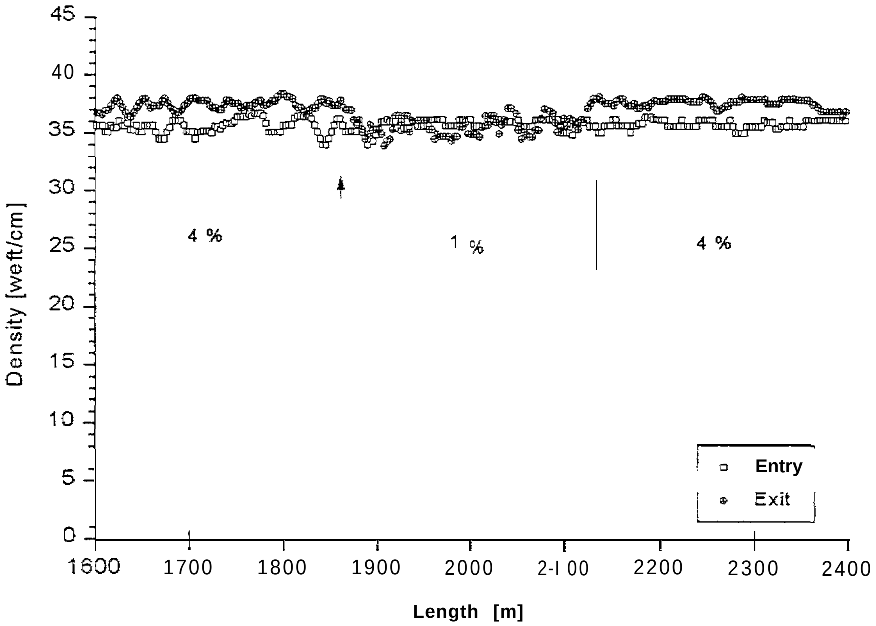

Figure 11: *Automatic control of the textile geometry during a thermo-setting process. Between 1850 and 2100 metres an arbitrary change of the se t-value was executed in order to test the au tomatic control reaction. The percentage values indicate the automatically con trolled overfeed se ttings.*

As is clearly shown, the arbitrary change of the set value results in the automatic reaction of the overfeed control (from 4 % to 1 %). At all times the mean number of threads per cm equal the set values. There is a marked rms-deviation of the thread number at the machine's exit, which is thought to be an oscillation effect of the controlling system. It has to be noted that in the proceedings of this project a rather simple controlling arrangement with a proportional characteristic was employed. This might be even amplified by the given measuring accuracy of ± 2%, which might result in a crude reaction of the whole circuit to small deviations of the sensor signal.

The **results** nevertheless indicate the potential of the technical design of the sensor system. It may be expected that a more sophisticated design of controlling electronics or programming design, e.g. using **a** Fuzzy approach, will minimize these detracting effects in an actual industrial application.

A typical example of a control experiment with *knitted* fabric is shown in Figure 12, which gives the recordings of the mesh/cm at the machine's entry, the exit and the over-feed setting.

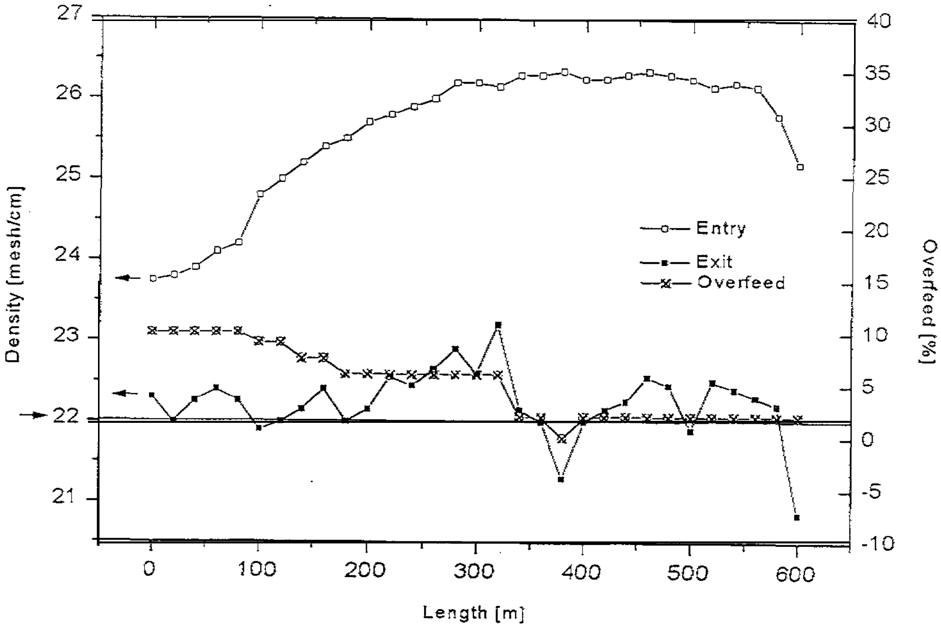

Figure 12: *Automatic control of the geometry of knitted fabric (19 % eleastomeric fibres, set value 22 mesh/cm) in* **a** *stenting frame.*

The data show, that in spite **of a** widely varying geometry of the raw material - values between 23.5 and 26.5 mesh/cm are observed - the set **value is** roughly equalled **with a mean of 22.2 ± 0.5 mesh/cm.** It **can be also seen, that the overfeed setting is changed steadily** by **the controlling feedback.**

4. Conclusions

It **was the scope of the work described here to develop** a **prototype intelligent multi-sensor system** based on a **low-cost, geometry sensitive** type **of sensor for** the **fast on-line** measurement of the thread density (number of weft threads *per* unit length) of moving textiles at industrial processing speeds.

The optical profilometry is a favorable principle for the assessment of geometric parameters of moving goods with regard to cost, measuring speed and performance. Sensors (based on the triangulation principle) deliver a time-dependent signal, where the number of threads per unit length can be taken from the time *interval* between peaks and the fabric speed. The signal could best be analysed by means of a software-based, mathematical frequency analysis.

A hardware concept of modular architecture allowed to cope with the various tasks of signal recording and analysis of the isolated sensors in continuous mode and in real time, the analysis software being implemented on a DSP (Digital Signal Processor), a particularly powerful microprocessor.

Aspects of multisensory architectures, i.e. the multisensory control system envisaged as the *main* aim of the project, as *well* as application of this system with others types of sensors as well as at other types of machinery could be incorporated in this basic layout

[t could be shown in the frame of actual control experiments at an industrial *stenting* frame, that variations of the textile structure (raw material) as well as arbitrary changes of the set values resulted in automatic reaction of the overfeed control. At all times the effective mean number of threads per cm equalled the set values.

In summary the technical approach is adaptable to several industrial problems with regard to documentation, quality control and automatic process control:

1. With an average measuring accuracy of approximately ± 2 % (as established in the laboratory tests) ***one sensor*** of the ***chosen*** measuring technique at the machine's exit can serve to identify samples with a rms-deviation in excess of 2%, *i.e.* non-constant geometry with a danger not to meet tolerances, or too high or low mean values, i.e. failure to meet the customer specified set-value as a means of on-line quality control. It sholud be noted, that today, tolerances are typically specified to ±5%.
2. Recording the geometry of the untreated and heat-treated article at the entry and the exit of the stenting frame using two sensors simultaneously can serve to record the effects of processing parameters. Possible examples of thermal processes in textile finishing are *drying processes,* where any effects to the geometry of the textile are basically unwanted, but a slight decrease of threads per cm, possibly due to mechanical stress by transport elements, is often oberserved, and heat-setting processes, which serve to correct the textile geometry to a specified set value. in these instances the multisensor-system may serve as a means of quality control, but also as a part of an arrangement for automatic process control .
3. Sensors could also be installed at various positions, namely at the midth and the edges of the textile and above and below the textile. The simultaneous measurement with sensors placed above and below the good is of interest, where a significant amount of textile is subject to one-sided surface treatments, e.g. *emerizing*, napping or *velourizing*. Here, profiling the

treated surface could possibly indicate the degree of the treatment while the simultaneous measurement nevertheless records the basic geometry.

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