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Fundamental Principles of Fibre Fineness Measurement

Part 14

Image Analysis

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IMAGE ANALYSIS

Principle

In the preceding articles in this series I have attempted to place each technology under a broad category. As is often the case the distinctions between these categories are not always black and white. Image analysis is one example of this.

Image analysis is today and enormous field, due largely to the rapid advances in computer technology. Perhaps the most spectacular applications, simply because the impact on the general community, are in the many areas of modern medical tomography, such as Magnetic Resonance Imaging (MRI), Ultra Sound Imaging and Computerised Axial Tomographic (CAT) scans.

Another significant and well known application is in the X-ray imaging equipment now commonplace in security applications such as screening luggage and airports.

Image analysis is used extensively by NASA for researching the many bodies in our universe and routinely for analysing satellite photographs for estimating agricultural production around the world of a wide range of crops.

Image analysis can be broadly defined as deriving useful information from images. In many applications these images are constructed from complex electromagnetic spectral data using high speed computers, rather than directly from photographic images.

In the case of wool fibre diameter image analysis is generally defined as deriving an estimate of fibre diameter by examining a photographic, digital or projected image of the fibres, either manually, electronically or digitally.

When I discussed the Projection Microscope, I categorised this technology as Optical Microscopy. The Laserscan instrument was placed this under the category of Photometry. However both of these technologies incorporate elements of Image Analysis.

In the case of the Projection Microscope, the measurement is derived making manual measurements of fibres from a magnified image projected onto a screen. During the early development, images of fibre cross sections were also photographed and subsequently measured. Projection Microscopy can therefore also be categorised as the analysis of an image.

The Laserscan also uses image analysis, in the optical detector and in the discriminator. The optical detector analyses a diffraction pattern projected onto the detector by measuring a drop in the voltage output of the detector. The discriminator is a crude digital detector consisting of 17 “detectors” – the electronic circuitry uses the signal output from these detectors to decide whether or not a fibre image projected on to the discriminator meets the criteria established to determine whether or not the ‘image” cast onto the detector is to be measured. In a similar vein, the Electronic Fibre Fineness Indicator (EFFI), developed by Sheep and Fur Animal Branch, Animal Husbandry Research Division, ARS, USDA in Beltsville Maryland in 1957 also uses elements of Image Analysis.

In presenting the story of the different technologies explored by the wool industry in its search for more accurate and more efficient technologies for measuring this most important characteristic of wool the classification of both of these technologies under another heading always was a matter of convenience. Such is poetic, or should we say, scientific licence. However, it does mean that in outlining the development of image analysis as a tool for estimating fibre distribution characteristics of wool, we can start the story in comparatively recent times.

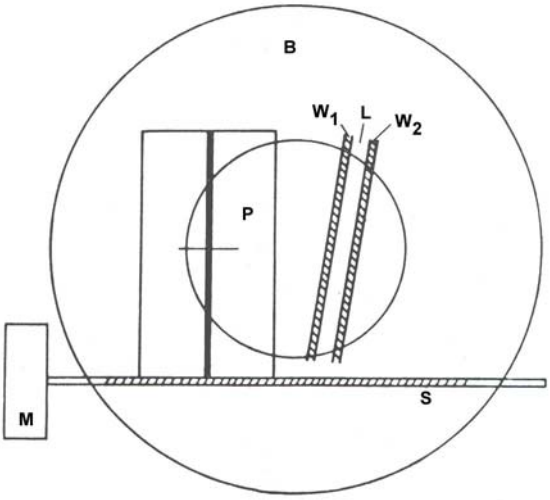
Development

Automating the Projection Microscope

Given that Projection Microscopy marked the beginnings of Image Analysis for the purposes of determining wool fibre diameter it is appropriate to begin the story of the modern development of Image Analysis with work by W.F. Du Bois & G.J.H Ten Cate reported in 1970. This was an early attempt to provide some automation of the microscopial measurement of cotton fibre dimensions.

These authors noted: *"The measurement of fibre dimensions with the aid of a microscope is a rather time-consuming affair, because these dimensions must be measured with the aid of a ruler or some other measuring device and the measurements must, in one way or another, be written down."*

To overcome these disadvantages Du Bois et al constructed device that was mounted over the ground glass screen of a projection microscope. It consisted of a bar with am extremely precise screw thread driven intermittently, but at a constant speed by a stepper motor (see below).



> *"Over the ground-glass projection disk, B, a bar, S, is mounted that is provided with an extremely precise screw-thread. This bar is driven intermittently but at a constant speed by a stepper motor, M. The number of steps per unit time is therefore constant. On the bar, a Perspex plate, P, is fitted and this is provided with a measuring line. This line moves stepwise but at a strictly constant speed of the (projected) microscopial images of the fibre(s).*
>
> *Every time the measuring line passes a dividing line in this image (e.g. the outer wall of a fibre) a hand or foot operated switch is pressed. For instance in measuring the width of the lumen (L) and the diameter of a fibre (W1+L+W1) the switch is pressed four times for every single fibre. The number of steps between two switchings is transmitted electronically to three counters, at the same time marked on a paper recorder. Because of the constant speed of S, this number is a measure of the distance between the successive walls of the fibre.*
>
> *When the measurement on a single fibre is completed, the counters are automatically switched back to zero."*

> *"The pitch of the screw thread is 1.2 mm, and the stepper motor gives 48 steps for each complete turn of the bar, S. One step therefore induces a displacement of the measuring line of 0.025 mm i.e. 25 µm. At a magnification of 500x this means that one step conforms to 0.05 µm in the fibre dimensions. Every step is counted so the unit of measurement of this device is 0.1 µm.*

There are no reports in the literature of this technique being applied to wool fibres, but the Du Bois and Ten Cate did indicate its potential for uses other than the measurement of cotton.

The earliest image analysis systems relied upon examining the area of fibre cross-sections. In the 1930's one common technique was to obtain thin cross-sections of a number of fibres, mount them on a microscope slide, take a photographic image of the slide through a microscope and then use a planimeter to estimate the area of each fibre cross-section. Philippen, Blankenberg and Merk (1971, 1972) described an instrument called a micro-image-analyser which was a refinement upon this technique, but which still relied on measuring fibre cross-sections.

Leaping forward to 1985 Hutchings & Ryder reported a more sophisticated technique for automating the Projection Microscope, this time with direct applicability to wool. Their apparatus consisted of a Gillet & Sibert conference microscope which projected an image upwards at about 45^0 onto an inclined mirror, instead of a screen, whereby it was reflected vertically downward onto a Summagraphics Bit Pad digitiser. The Bit Pad was mounted at a distance below the mirror such that the magnification was about 500x. This distance was not precisely controlled because the instrument was calibrated before each sample was measured.

The Bit-pad was controlled and the data from it processed by a computer. The system was calibrated by touching each end of a projected 300 µm scale with the Bit-pad stylus. Individual fibre measurements involved touching opposing edges of each projected fibre image with the stylus. The computer software recorded each position from the Bit-pad output and calculated the diameter. All fibre measurements were retained, and at the end of the process mean, standard deviation and a histogram were calculated and output in a printed format.

Areas on the opposing corners of the Bit-pad were set aside to enable the operator to quickly record whether a fibre was medullated and/or whether it was pigmented. The remaining corners contained areas where the operator could reject a measurement and to end the process. Again, activation of these functions simply involved touching the relevant area with the stylus.

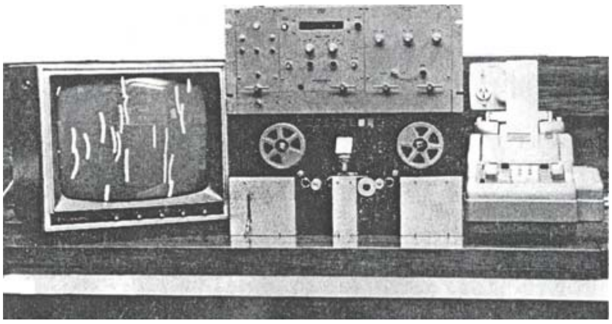
However, both of these innovations were primarily aimed at reducing the tedium involved in the projection microscope method by providing a means to automate some aspects of the procedure. Fundamentally the method itself remained the same.

Refining Photometric Techniques

A more revolutionary approach was announced to the world by Edmunds, Perry & Bedford in a paper published in 1973 in the Journal of the Textile Institute, titled "*FIDIVAN – an Automated System for the Rapid Measurement of Fibre Diameters*". This was an abridged version of an earlier report presented to the IWTO Technical Committee in Monaco in 1972.

The acronym FIDIVAN was derived from the name coined for the instrument – **FI**bre **DI**ameter **V**ideo **AN**alyser.

This instrument borrowed heavily on ideas incorporated Electronic Fibre Fineness Indicator (EFFI) developed in the USA in 1957 and the Fibre Diameter Analyser developed at Textile Department at the University in 1969 (see AWTA Ltd Newsletter, May 2006).



The FIDIVAN instrument

Degreased and washed fibres were first surface-stained with an aqueous iodine solution and rinsed. The still wet fibres were then cut with a semi-automated microtome to obtain 400 µm long snippets. These were dried and conditioned in a small sample bottle using a stream of conditioned air for about 3 hours. A pre-set volume of light-petroleum carrier liquid was then dispensed into each sample bottle.

The solvent and snippets were vigorously dispersed and the suspension dispensed by low pressure compressed air onto the emulsion surface of a slowly moving 16-mm film in the dark. While the snippets were slowly settling through the thin layer of the carrier liquid onto the film a 50 Hertz electric field was applied across the film causing them to become aligned parallel to one another. After a set period the film was exposed by an automatically triggered electronic flash. The exposed film was then processed in the normal way providing up to 100 30 mm long negatives, each containing thousands of images of transversely aligned fibre snippets.

The FIDIVAN instrument was then used to analyse these images to extract the fibre diameter information.

The film was cut into 30 cm lengths, these being spliced to form a continuous loop. One loop was then mounted on the reels of a film transport unit. The drive of this unit rotated the reels repeatedly in a stepwise manner. In this way 90 separate fields of view, each 3 mm x 2 mm were brought successively under a low powered microscope.

The microscope formed an image (magnified 4x) of the illuminated section in its field of view on the target of the tube in a high quality closed-circuit television camera, and the aligned snippet images contained in the field scanned at high speed by the raster of the camera. Since the image was a negative consisting of white fibre images on a black background, aligned at right angles to the direction of scanning, the output of the camera was a sequential series of voltage pulses, each directly proportional to the diameter of an individual snippet at a point along its length.

FIDIVAN used a single channel pulse-width analyser to determine the width of each of these pulses. This was achieved by the instrument's Diameter Selector, which set up the pulse- width analyser to respond to a particular 2 µm range of fibre diameters. In all the Diameter Selector had a total of 35 positions corresponding to diameters ranging from 10 to 80 µm in 2 µm steps. The film loop was rotated a total of 35 times, once for each setting. At the end of each revolution the number of accepted pulses was printed out so that at the end of the 35 rotations a full frequency distribution was obtained.

Edmunds, Perry & Bedford were very optimistic about the potential utility of FIDIVAN, while acknowledging that there were aspects that required improvement. However, only two reports were presented to IWTO, both during 1972. There were no further reports in subsequent years, and it can only be surmised that the authors encountered technical difficulties that they were unable to resolve.

Computer based Analysis of Digital Images

The late 1970's and 1980's saw a revolution in computer technology and in digital camera technology. This enabled a completely new approach, leading firstly to the FIDAM (**F**ibre **I**mage **D**isplay **A**nd **M**easurement) instrument, and subsequently to the OFDA (**O**ptical **F**ibre **D**iameter **A**nalyser) family of instruments.

FIDAM

FIDAM was developed by AWTA Ltd. It's genesis occurred in 1981 when Mark Brims, then employed by AWTA Ltd as a Research Officer, built a prototype fibre image analyser system, which demonstrated the potential of image analysis for estimating the fineness of wool fibres (Mark is now the Director of BSC Electronics Pty Ltd, the manufacturer of the OFDA). The FIDAM instrument, as it evolved, became very different from this early prototype, but the fundamental principle was the same.

In 1987, after 6 years of development, McNally and Edmunds described the basic principles of this instrument. FIDAM consisted of a video camera, which viewed fibre snippets through a low powered (40x) microscope. The snippets were spread over the surface of a large glass slide using a mechanical spreader, and the slide was moved on a stage beneath the lens of the microscope. The focus of the microscope was fixed and therefore the fibres were generally slightly out of focus. A frame grabber was used to capture the image of each section of the slide as it was being viewed. These digitised images were then analysed by a computer program, using a series of algorithms to select a transverse width at points along the length of the fibre images, and to estimate the magnitude of these widths. The FIDAM instrument therefore defined fibre fineness in terms of the estimated width of an image of the fibre, which was generally slightly out of focus. The instrument relied on the computer program to correct for any errors arising from the lack of focus of the image and to reject images where these errors were too large to correct.

The FIDAM instrument.

Shown here is the microscope, camera and X,Y stage. The associated computer and other ancillary equipment are no longer available.

Further papers describing the instrument were published by Marler and McNally (1988) and Van Schie, Marler and Barry (1990). The final paper in this series concluded: "*The performance of the FIDAM* *instrument in measuring the mean fibre diameter of raw samples compares more favourably with the airflow technique than the FFDA. Further research is required to understand the differences in the fundamentals of the measurement process for single fibre measurements versus bulk fibre web properties before commercial acceptance could be considered. This should include the influence of medullation and the co-efficient of fibre diameter on both web and single fibre measurement systems. AWTA Ltd will not be commercialising FIDAM for raw wool testing*”.

The reason for this decision is that CSIRO had at that time solved the issues that had plagued the FFDA instrument, and were about to release a new enhanced version trademarked “Sirolan™ Laserscan”. The Company decided to pursue the implementation of this technology instead of the FIDAM technology on the basis of 4 criteria:

- precision and accuracy
- speed;
- reliability; and
- cost.

OFDA

In 1991, Baxter, Brims and Taylor described the OFDA (Optical Fibre Diameter Analyser). The principle of this instrument was effectively the same as the FIDAM, although the software and the hardware were developed separately, and the system used different methods of data acquisition and analysis. The authors also submitted a Draft Test Method based on the instrument. A round trial based on this draft was conducted, producing an overall precision for tops, which matched the FFDA and was considerably better than the Projection Microscope. However it was noted that the estimate of Standard Deviation provided by the OFDA was higher by about 4-7% than the Projection Microscope estimates. The draft method was accepted by IWTO as a TME (Test Method under Evaluation).

In the following year the same authors reported the results of further studies based on the OFDA. In particular the authors focused on:

- the effect of contaminants such as grease;
- operator influences;
- snippet geometry; and
- the performance of the computer algorithms.

The OFDA100 instrument.

Baxter, Brims and Taylor reported that the instrument was sensitive to snippet length, for both Mean Fibre Diameter and Coefficient of Variation in Diameter, but these effects diminished as the snippet length approached 2 mm.

At the Nice meeting in 1992, Baxter reported on some round trials with greasy wool cores using the OFDA. This was a study of four sample preparation techniques and their effect on the precision of the TME. It showed that mini-coring the aqueous scoured core sample or mini-coring a sample prepared using a Waring Blender produced a level of precision equivalent to that of the Airflow for fine wools, but not for the coarse wools.

Baxter and Teasdale (1992) investigated the effect of calibrating with Interwoollabs tops on the precision of the OFDA system and reported that it was negligible. However, Lupke, Wright and Botes (1992) reported some comparisons of the OFDA and the Airflow for greasy wool samples from individual fleeces, which indicated a systematic bias of approximately 0.5 microns.

Subsequent round trials on greasy core samples did not confirm this bias (Edmunds, 1993 and Baxter and Brims, 1994), although, they did show significant differences between Airflow and OFDA on some very coarse wool samples. However, if these examples were excluded, the data suggested that on average, the OFDA estimates of Mean Fibre Diameter were marginally finer than the Airflow. A similar trial using wool tops (Baxter and Brims, 1994) also showed close correlation with the Airflow and with the Projection Microscope. However, data presented in this paper provided the first indication of a systematic pattern in the differences between Standard Deviation measured using the OFDA and using the Projection Microscope. This bias was subsequently confirmed by independent experiments.

In 2000 the OFDA100 range of instruments was extended with the release of the OFDA 2000. This was a portable version specifically targeting the on-farm fleece testing market. Based on image analysis of “micro-staples” drawn from full length fleece samples it provided estimates of MFD, SD, CVD, Curvature and Fibre Diameter Profiles along the length of the staples. .

However, the instrument could also be configured in “OFDA100 Mode” and consequently IWTO permitted its use for IWTO Certification by IWTO-47.


The OFDA2000 instrument.

Apart from its portability and additional functionality the major change in the instrument was the porting of system software from the DOS operating system of the OFDA100 to a Windows operating system. BSC Electronics, while continuing to maintain the OFDA100 is not doing any further development of this platform. As a consequence the instruments will become redundant because the computers and their operating systems are already redundant. It is not possible to simply transfer the OFDA2000 software across to an OFDA100 as the software on both instruments is hardware specific.

The OFDA range was further extended in 2002 with the release of a new instrument branded the OFDA4000. This instrument was targeted at wool combing mills. It reports the same parameters as the OFDA2000, but for wool tops and also provides an estimate of Hauteur. In this market the OFDA4000 competes with the Almeter, but has substantially more functionality, providing the mills with a single instrument for Fibre Diameter Distribution estimates as well as Hauteur. IWTO has at this stage approved a Draft Test Method for the instrument (DRAFT TM-62). However, development of this Draft Test Method has not been without controversy.

Development of the IWTO Specification – IWTO 47

The Draft Test Method for the OFDA100 was advanced to a full test specification (IWTO-47) in 1995, following an extensive inter-laboratory round trial on samples of wool tops and raw wool (Harig, 1995). In general this trial confirmed some of the discrepancies that had already been reported, and also that they were quite small. The pattern in the Standard Deviation referred to above was more clearly apparent in this data. However, in this instance, for raw wool, the OFDA Mean Fibre Diameter was slightly coarser than the Airflow. Later work by Sommerville (1997, 1998) and Knowles (1998) on superfine wool showed that for these wools the OFDA was generally finer than the Airflow.

Sommerville (1998) was also able to demonstrate that an extrapolation error associated with the Airflow calibration was a contributing factor to these observed differences.

Compared to other instrumental techniques, the OFDA was different in its calibration requirements. Turpie (1996) and Turpie and Steenkamp (1996) reported on the effect of relaxation of wool slivers on the measurement of Mean Fibre Diameter by Airflow, Sirolan-Laserscan and OFDA. Of the three instruments, only the OFDA exhibited any significant effect. The current IWTO Specification for the OFDA requires a specific calibration for greasy wool and another calibration for sliver. These calibrations use different preparation techniques for the calibration tops. This was not then required for the Sirolan-Laserscan.

At the Christchurch meeting of IWTO in 2000, the Independent Round Trials (ILRT) Group reported data showing that the ODFA100 was very sensitive to the sample preparation technique. The instrument could be calibrated for Mean Fibre Diameter, but this introduced biases in the Standard Deviation. If it was calibrated for Standard Deviation this introduced biases in the Mean Fibre Diameter.

Consequently IWTO-47 was amended to require separate calibrations when certifying Mean Fibre Diameter and Standard Deviation.

Resolving Differences

The differences between ODFA100 and Airflow, can to some extent be attributed to the same factors that also cause differences between the Sirolan-Laserscan and Airflow, so these factors will not be further considered here.

The systematic bias in OFDA100 measurements of Standard Deviation compared with both the Projection Microscope and the Sirolan-Laserscan has never been satisfactorily resolved.

Basically, when the OFDA100 is calibrated for diameter measurement, the SD measurements exhibit a highly reproducible diameter dependent bias. For very fine wools the OFDA100 SD is always higher. As the diameter increases the SD's of all the instruments converge, in some experiments becoming negative in the mid micron range. As the diameter increases further the difference becomes increasingly positive. When plotted over the full range the differences curve assumes a somewhat parabolic shape.

Likewise, there is a systematic difference in the shape of the distribution histograms. At the finer and broader ends of the range the OFDA100 distribution is somewhat normal, whilst within the intermediate range it assumes a skewed conformation, very similar to the Projection Microscope and the Sirolan-Laserscan.

Technically a resolution of this difference was found when the ILRT Group provided the data that showed that calibrating for Mean Fibre Diameter and SD separately mitigated these differences, and IWTO-47 was amended accordingly.

Scientifically this is probably less than satisfactory, as scientists always want to understand and explain such fundamental differences.

Some unpublished modeling work by AWTA Ltd conducted by its National Technical Manager, Mr. Jim Marler has suggested that part of the explanation can be found in the large error for individual fibre measurements made by the OFDA1000. The instrument uses a CCD camera where the pixel size is 4 µm square – comparatively large compared with the actual diameter of the fibres. Errors arising from this low resolution are compounded by the fact that the images captured by the instrument are also generally slightly out of focus and the software is required to apply an algorithm to adjust for this.

When allowance is made for these errors, and the output of the instrument mathematically modeled, the resultant distributions and standard deviations are comparable to those actually produced by the instrument.

Commercial Implementation

The ODFA100 is widely used in mill laboratories around the world for quality control purposes and also by many fleece testing laboratories.

AWTA Ltd has a number of these instruments and can provide test results using IWTO-47, but this service is an add-on rather than a default service. To facilitate the trading of wool if Certification according to IWTO-47 is requested, Certification by IWTO-12 (Sirolan-Laserscan) is always provided.

The best comparative measure of the precision of the OFDA100 is provided the Interwoollabs Round Trials which are reported each year to IWTO.

These can be viewed at the end of the chapter on Photometry which proceeds this chapter and demonstrate that the instrument in better than both the Projection Microscope and Airflow, but not quite as good as the Sirolan-Laserscan.

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