Chapter III Improvements in the sewing test rig

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1. Chronological summary

This chapter provides a brief description of the main enhancements and improvements of the sewing test rig since its first functional version until version 3.2. An extended description of these developments can be found in Annex C.

Version 3.2 introduced the whole new concept of sewability tests that will be discussed separately in chapter 5.

Table III- 1 summarises the main developments achieved.

Besides an extensive set of new functions introduced, great care has been put into the maintenance and improvement of the software.

User interface was also redesigned to increase functionality and ease of use, allowing a quicker data acquisition and analysis.

Table III- 1: Chronological outline of the AST software evolution up to version 3.2

Date	Version	Description
2/1998	1.2a	> LVDT integration
3/1998	1.2e	> Zero point calibration panel > Minor functionality improvements
04/1998	2.0	> Major redesign of user interface
05/1998	2.1	> Minor functional details
05/1998	2.2	> New calculation routines for processing of stitch cycle phases (phase processing), with zero correction for phase processing > New panel for multiple acquisitions > First version of spectral filtering routine
06/1998	2.3	> Integration of thread consumption measurement
07/1998	2.4	> XY-graph panel and xy-graph building routines added > First approach to a fully automatic feature extraction routine
03/1999	2.5	> Compatibility with PCI-6025E data acquisition board > Integration of PiezoII type conditioning board (second sewing test rig)
07/1999	2.6	> Addition of synchronism information to the signal properties for more accurate angle scale and phase angle calculation
11/1999	2.7	> 3-D graph panel and 3D-graph service routine library created
11/1999	2.8	> Second approach to automatic feature extraction routine, with signal pre-processing and more accurate phase angle definition > Signal files use now binary format. File size reduced, read/write speed greatly improved

Date	Version	Description
02/2000	2.9	> New buffered continuous acquisition mode eliminates delay between stitch count and acquisition triggering. > Descriptive statistics panel added;
06/2001	3.0	> Data structures for sewability testing created > Subroutine structure and new routines for test processing and display created > File I/O for test results created > Measurement of presser-foot displacement reference cycle introduced > Measurement of static thread tensions introduced
06/2003	3.2	> Several miscellaneous functionality enhancements and code redesigns. > Sample labels introduced.

2. Presser-foot displacement measurement

A major improvement of the sewing test rig was the measurement of presser-foot vertical displacement, introduced in by Silva in [1], that required several hardware and software developments.

The set-up proposed for presser-foot displacement measurement adds an LVDT (Linear Variable Differential Transformer), placed in the axis of the presser-foot bar. Figure III- 1 shows a diagram and a picture of the resulting configuration.

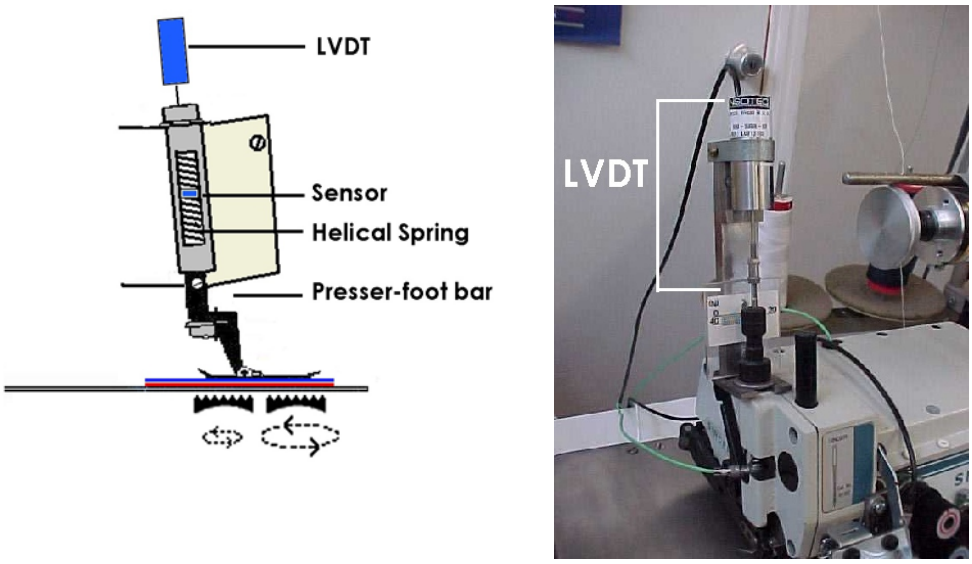


Figure III- 1: Set-up of LVDT for presser-foot displacement measurement

A simple conditioning circuit was developed[1] that didn't include programmable gain or high-pass filters.

No new programming functions had to be developed to drive this board, but a new *gainless* type of channel, with the associated calibration procedure and signal scaling routines was created in the system configuration and data structures.

3. Thread consumption measurement

3.1. General set-up

In order to add more information to the analysis of the stitch formation process, Carvalho,M. proposed and developed a device to measure thread consumption [2].

Omron E6B2-CWZ6C quadrature digital encoders with a wheel-shaped thread guide on its shaft and a custom-designed board using a Microchip PIC16C74A microcontroller were used [4]. Specific hardware driver modules were developed.

As thread is pulled by the machine, digital counters count pulses that are converted to a thread length value with the appropriate calibration factors.

Figure III- 2 shows the machine equipped with the three encoders.



Figure III- 2: Digital encoders for thread consumption measurement

A particularly important issue is the synchronisation of the counting operation and the signal of other sensors. The counting operation must be triggered synchronously with the acquisition period.

The new device (based on the PIC controller) used the digital ports of the data acquisition board to receive and send commands and data. The addressing scheme defined previously for the AST system's bus [5] was adopted, so that the device could be directly connected.

A set of functions for calibration of the thread length measurement was provided in the firmware.

Several modifications in data structures and functions were performed to accommodate the new device. This involved hardware configuration data, calibration factors, file formats and graphical display functions.

3.2. Calibration

To calibrate the thread consumption counters, a specific calibration panel was developed.

The calibration process itself is similar to that of the analogue sensors. A known value of the measured variable - in this case a known thread length - is applied to the system, and the output is measured.

3.3. User interface

Display of consumption values is a new functionality included in the system.

A new type of display scale in the graph's scale selector was added, as shown in Figure III- 3.

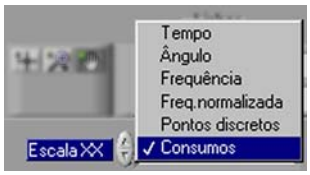


Figure III- 3: New scale selector for AST graph

Consumption values are displayed as vertical bars, distributed over the x-scale in order of selection, as seen in Figure III- 4.

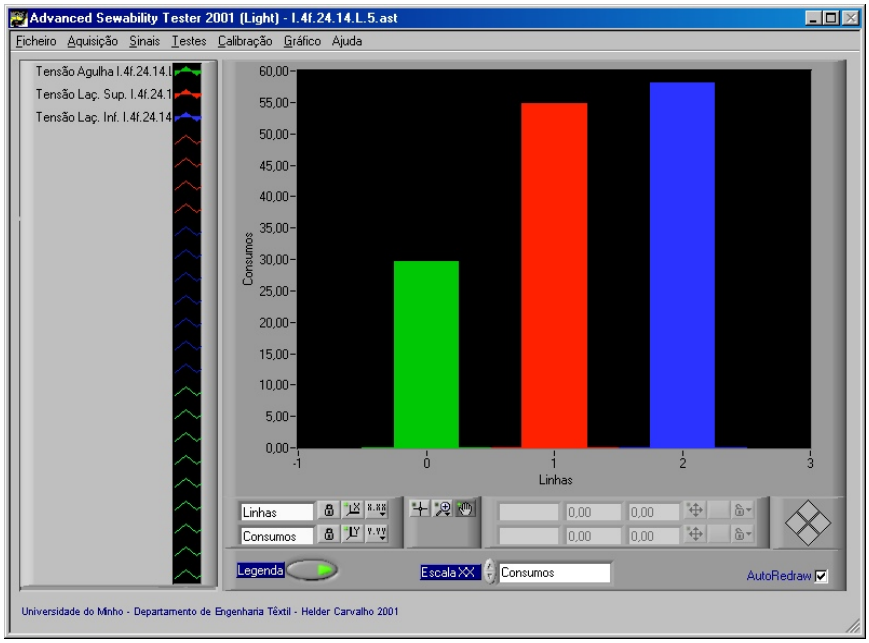


Figure III- 4: Bar graph for thread consumption display

4. Set-up of a second sewing test rig

Silva introduced the LVDT in the first sewing test rig and performed a series of experiments with the purpose of studying the conventional spring-hinged presser-foot feeding system[1].

After these tests, a second sewing test rig was set up with the aim of applying an active electromagnetic actuator and comparing the behaviour of both alternatives.

4.1. Hardware drivers for the new signal conditioning board

New signal conditioning boards were developed for the second test rig that include a piezoelectric channel, an LVDT and the synchronization signal, resulting in a single board, with improved performance[3].

The major improvement introduced with the *Piezoll* board was the software-controllable offset (zero adjustment) of the piezoelectric conditioning channels. This was achieved using two channels of the MDAC (Multiplying Digital to Analogue Converter) that was used for gain control. A constant reference voltage is applied to these channels, and their output is summed to the output of the conditioning chain. This summed value can now be varied by software, allowing a quick offset adjustment.

Gain and offset control was considered not to be necessary for the LVDT channel, since the scale necessary for displacement measurement does not vary significantly with sewing conditions, as opposed to the other sewing variables.

With the use of this new board, several changes were brought into the system software. These included the hardware drivers, the system's signal and configuration data structures, calibration and scaling functions as well as some details of the user interface.

4.2. Service to the new PCI-6025E acquisition board

The PCI-6025E data acquisition board from National Instruments was chosen for the new sewing test rig. This board is a low-end board with improved features when compared to the Lab-PC+ used on the first sewing test rig. Some changes were necessary in the software to ensure compatibility and take advantage of its improved features.

The first version of the AST software was designed to work with the Lab-PC+ data acquisition board. With the choice of a different board, support for multiple boards and detection of the board had to be introduced. Several parameters and procedures were then adjusted according to the acquisition board detected. This approach can be used to assure compatibility with different devices that can be selected in the future.

5. General improvement of functionality

5.1. Acquisition functions

Although fully operative in its acquisition functions since its first versions [5][6] the AST program has gone through several redesigns and additions with the objective of functional enhancement and maintenance. This section gives a general idea of the work carried out.

5.1.1. Panel for multiple acquisitions

The research of the sewing variables demands for extensive series of tests. Each subject studied by the various researchers using the AST system requires multiple acquisitions to be collected. In order to quicken this process, a subroutine for multiple acquisitions has been set up. Figure III- 5 shows the panel of this subroutine.

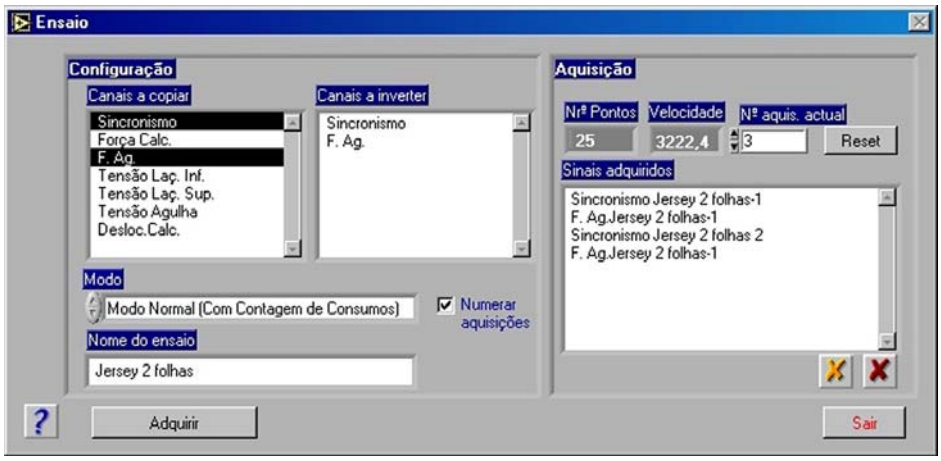


Figure III- 5: Multiple acquisition panel

With this subroutine, the user selects the channels whose signals he wishes to be stored. A name is assigned to the test being performed, and an acquisition mode is chosen. The acquisition panel for the mode selected is then called, and the signals acquired from the selected channels are stored in a temporary signal register. If desired, the signal records are automatically numbered. When the user exits this panel, the acquired signal records are loaded into the input signal register of the AST's main panel.

5.1.2. New continuous acquisition mode

The acquisition sequence used in the first versions of the AST system starts with a configurable stitch count in which the user accelerates the machine to its final sewing speed. This stitch count is software-controlled, using a loop in which the synchronism signal is monitored.

When the configured count is reached, the hardware configuration, both of the external conditioning, as well as that of the internal acquisition board, are set to acquisition mode. The acquisition board's hardware trigger is enabled, and acquisition is triggered with a rising edge of the synchronism signal.

This sequence presents the disadvantage of having a non-predictable delay between the end of the stitch count and the actual beginning of the acquisition.

It is thus not possible to relate the stitch cycles displayed on the PC screen to the actual stitches on the fabric sample. This would be very important, for instance, in the analysis of seam defects.

To solve this problem, an acquisition routine has been developed in which the stitch count is part of the signal acquisition process. A continuous acquisition is started and stitches are counted in real-time. The subset of data acquired immediately after the end of the configured stitch count is returned. In this mode, continuous acquisition using a circular sample buffer is used. No delay exists between the end of the stitch count and the beginning of the acquisition.

Figure III- 6 shows the dialog box associated with this new acquisition mode.

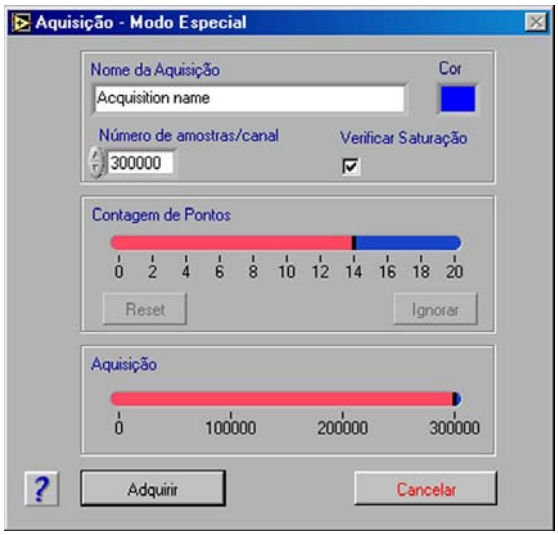


Figure III- 6: Dialog box for continuous acquisition mode

The interface to this new acquisition mode is not very different from the traditional single-shot acquisition. It displays a stitch counter, a text control and a colour box to assign a name and colour to the acquired signals[1].

The main difference, and an additional advantage of this mode, is related to the number of samples that can be acquired. Unlike in the previous mode, an acquisition in this new mode is in reality composed of multiple, subsequent acquisitions that are concatenated. This means that the record length (number of samples to acquire) is not limited to the size of the hardware buffer (64K samples on the Lab-PC+ board). Moreover, the number of samples acquired can be displayed on the dialog box during acquisition.

The great drawback of this mode is its incompatibility with the operation of the thread measurement device due to a technical detail related to the function of the device. This problem does not exist anymore in the new synchronized acquisition mode and the thread measurement device under development (see section 6).

[1] The acquisition mode dialog box shown in chapter II does not include the colour control. Association of a colour to a signal was only introduced in the latest versions.

5.1.3. Quasi-static thread tension measurement

In the first versions of the system, only the measurement of dynamic signals had been envisaged. All of the acquisition functions had been tuned for in-process measurement, except those related to calibration.

As studies on thread tensions evolved, it became necessary to quantify the pre-tension introduced on the thread at the tensioners. This would be used to establish adjustment ranges and relate those to the results collected with dynamic measurements.

A simple acquisition panel was built to fulfil this function. It performs multiple one-shot acquisitions and monitors the peak tension value measured on each of the threads. The static tension value is computed as the maximum peak value obtained in all of the acquisitions, or as an average of the peak values obtained. The front panel of this function is shown in Figure III- 7.

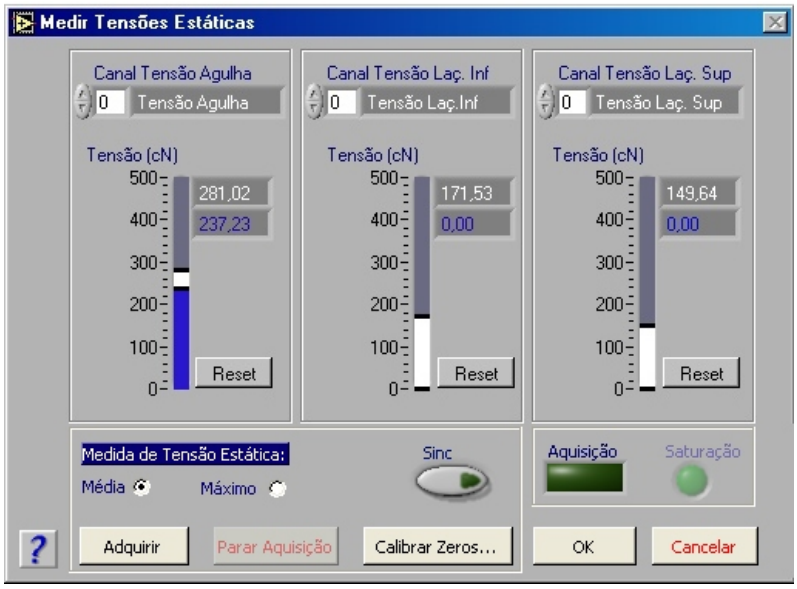


Figure III- 7: Measurement of static thread tensions

To produce (quasi-) static tension on the threads, the thread is pulled at a low and constant speed. This is done manually or with the aid of an electric motor, with which a good repeatability of the measurement is achieved. Alternatively, it can be achieved by letting the machine run at a very low speed, and measuring the value during actual stitch formation.

5.1.4. Presser-foot displacement reference cycle acquisition

After the study of results related to the feeding system[1], the author suggested the measurement of a reference cycle for the presser-foot movement, acquired at a low sewing speed. This reference is valid for a specific fabric and machine set-up and can be used later as it is stored in a database. It can also provide an estimate of the material's thickness (although specific for the presser-foot's pre-tension value).

The reference values and signals can then be compared with results acquired at higher sewing speeds, with the aim of computing the deviation from the ideal (reference) cycle. Important conclusions can then be inferred about the appropriate control action to be taken to compensate for these differences.

Figure III- 8 depicts the front panel of the subroutine developed for this purpose:

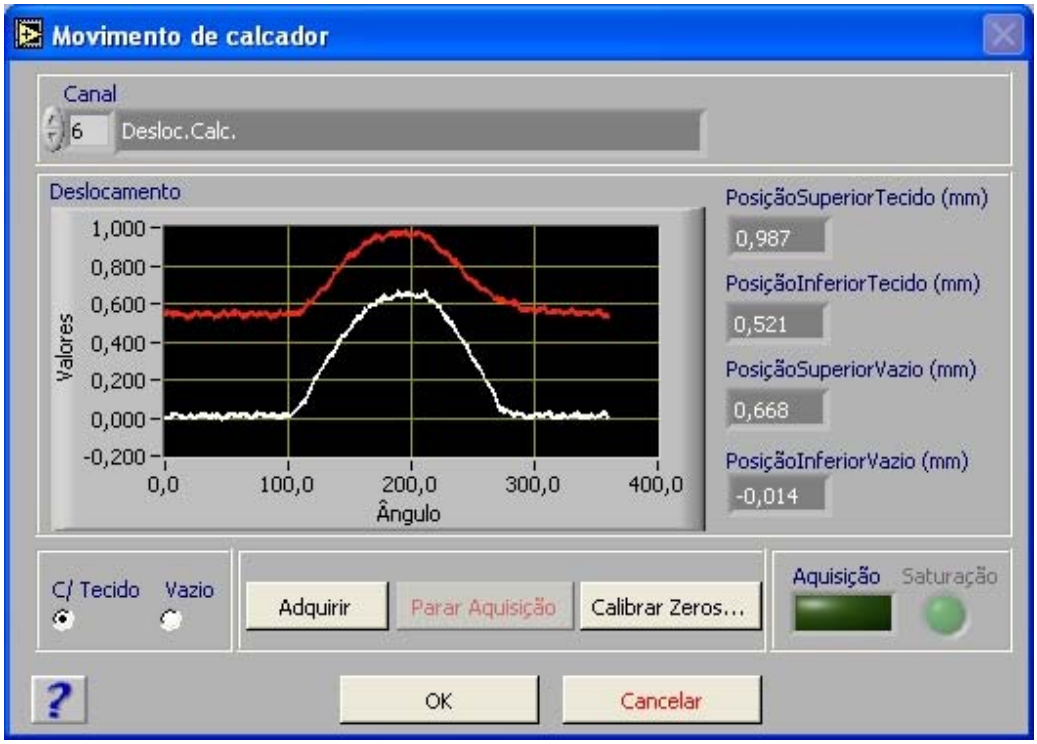


Figure III- 8: Presser-foot reference cycle acquisition

The portrayal of the presser-foot's displacement reference uses a cycle of machine operation with fabric and another without it. Some measurements are performed on the signal and are stored along with the acquired signals. The information hereby collected is the basis for some of the parameters calculated for sewability tests that will be discussed later.

5.1.5. Sample label generation and printing

Experimentation with the AST system always involves the production of a great amount of seam samples. These samples are studied later with the simultaneous analysis of the results obtained from the signal processing routines. In previous versions of the system, the users marked the samples with a pen, which was impractical.

To ease this task, sample labels are now generated for each acquisition performed. The following information is displayed on the label

- Date and time of acquisition
- Acquisition number: A unique number assigned by the AST software to each acquisition. This number is automatically incremented after each acquisition;
- Count: Stitch count performed before start of the acquisition. This indication is displayed in the format "x+y", in which x is the number of countdown stitches configured by the user, and y is the estimated number of stitches that occur between the end of the software count and the beginning of the actual acquisition. Future versions of the AST system include hardware counting of the preparation stitches, eliminating the delay and thus providing an exact stitch count.

- Sewing speed [spm]
- Name of the test, introduced by the user in the acquisition dialog box.

Sample labels are printed on A4-sized pages, each including 10 labels. They may also be saved in an RTF file for later viewing and printing.

5.1.6. Restructuring of the acquisition subroutines

As always occurs in this kind of development, additions and modifications create the need for periodic streamlining of subroutines and hierarchy structures.

One of the main component groups of the AST software to undergo several maintenance actions in this sense was that related to all functions involving acquisition. The main purpose of these actions was to try to unify the subroutines used for acquisition in all of the AST's functions. This would ensure coherency between values acquired in different modes and avoid duplicate code.

To achieve this objective, a separate library for each of acquisition, external hardware and calibration function groups was created. In each of these libraries, a multi-layer structure was implemented. The intent of this multi-layer structure was to use only the higher-level functions at the application level.

This structure is effective in the current state of the system, but some improvements, to obtain a professional version, are under study.

5.2. Calibration functions

The calibration tools have suffered various upgrades and improvements. Some of them are related to the new sensors added to the system and the new acquisition function that were described previously.

Another improvement was the zero calibration utility. The intensive use of the system in the project has shown the need for a practical way to monitor and correct the zero calibration of the various types of analogue channels.

Although this operation was possible with the calibration panel, a quicker and more straightforward means of performing this operation was provided by a zero calibration utility, depicted in Figure III- 9.

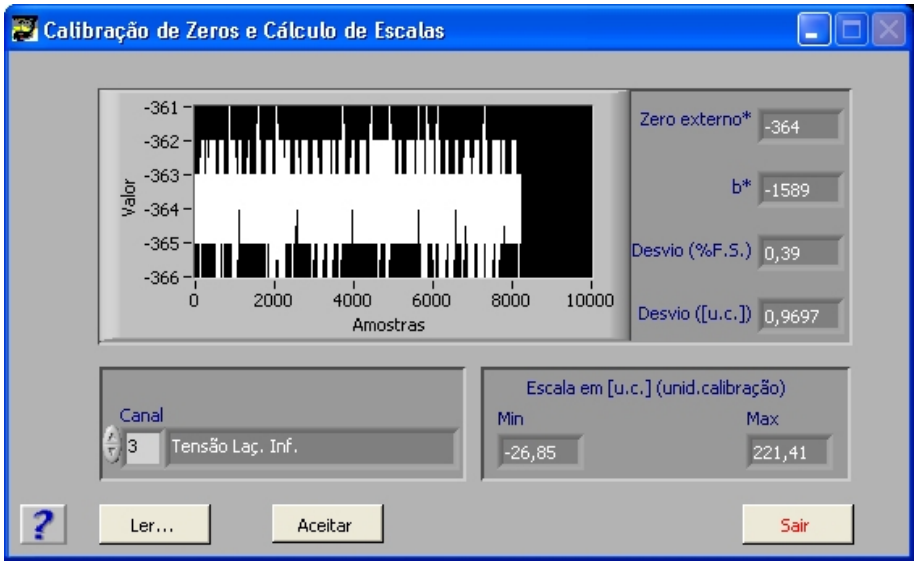


Figure III- 9: Zero calibration utility

With this utility, it is possible to correct the zero deviation since the last calibration. The panel indicates the percentage of full-scale [%FS] and absolute deviation [u.c.: unit of calibration], as well as the measurement range for the current gain setting[1].

This utility is used periodically by the users of the system and provides valuable information on the reliability and accuracy of the hardware.

5.3. Time and Angle Scale Calculation and Conversion

Many of the display and processing functions depend on the calculation of X-scales for the acquired signals.

The first acquisition modes provided by the AST system were based on a fixed sample frequency. The X-scale resulting from this method is inherently a time scale. However, an angle scale is computed in order to allow analysis of the signals with respect to the stitch cycle.

The first versions of the AST system used average sewing speed to obtain an angle scale. This resulted in significant errors when speed was not constant, which is a normal situation even if a constant-speed seam is tried.

A new technique, using the synchronisation signal, was implemented. This signal, delivering a pulse at the beginning of each stitch cycle, allows the exact definition of the beginning and end of each stitch cycle. The new technique allowed a significant improvement in angle scale calculation, sufficient for most tasks, although having some imprecision within the stitch cycle. However, the changes of speed in a stitch are not high. The synchronised acquisition mode under development will, within a specified resolution, allow an exact computation of angles.

5.4. Time-Domain Measurements: Phase processing

5.4.1. Signal subsets based on stitch cycle phases

The cyclic nature of the stitch formation process has always been considered in the analysis of the signals obtained with the sewing test rig.

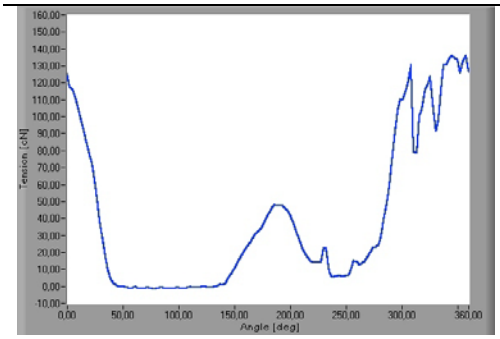
It has been observed that all of the signals can be divided into stitch cycles, and within the cycles phases can be defined. Each of these phases is related to an event occurring at the same moment in all cycles. Many studies have been conducted in which this approach has been used successfully, of which [1][2] are the best examples.

The tools to perform this analysis had been built into the software in its initial version, but have since then been greatly enhanced:

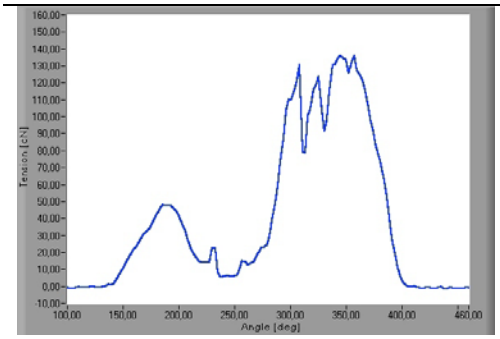
- Whilst in its initial version only peak detection was provided to the users, other features have now been included;
- The previously described angle scale calculation methods have been a valuable contribution towards the automation of this calculation, avoiding the manual correction of the errors produced by the former method;
- The zero correction function has been helpful to reduce measurement errors related to zero drift, especially when processing needle-bar force signals;
- The possibility of choosing an initial angle for stitch cycle demarcation has eased the task of phase interval definition.

[1] Refer to [5] for description of the *b** and *Zero externo** values

To mark the phases that will result in signal subsets, angles are defined on the first stitch cycle and then copied to the remaining cycles in the acquisition. This method is illustrated with the example of a needle thread tension signal in Figure III- 10:

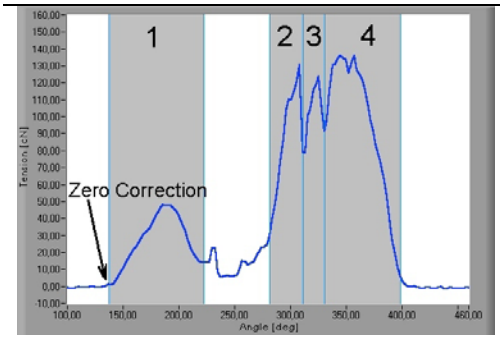


Under the current calibration of the synchronizer, the stitch cycle, defined between 0 and 360°, shows up as depicted. Some peaks are occurring around the angle of 360°, so that a redefinition of the beginning of the stitch cycle, at another angle, is necessary.



After defining an *initial angle* of 100°, the first stitch cycle is now located between 100 and 460° and all the relevant events are included in this interval.

Phase intervals can now be input.



Four phase intervals have been defined for this signal. The software shows the phases by means of vertical cursors.

If the user selects the zero correction function, the sample located at the beginning of the first phase interval in each cycle is used as reference. Its value is subtracted to all samples of the signal subset. This will compensate a possible offset.

Figure III- 10: Phase definition with initial angle and zero correction

After this operation, the software will replicate the phase intervals to all remaining stitch cycles and extract the signal subsets, on which feature calculations will occur. If zero correction is selected, the subsets will be corrected for zero drift in each stitch cycle before any computation occurs. Zero correction is done based on an average of values in the vicinity of the zero correction point (see Annex C, section 5.4)

The subsets extracted from the signals are arrays of discrete signal values, and the following features are calculated on them:

- Peak (maximum) of signal subset
- Valley (minimum) of signal subset
- Angle of occurrence of peak or valley

- Average of signal subset
- Energy of signal subset
- Power of signal subset

The computation of these features is further described in chapter V-1.2.

5.5. Frequency-Domain Measurements and Processing

5.5.1. Extraction of frequency components

To ease the display and analysis of signal spectra, the FFT-based spectral analysis tools have been complemented with a function devised to extract the values of the signal's frequency components. This function allows a clearer observation of the signal spectra and greatly reduces the amount of memory needed to store a spectrum, since it only stores the component's values, instead of the whole discrete spectrum.

The algorithm used is based on the assumption that the signals under analysis are all periodic, exhibiting a fundamental component at the base frequency and harmonics at the integer multiples of the base frequency.

The fundamentals of FFT-based signal analysis have been extensively described in [5]. Some of the conclusions drawn, as well as their consequence for the algorithm in hand, are described next.

1. The spectrum of a periodic signal contains a fundamental component at the base frequency of the signal, and harmonics located at integer multiples of this frequency. Moreover, the DC component is displayed at the zero frequency.

2. The FFT-algorithm returns an array of the same size m of the processed signal. This array contains samples of the spectrum in a double-sided arrangement, with the frequency interval of $\left]-\frac{f_s}{2};\frac{f_s}{2}\right[$ and symmetrical around the DC component. This means that the energy of the signal at a particular frequency is divided between a positive and a negative frequency component. One half of the spectrum is thus redundant.

3. Considering only the positive part and correcting its amplitudes appropriately, the redundancy is eliminated and a single-sided spectrum is obtained. This array contains a number $\frac{m}{2}$ of samples.

For the signals obtained from the sewing machine, the fundamental frequency f_{fund} is related to the sewing speed v_s by

$$f_{fund} = \frac{v_s}{60} \qquad (1)$$

The AST software uses the one-sided spectrum for spectrum analysis. This means that, for an acquisition with a number *m* of samples, the result of FFT-processing is an array of $\frac{m}{2}$ values.

The resolution of the spectral analysis is therefore:

$$\Delta f = \frac{f_s}{m} \tag{2}$$

and the values in the array represent a frequency band extending from 0 to $\frac{fs}{2} - \frac{fs}{m}$.

The extraction of the frequency components involves the following steps:

1. Define the frequency bands in which the harmonics are located:

$$B_p : \left[(p - \frac{1}{2}) \cdot f_{fund} \; ; (p + \frac{1}{2}) \cdot f_{fund} \right[\tag{3}$$

with

p:	Index of component
B_p:	Frequency band for component p
f_{fund}:	Fundamental frequency of signal

2. Compute the indexes of the spectrum array corresponding to the frequency bands defined.

   Using equation (2), element i of the spectrum array corresponds to the frequency

$$f(i) = \frac{f_s}{m} \cdot i \tag{4}$$

   and the frequency interval defined in (3) can be rewritten as

$$I_p : \left[(p - \frac{1}{2}) \cdot \frac{f_{fund} \cdot m}{f_s} \; ; (p + \frac{1}{2}) \cdot \frac{f_{fund} \cdot m}{f_s} \right[\tag{5}$$

where

p:	Index of component
I_p:	Interval of spectrum array indexes for frequency component p

3. Measure the frequency components as peak value of the spectrum in the intervals.

Figure III- 11 illustrates the process, showing the definition of the frequency bands (blue lines) and the values that are extracted (red cursors). (This representation is not actually available to the user; it has been produced specifically to illustrate the procedure. In the software, the extraction of components is a single-step and transparent operation over the spectrum of a signal.)

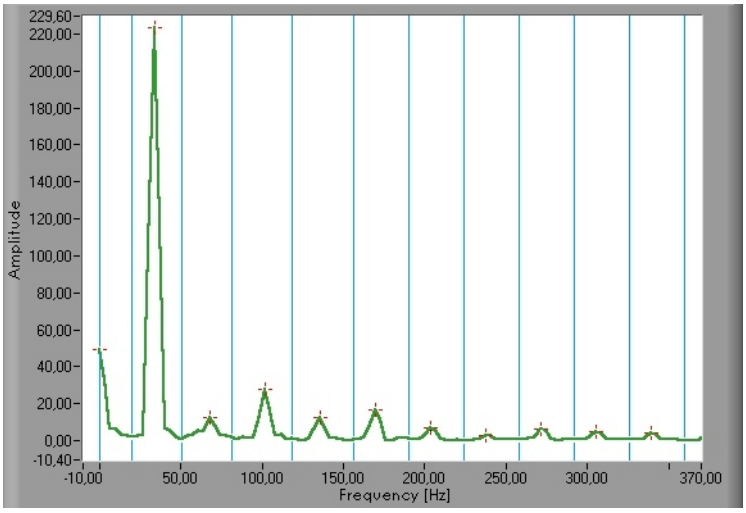


Figure III- 11: Frequency bands and measurement of component values

It is important to stress that this computation is inaccurate in the sense that it does not correct errors produced by the picket-fence effect or spectral leakage. It is accurate only in the situation of an integer number of periods in the acquired signal, and tools have been provided to meet this condition.

Nevertheless, the user is free to use the time windowing functions provided by the AST software and correct the amplitudes explicitly. The extraction of components using this method has revealed to be satisfactory in practice.

5.5.2. Spectral filtering and reconstruction

The need for a spectral filtering function resulted from the analysis of needle-bar force signals. In these signals, the following mechanical actions are present:

- Needle penetration and withdrawal forces;
- Needle-bar acceleration forces;
- Forces produced by the threads on the needle-bar.

The effect of the latter two actions is irrelevant to the objective of the measurement, and needs to be eliminated in a pre-processing stage, before the signals are further treated.

To determine which frequency bands should be filtered, preliminary experiments were carried out using different fabrics, different number of layers and using no fabric at all. The machine was run without thread, in order to eliminate the effect of the thread.

The first approach to this pre-processing function was the use of standard time-domain IIR digital filters. Direct elimination of the desired frequency components in the frequency domain, however, revealed more flexible and represents the

best approach to an ideal filter. An additional advantage is the elimination of the time-scale shift introduced by IIR filters, making it easier to define phase intervals for phase processing of the filtered signals.

A first definition of an adequate stopband for the filtering operation was obtained.

The definition of a stopband, in this context, is not done in terms of frequency bands with rigid limits, but in terms of harmonic components to be eliminated.

Signals acquired from the sewing machine at constant sewing speed are periodic signals owning harmonic components at multiples of the fundamental frequency (that corresponds to the rotation speed of the machine). The definition of a stopband in terms of harmonic components normalizes the stopband to the fundamental frequency.

The following examples show the naming convention adopted to define a stopband in this work:

- *0-1-3*: Elimination of DC (0), fundamental (1) and harmonic 3
- *0-1-2*: Elimination of DC (0), fundamental (1) and harmonic 2

The technique was adopted for off-line use in the sewing test rig. A spectral filtering tool was implemented that allows the user a flexible choice of the components to be filtered, not constraining him to a specific stopband. The high processing time of this algorithm most likely impairs its use in real-time applications.

Figure III- 12 shows the processing sequence for spectral filtering:

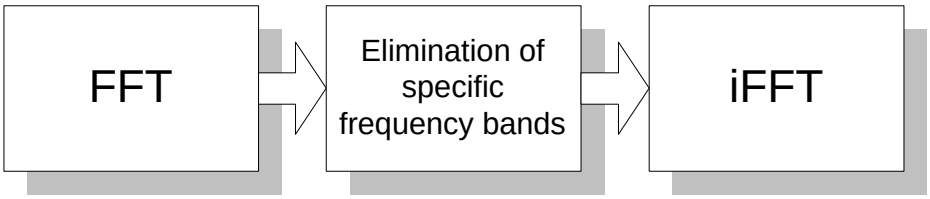


Figure III- 12: Processing sequence for spectral filtering

The sequence consists of performing an FFT, setting the values of the resulting array to zero in the frequency bands that contain components to be eliminated, and performing an inverse FFT that will deliver the filtered signal. The time signal resulting is used to extract relevant parameters of the sewing process.

To determine the array elements that are to be eliminated in the spectrum, the intervals of the specific components are computed by the same method presented for frequency component extraction (equations (3),(4)and (5), see 5.5.1).

Unlike in spectral analysis, in which a real FFT is used for the computation of an amplitude or power spectrum, in this case a complex FFT is performed to allow for the inverse transformation.

A more extensive description of this study will be given in Chapter IV.

5.6. Descriptive statistic tools

The statistical analysis of the signals, and especially of processing results, has been made possible by a software module developed for this purpose. The user

interface panel, shown in Figure III- 13, provides a quick way of defining some simple descriptive statistical parameters over the signals or other sets of data.

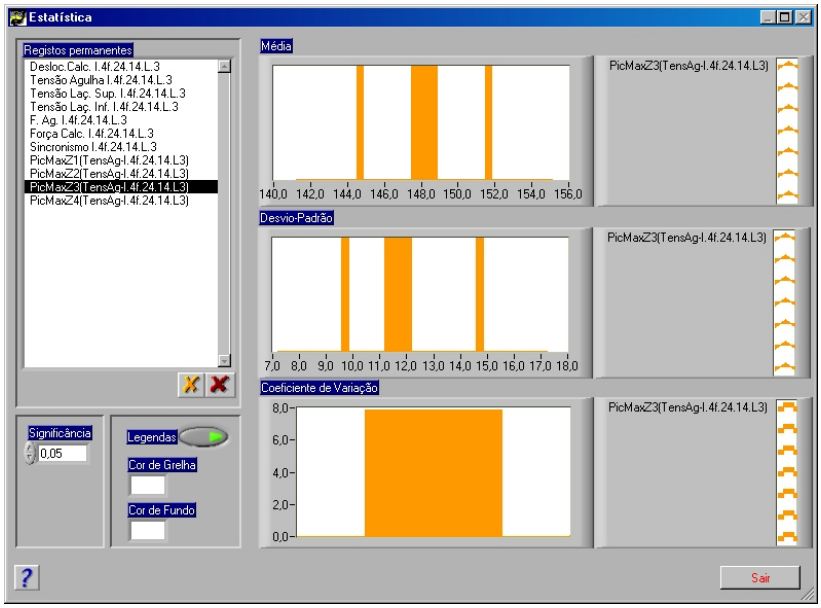


Figure III- 13: Statistical analysis panel

A brief explanation of the statistical parameters, its application possibilities and the underlying calculation methods is given in the following sections.

5.6.1. Mean with confidence interval

The mean of a data set with a representation of its confidence interval is a useful tool for comparing data sets through hypothesis testing.

The mean and confidence interval of the selected data sets (*population samples*) are displayed in a bar diagram, in which a thick vertical bar is plotted on the average of the sample and thinner vertical bars are plotted on the limits of its confidence interval (Figure III- 14).

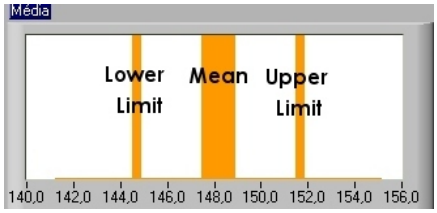


Figure III- 14: Representation of confidence interval for the mean of a data set

A normal distribution is assumed for the data sets.

The confidence interval is the interval of values in which, with the probability (1-*p*), the real mean of the population can be found. The parameter *p* is known as *confidence level*.

If confidence intervals of two data sets intersect, they are considered to be statistically equal for the defined confidence level, if they have equal variance. The computation of standard deviation and its confidence interval is also provided and can be used to test the variance of the samples. It will be analysed in the next section.

The mean of a population sample, $\bar{x}_s$ is computed as

$$\bar{x}_s = \frac{1}{N}\sum_{i=1}^{N} x(i) \tag{6}$$

with

x(i): population sample *i*

N: size of population sample- degrees of freedom

To compute the confidence interval of the mean, the inverse one-tailed *t*-distribution is used.

For a confidence level of *p*, the population mean, $\bar{x}_{pop}$, lies in the interval [8]:

$$\bar{x}_s - t_{1-\frac{p}{2}}(\nu)\cdot\frac{\sigma_s}{\sqrt{N}} \le \bar{x}_{pop} \le \bar{x}_s + t_{1-\frac{p}{2}}(\nu)\cdot\frac{\sigma_s}{\sqrt{N}} \tag{7}$$

with

$$\nu = N - 1$$

degrees of freedom, and the standard deviation σ_s computed for the sample (*N*-1 degrees of freedom):

$$\sigma_s = \sqrt{\frac{\sum_{i=1}^{N}\left(x(i)-\bar{x}\right)^2}{N-1}} \tag{8}$$

5.6.2. Standard deviation with confidence interval

The standard deviation gives a measure of dispersion of the individual observations around the mean value of the population sample. This is expected to be very important to characterise the regularity of certain sewing parameters. High dispersion of values may indicate fault situations in some measurements.

The confidence interval for the standard deviation can be used to compare data sets in the same way as described for the mean value. Furthermore, it can be used to validate the condition of equal variance put upon the hypothesis testing of the sample means.

Standard deviation is computed by equation (8). The confidence interval is obtained using the χ^2 distribution [8]. The standard deviation of the population lies in the interval

$$\sqrt{\frac{\sum_{i=1}^{N}\left(x(i)-\bar{x}\right)^2}{\chi^2_{1-\frac{p}{2}}(\nu)}} \le \sigma_{pop} \le \sqrt{\frac{\sum_{i=1}^{N}\left(x(i)-\bar{x}\right)^2}{\chi^2_{\frac{p}{2}}(\nu)}} \tag{9}$$

with

$$\nu = N - 1$$

degrees of freedom and a confidence level of *p*.

The standard deviation and its confidence interval are displayed in the same graphical format as the mean.

5.6.3. Coefficient of variation

The coefficient of variation CV(%) is another measure of dispersion, computed as follows:

$$CV(\%) = \frac{\sigma}{\overline{x_s}} \cdot 100 \qquad (10)$$

It is displayed in a conventional bar graph, with the values plotted on the y-axis. This parameter is very useful, because it provides a measure of dispersion relative to the mean of the sample.

5.7. Display functions

Graphic display functions in the AST software have been extensively redesigned and restructured since its first versions. The need for this redesign has evolved from the new functionalities of the system, e.g. the measurement of thread consumption values and the new 2-D and 3-D graphs introduced. The addition of these functionalities significantly increased the amount and complexity of display functions, and a constant streamlining of the display function hierarchy has been necessary.

The phase processing algorithms created for sewing signal processing have the attribute of delivering multiple feature values for each stitch cycle. The result of this processing is a set of arrays in which each array contains the feature computed in a specific moment (phase) of the stitch cycle.

In the course of the work undertaken with this tool, the idea for 2 and 3-dimensional display appeared. Instead of showing the sequence of each of the phases separately, a single plot could be created in which 2 or 3 phases would be represented simultaneously, by using them as coordinates for a point. This would allow the observation of patterns and clustering behaviour when displaying multiple stitches.

The first of the n-dimensional graphing utilities created allowed the generation of 2-dimensional graphs and was called “X-Y Graph Panel”. Many studies were conducted with this graphing method, of which the observation of presser-foot displacement behaviour is possibly the best example to illustrate its benefit.

Figure III- 15 shows two stitch cycles of the presser-foot displacement in a low and in a high-speed situation.

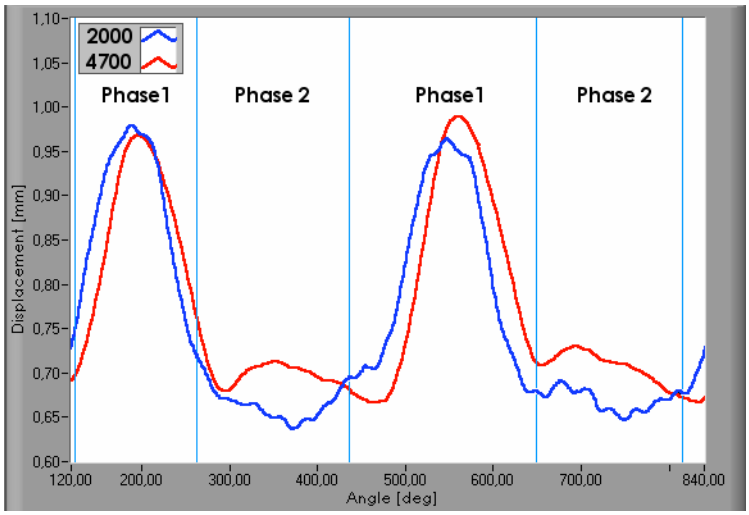


Figure III- 15: Presser-foot displacement at 2000 (blue) and 4700 spm (red), two stitch cycles [mm]

The phase definition clearly distinguishes two stages of the presser-foot movement: The material feeding stage (marked with phase 1) and the stitch formation stage (phase 2). During the stitch formation phase, the feed-dog remains underneath the stitch plate, and the presser-foot holds the fabric for stitch formation. As can be observed in Figure III- 15, at high speeds the presser-foot has the tendency to "bounce" in phase 2, failing to maintain a constant contact with the fabric.

Furthermore, the presser-foot has the tendency to "overshoot" in phase 1, meaning that it is pushed too high and looses contact.

To observe both effects in one graph, a set of acquisitions is processed and the peak values of presser-foot displacement in phases 1 and 2 are computed. Figure III- 16 shows the 2-dimensional representation of the peak values, in which the described behaviour can be observed very clearly.

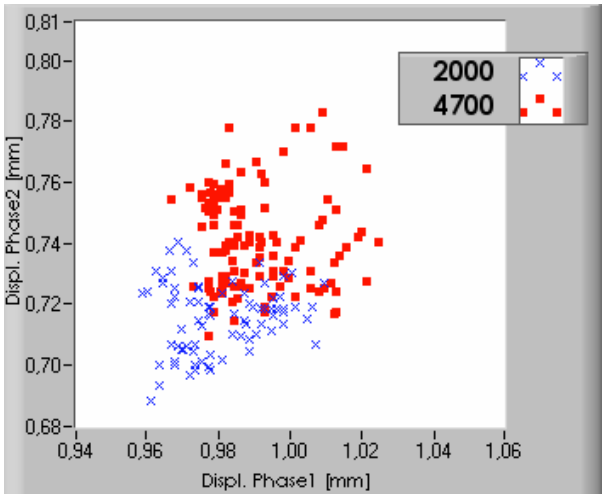


Figure III- 16: Example of X-Y graph - Peak in phase 1 (x-axis) versus peak in phase 2 (y-axis) for two sewing speeds

Similarly, 3-D graphs supply a representation of 3 features for a stitch. The thought of creating a 3-D graph resulted from the analysis of the needle-bar force signals. After pre-processing of these signals (refer to 5.5.2), three events are distinguishable:

1. First contact of the needle tip with the fabric;
2. Actual penetration of the needle;
3. Withdrawal of the needle.

Needle penetration analysis will be thoroughly studied in a later chapter of this thesis. To demonstrate the 3-D graph panel, an example based on this kind of data is presented.

In this example, a denim fabric was stitched with two needles of different diameter (0,7 and 0,9 mm). The maximum values of the forces present in the three phases described previously were measured on the pre-processed signals. The 3-D graph tools allow the generation of a 3-D graph as shown in Figure III- 17.

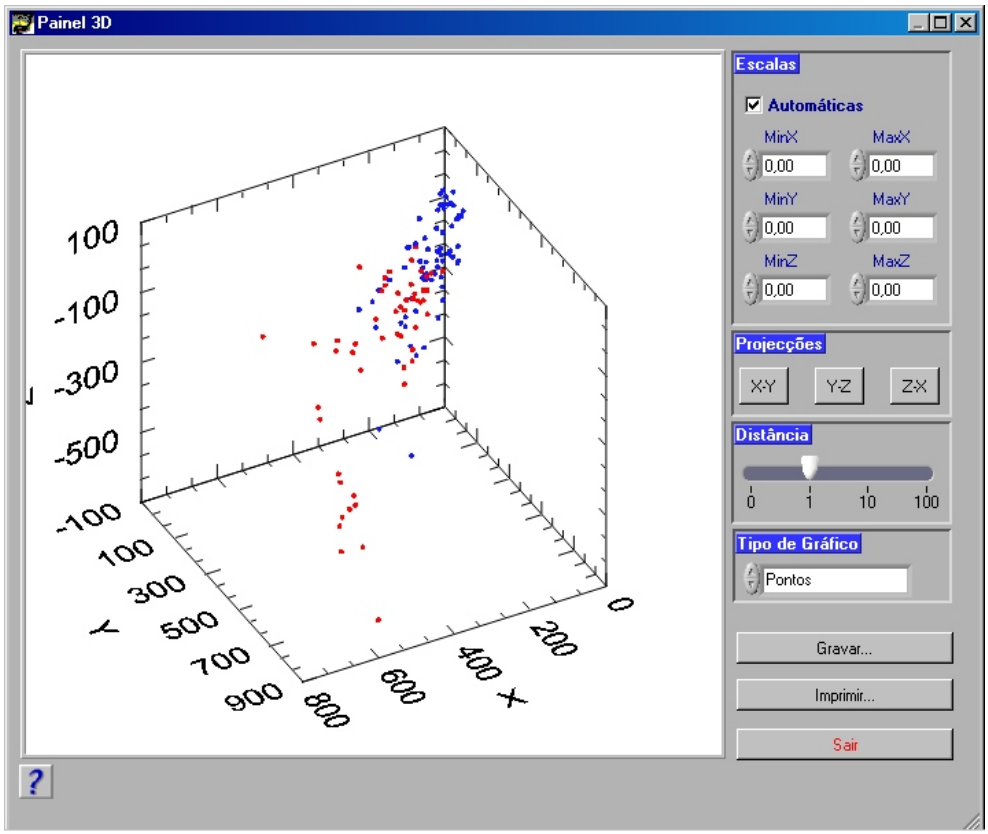


Figure III- 17: 3-D Graph Panel showing feature values for needle penetration with 70 (blue) and 90 needle (red)

The graph shown in Figure III- 17 evidences the clustering of points obtained for each needle. Although not completely clear in this static representation, in practical use the 3-D graph can be rotated by the user, 2-D projections of the graph can be generated, and the viewing distance is adjustable. This functionality allows a clear analysis of the data.

5.8. File I/O

File I/O has evolved to accompany the development of other functions in the program.

The addition of new devices and functions implied changes of the signal and configuration data structures, as described in this document. Each one of these modifications has been complemented with the corresponding adjustments of the data format written to files. Backward compatibility has always been ensured, meaning that files created with earlier versions of the program can always be read.

Besides this incremental evolution of data formats, a major change has been operated on the physical file format used. In the first versions of AST, text files were used for all data files. The intention was to make the files compatible with other programs, in order to ease the export and import of data.

A new format has been adopted, in which the signal data structures are written directly to binary files. This eliminates the time-costly conversion of numbers from and to the text representation, and eliminates some overhead. The result has been a reduction in file size of about 30%, and a remarkably faster data transfer to and from the disk.

The former file I/O subroutines have been kept in the software. Data import and export are still possible and very often used for analysis or presentation purposes. Also, a small utility has been created to perform a batch conversion of old files to the new format.

5.9. User Interface

5.9.1. Improvements of general nature

Many modifications on the user interface have been operated since the first versions of the AST software. Whilst many of them are of purely aesthetical nature, others incorporate some new solutions and also a constant approach to the standard Windows environment.

Labview was designed for measurement and automation applications. The tools provided for user interface design result in a different appearance when compared to standard Microsoft Windows applications. Labview is also a multi-platform application, being available for other operating systems such as Linux, Unix and Macintosh. The objects in Labview, though, are in most cases common and are naturally not matched to the design of a specific platform.

Nevertheless, Labview has evolved very positively in providing some elements of the Windows interface that were lacking in its older versions, besides having redesigned all the controls and indicators in its most recent version. The AST program accompanied this development, adopting the new controls and features that were being provided by Labview. Examples of these are the native Windows menubar (Figure III- 18) and the tab controls (Figure III- 19), which did not exist in the first version of Labview.



Figure III- 18: Standard Windows menubar



Figure III- 19: Tab control, allowing grouping and simultaneous display of related controls

The AST program has also been totally redesigned with the new controls and indicators of Labview version 6, that have an appealing 3-D look. Figure III- 20 and Figure III- 21 show a comparison of the AST's oscilloscope panel in versions 1.2 and 3.0 of the AST software. The oscilloscope panel is perhaps the best example to illustrate the difference in appearance from earlier versions.

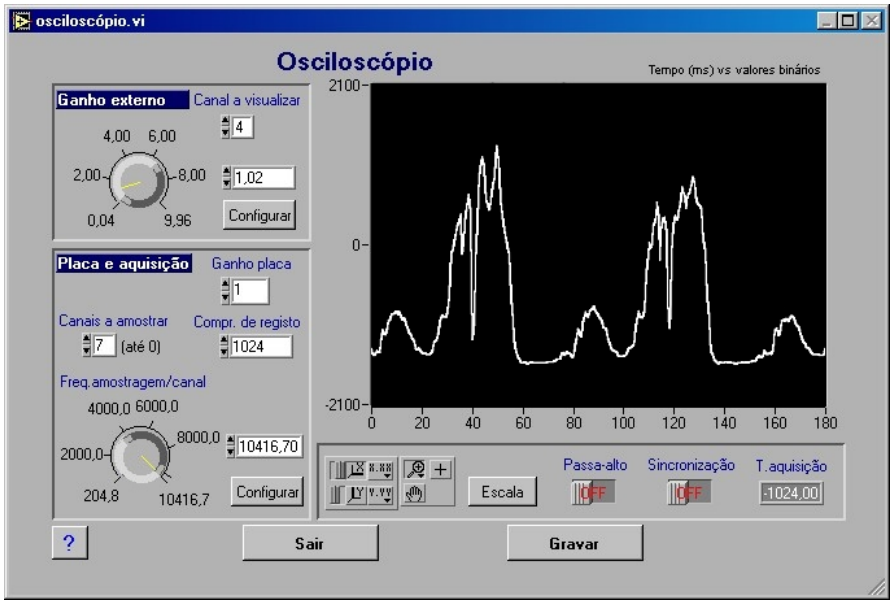


Figure III- 20: Oscilloscope panel in version 1.2a

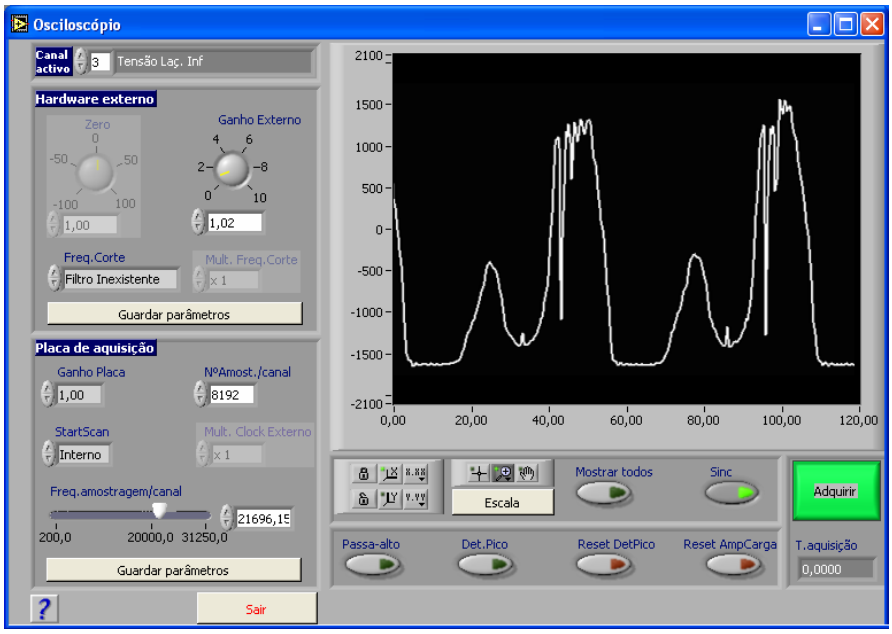


Figure III- 21: Oscilloscope panel in version 3.2: Besides the new 3-D controls, other features have been added

5.9.2. Data manipulation and analysis: An approach to exploratory data analysis

The AST software and the way it has been used have always approached *exploratory data analysis* methods [9]. This type of analysis, in which visual, interactive analysis of the data is preferred to traditional statistical treatment, is most useful in the early stages of investigation, before the phenomenon being studied is well understood [9]. This is exactly the framework in which the program has been developed.

All of the signal processing and data visualization tools previously described fit into this philosophy. Some additional enhancements have been introduced to help in the manipulation and identification of data sets and their interrelations, a very important aspect of exploratory data analysis.

Signal selection and manipulation has been greatly simplified with new controls and selection modes. The first and most important improvement, introduced very early (version 2.0), was the replacement of the “signal register” control used in the first versions. Figure III- 22 shows this control and the new version with standard listboxes that took its place.

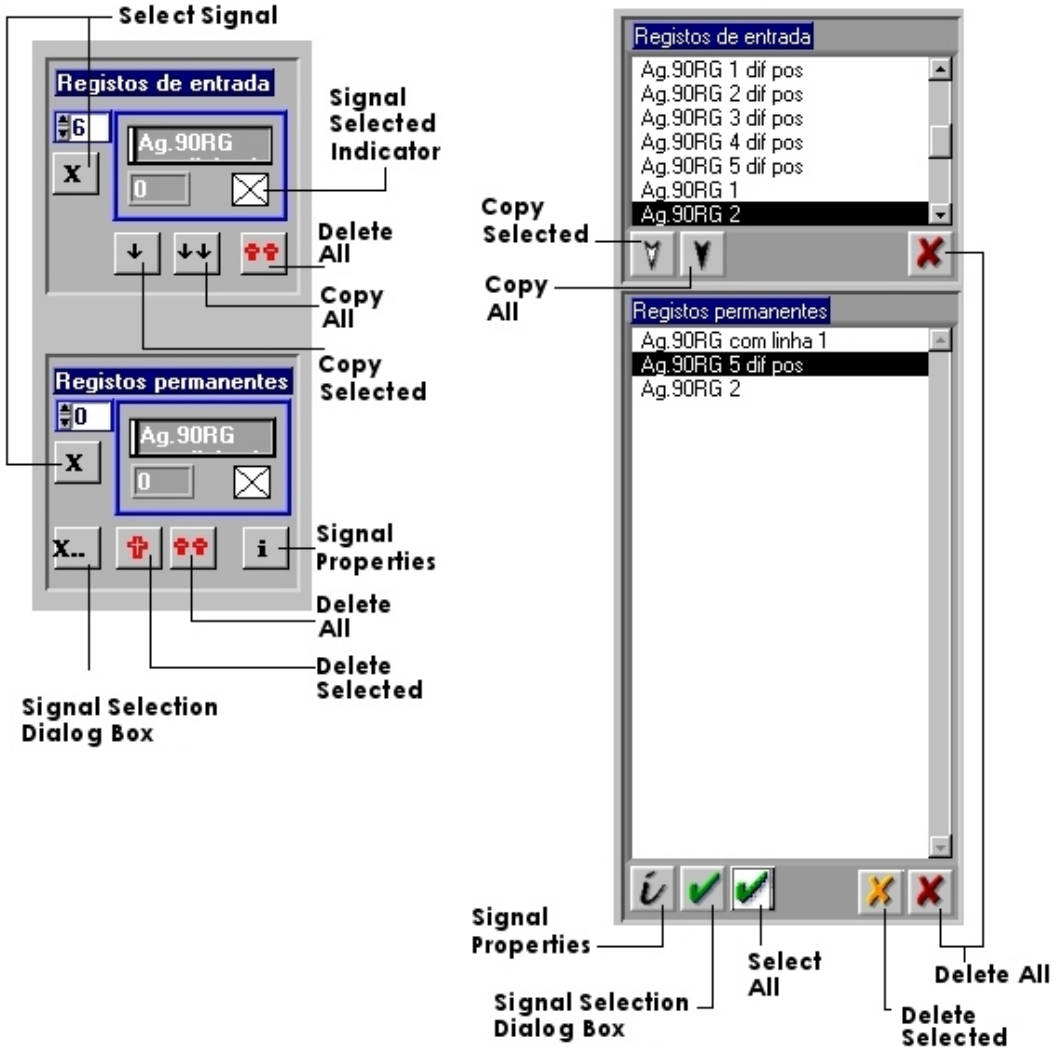


Figure III- 22: Signal control registers in the first and later versions of the AST application

These signal register controls are used to select signals for display or processing tasks. The input register receives all the signals or data sets read from a file or acquired by the acquisition board. The input register only exists in the AST's main window. The user selects signals to be copied into the permanent signal register, where they are accessible to other panels, namely those that fulfil processing tasks.

As can be seen, the use of listboxes allows a clearer view of the contents of the registers. Moreover, the signals are selected directly on the listbox, making it much easier to select and unselect multiple signals. Other tools have also been added to ease the selection and manipulation of signal records.

A further aid to the identification and analysis of signals are signal colouring and naming.

As of version 3.0, all signals are assigned by the user a colour at acquisition time. All data sets resulting from processing of these signals will be assigned the same colour. In this way, it is possible to differentiate signals and data sets belonging to the same experiment.

The naming convention for the signals or data sets is also important. At acquisition time, a name is assigned to each signal. This name is composed by

- The channel name from which the signal was acquired;
- An optional string introduced by the user;
- An optional automatic acquisition number.

Whenever a processing operation is performed on the signal, the signal name is updated in the resulting data set to reflect it.

The features described are still a modest approach to exploratory data analysis, but have revealed very effective in practice.

6. Work under development

Currently a new version of the sewing test rig, for application on a last-generation Pfaff lockstitch machine, is under development.

The new test rig is an opportunity for a redesign of the system, aiming to increase functionality even more.

The first major change is the new PCI-MIO-16E-1 acquisition board, which is far more powerful and flexible than the currently used boards. It samples at a far higher rate (1.25MS/s) that allows the implementation of a completely new acquisition mode. In this acquisition mode, the sample frequency is variable, tracked by the machine's operating speed. An output signal of the machine's motor delivers 256 or 512 pulses per motor rotation. This signal is used to trigger signal sampling, which allows a fixed number of samples per stitch cycle. More importantly, an exact calculation of the angle scale for the acquired signals is possible, which eases many of the signal processing tasks related to sewing process analysis.

The next improvement was introduced in the acquisition procedure (see section 5.1.2). In the current versions of the software, a stitch countdown before the actual acquisition is performed by software. A delay between the end of the countdown and the actual beginning of the acquisition is present. It is only possible to estimate this delay, and it is thus not possible to draw an exact correspondence between the physical seam and the signals acquired. In the new version, a hardware counter of the acquisition board performs the stitch countdown and triggers the acquisition by hardware. This makes it possible to exactly mark the beginning of the signals on the sewn sample.

Finally, a completely new thread consumption module was developed. The new device is based on the PCI-6601 timer/counter board of National Instruments. This board has 4 32-bit counters and has several configuration modes. Hardware drivers have been developed to implement 4 thread consumption counters, fully integrated with the AST's acquisition sequence and including calibration and test functions. The new thread consumption measurement device is able to measure thread consumption on a stitch-by-stitch basis, unlike the current system that only measures thread consumption for a whole seam[1].

Prototypes for the hardware and software of this new system have been developed [10][11]. Sensor integration and hardware testing is currently in course.

[1] Because of the discontinuous way the thread is pulled by the sewing machine, an accurate stitch-by-stitch measurement is not expected possible, but resolution might be significantly improved.

7. References

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