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1. The sewing test rig

1.1. General Description

The sewing test rig set up by Rocha in 1996 [1] was composed of

- A three-thread, differential bottom-feed overlock machine;
- Sensor set-up for thread tension measurement;
- Sensor set-up for presser foot compression force;
- Basic signal conditioning hardware;
- A PC with a data acquisition board (National Instruments Lab-PC+);
- A basic MSDOS based software package with acquisition, display and file I/O functions.

In its MSc thesis[2], the author improved the accuracy, reliability, ease of use and functionality of the test rig. The test rig’s structure after this redesign is shown in Figure 1.

![Diagram of the sewing test rig](image)

Figure 1: Structure of the sewing test rig (1998)

In the next two sections a brief enlightenment of the achieved state of development regarding hardware and software will be given (version 1.2 of the system). This is the starting point for the work that is now being presented.
1.2 Hardware

At the beginning of this work several major improvements had been introduced on the sewing rig’s hardware. A detailed analysis of these is given in [2]. This section will only cover the most important features.

1.2.1. Sensors

The sensor set-up for presser foot and needle-bar force, developed by Rocha[1], has not been changed. It uses commercial piezoelectric sensors that are introduced in the presser foot and needle bars as shown by the following principle scheme:

Figure 2: Sensor set-up for needle and presser foot bar force measurement

This sensor set-up was considered satisfactory, although one inconvenience remained unsolved. The positioning of the sensor on the top of the needle-bar adds the acceleration forces of the whole needle-bar mass to the measurement, although only the interaction between the needle and the fabric is relevant to the objectives of the research undertaken. An alternative set-up has not been found for mechanical reasons, so that signal-processing tools have to separate the measured effects.

The choice of the sensor type has advantages and drawbacks. Piezoelectric sensors are excellent sensors for dynamic measurement, being probably the best devices in this regard. However, a piezoelectric sensor system is not able to measure static forces (see 1.2.2).

This is not a drawback for the measurement of needle penetration force (a purely dynamic signal) but it certainly is a disadvantage for measuring the static component of the presser foot force. Nevertheless, the measured dynamic component of this force has led to relevant results.

Figure 3 shows a picture of the sewing machine with the piezoelectric sensors. Only the presser foot force sensor is visible, since the needle-bar is concealed within the sewing machine.
A major improvement was made on the thread tension sensors. Although used throughout this text, it is not precise to say that these sensors measure thread tensions, as they actually measure forces; tensions would have to be computed relating the force to the thread’s cross-sectional area. However, the term tension will be maintained, since it is commonly used to describe all subjects related to thread tensioning.

Thread tensions are sensed using strain gauge based transducers. The design of the first sensors used, although adequate for a first study, possessed several shortcomings. Figure 4 shows the design.

![Figure 4: Former thread tensions sensors](image)

The threads were passed around the tip of the sensor. Forces applied on the thread during stitch formation were thus transmitted to the cantilever bar at its tip and the strain produced on the base of the bar was picked up by two strain gauges in a half-bridge configuration.

These sensors used conventional strain gauges. In order to maximize sensor sensitivity, the length of the cantilever bar had to be maximized and its thickness minimized, which impaired the sensors dynamic response. In fact, neither the higher frequency response, neither the damping was satisfactory: the output signals revealed oscillations upon quick force variations.

Other drawbacks included the inexistence of a thread guide at the tip and the slightly plastic behaviour of the aluminium used for the cantilever, resulting in significant zero drift.
A close study of the requirements for thread tension sensors resulted in a custom-made thread tension sensor by Petr Skop (Czech Republic). These new sensors, shown in Figure 5, have successfully replaced the former ones, exhibiting very satisfactory properties in all of the above-mentioned aspects. They use high-sensitivity semiconductor strain gauges that allow the mechanical design of the cantilever bar to be optimised for dynamic response. A thread guide is provided at the tip.

![Figure 5: Thread tension sensor by Petr Skop](image)

### 1.2.2. Conditioning hardware

Conditioning hardware for the piezoelectric and strain-gauge based sensors, as well as for a digital signal providing a synchronism to the acquisition (to be analysed later on), was totally redesigned by Andrade and the author [2][3]. Two signal conditioning boards were developed.

The first board, designated as piezoelectric type, features two channels for piezoelectric sensors and a CMOS to TTL conversion with isolation for a digital signal from the machine’s motor. Figure 6 shows a simplified block diagram of this board.

![Figure 6: Piezoelectric Type conditioning board](image)

Annex B
Piezoelectric signal conditioning was based on a charge amplifier. Charge amplifiers can provide quasi-static measurements under certain conditions\([2][3]\). However, a zero force reference has to be provided to the conditioning system upon power-up of the hardware. Taking into account that the force sensor positioned in the presser-foot bar is under constant stress, a method for releasing the stress to the sensor was needed. Due to practical reasons, such a method was not achieved, quasi-static measurement was thus abandoned, and the system was designed seeking an optimal frequency response in the relevant dynamic frequency range. This also contributed to avoid the delicate problems of zero drift involved with quasi-static measurements.

Being unable to obtain static measurements posed some questions concerning the calibration of the measurement system. To enable the user to perform a static calibration of the system, peak detectors were built into each of the outputs. The user can therefore apply a static force on the sensor and still measure the response of the system at the output of the peak detector. Functions for resetting the output of the peak detector and of the charge amplifier, as well as for selection of the calibration mode, are software controllable.

The board communicates with the PC using the digital I/O ports of the data acquisition board. One of the ports serves as an addressing bus, addressing individual boards and functions within them. The other port serves as a data bus, carrying data that can be a gain setting or a state byte for the analog multiplexers that control several functions. Other functions built into the conditioning board include programmable gain for measurement range selection, using an MDAC\(^1\), and switchable high-pass filters that are used in the calibration process\([2]\).

The second board, designated as strain-gauge type, supplies 4 strain gauge conditioning channels, equipped with software controlled variable gain and a high-pass filter for calibration procedures. It uses a Burr-Brown INA 103 instrumentation amplifier as input stage for the conditioning chain.

Figure 7 shows the simplified block diagram for this board. It is possible to see that the software control scheme for the board’s functions is very similar to the one used before, but simpler, considering that the only switchable function available is the high-pass filter.

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\(^1\) MDAC: Multiplying Digital to Analog Converter
The excellence of both the INA 103 input amplifier as well as the sensor has resulted in an excellent performance of this board. Dynamic response, low noise and low zero-drift are its most evident qualities.

The piezoelectric conditioning board has also revealed to be an efficient performer. However, piezoelectric conditioning involves a more complex and delicate design. Low-frequency response, zero-drift and noise can still be fine-tuned in a later development. Nonetheless, its performance is very good for the defined objectives.

13. **Software - General description**

The development of a new software package has been perhaps the greatest investment made in the reshape of the system.

One of the most fundamental premises established for the development of the system is that of being modular and thus expandable. This was particularly important for the software, because many enhancements were expected to be added.

LabView was chosen as the development environment for this new program. This tool, produced by National Instruments, has been customized for the design of measurement and automation applications.

The resulting program surpassed the functionality of all of the services delivered by its predecessor (acquisition, display and file I/O), and added some other important tools. This allowed visual and mathematical analysis of the acquired signals to be done much more easily, replacing the flexible but sturdy standard spreadsheet program.

The new application had a standard Windows interface and delivered the following tools:

- Data acquisition;
- Powerful signal display;

Figure 7: Strain-gauge Type conditioning board
> File I/O;
> Sensor Calibration;
> Conditioning hardware driver, configuration and test modules;
> General purpose signal processing tools;
> A basis for process-specific signal processing algorithms.

The program defined signal records as its fundamental data structure.

A signal record is composed of the acquired signal and a collection (cluster) of properties concerning, among others, calibration, acquisition conditions and origin of the signal.

A signal record is obtained when the software is put into acquisition mode and a seam is produced on the machine. The acquisition is triggered by the synchronism signal, a signal that delivers a pulse per stitch at a pre-determined position of the machine’s shaft. After a signal record has been obtained, all of the display, analysis and file I/O functions are available within the software, that uses the signal properties to carry out a number of operations on and with the signals.

Signal records were stored in text files, easy to export to general-purpose analysis packages. This made it possible to try new signal processing tools and integrate them later in the program.

The concept followed in the design of the subroutine hierarchy and user interface improved the first version program with many more functions and ease of use. Presented in the author’s MSc thesis as version 1.1, it has undergone several modifications translated in versions 1.2a to 1.2e and 2.0 to 2.9. Its current version is 3.2.

The application was called Advanced Sewability Tester (AST) by one of the team members [Silva]. At that time, it was just an acquisition and general-purpose analysis tool, but the name revealed the project of refining and creating tools for real sewability testing.

The next sections present a brief outline of the most important functionalities of the first version of the program, which represents the starting point for this work.
1.3.1. Main panel

The main panel is the starting point in AST. It gives access to all functions of the software and provides a large graph for immediate display of signals after acquisition or file read. The graph possesses various auxiliary tools like zooming, locked cursors and auto-scaling that allow a very efficient visual analysis of the signals.¹

Two menus, for general and graphing functions allow the user to perform several operations. A scale selection chooses angle, time or frequency for the x-scale of the graph.

At the left side the registers for signal records are located. They allow the selection and deletion of individual records. All signals read from files or obtained by acquisition are loaded into the input register. They can then be copied into the permanent register, be worked on and saved into files.

1.3.2. Acquisition dialog box

The acquisition dialog box (Figure 9) appears when the system is put into acquisition mode. A numerical countdown indicator performs a configurable stitch count before acquisition triggering is enabled. This allows the machine to attain its final sewing speed.

Acquisition is then hardware-triggered by a synchronism signal, provided by the motor. When the final number of samples is acquired, the signal records will be

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¹ These are standard LabView functionalities and were not developed by the author.
loaded into the input register. Each record is given a name that is concatenated from the channel name (configurable) and the name input as test name in the acquisition dialog box.

Acquisition is always performed at constant sewing speed. Considering that sample frequency is fixed, speed variations would distort the angle scale and thus make it impossible to find references to the events in the stitch cycle.

Figure 9: Acquisition mode dialog box

1.3.3. Calibration panel

Figure 10: Sensor calibration panel
The calibration panel is used for sensor calibration. It is specifically designed to meet the appropriate calibration methods for the signal conditioning hardware used[2].

Calibration parameters are stored in the AST's configuration file. They are calculated by linear regression over a set of known inputs and resultant output values. A normalization procedure delivers gain-independent parameters, so that acquired signals can later be correctly scaled even if gain settings have been changed.

1.3.4. Oscilloscope panel

![Oscilloscope panel](image)

Figure 11: The oscilloscope panel

This panel offers the possibility of displaying signals in real-time, making it easier to adjust acquisition and hardware settings like sample frequency, acquisition length and hardware gains. It is also useful to test the hardware in all its functions (for example peak detectors and high-pass filters).
1.3.5. The analysis panel

Figure 12: The signal analysis panel.

The analysis panel is one of the most important and innovating tools created for the sewing test rig.

It included standard signal processing tools like DFT/FFT-processing with several time windows and various digital filters, that would later reveal very important for certain signal evaluations.

It also introduced the concept of stitch cycle phases, a process-specific analysis method. In this method, an angle scale is calculated for the signal and phases of the stitch cycle are defined. These phases are related to events that occur during the cycle. A subset of the signal can then be retrieved and analysed.

Version 1.1 only included functions for peak detection during these phases. Results were delivered in text tables that could be exported to a file compatible with spreadsheet programs and other applications.

Besides these tools, other miscellaneous functions were included in the analysis panel.

1.4. Software – Data structures

In this section a brief description of the fundamental data structures created for the AST software will be given.

Many changes have been brought into these data structures in the progress of this work. A description of the initial definition of the structures will make it easier to describe the subsequent changes carried out.

A more detailed analysis of these data structures is given in[2].
### 1.4.1. System configuration

The configuration parameters for the AST software are divided into 3 groups, described by the following tables.

**Table 1: General configuration parameters**

<table>
<thead>
<tr>
<th><strong>Device Number</strong></th>
<th>Device Number used for acquisition board addressing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gain(Internal)</strong></td>
<td>Hardware gain of data acquisition board</td>
</tr>
<tr>
<td><strong>Working folder</strong></td>
<td>Default folder for file I/O</td>
</tr>
</tbody>
</table>

**Table 2: Acquisition configuration parameters**

<table>
<thead>
<tr>
<th><strong>Channels to sample</strong></th>
<th>Channel list for acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Desired sample frequency</strong></td>
<td>User-chosen sample frequency</td>
</tr>
<tr>
<td><strong>Adjusted sample frequency</strong></td>
<td>Correction of desired frequency to meet board’s internal timer resolution</td>
</tr>
<tr>
<td><strong>Record length</strong></td>
<td>Number of samples acquired per channel</td>
</tr>
<tr>
<td><strong>Acquisition preparation</strong></td>
<td>Method for acquisition preparation: Time or stitch countdown</td>
</tr>
<tr>
<td><strong>Acquisition timeout</strong></td>
<td>Timeout value for acquisition triggering</td>
</tr>
</tbody>
</table>

The analog channel configuration is a cluster inserted into an array. Each element of this array corresponds to one analog input channel of the data acquisition board.

**Table 3: Analog channel configuration parameters**

<table>
<thead>
<tr>
<th><strong>Name</strong></th>
<th><strong>AST internal channel name</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>Slope of calibration line (gain of the measurement chain), independent of gain settings</td>
</tr>
<tr>
<td>b</td>
<td>Total offset value of measurement chain, independent of gain settings</td>
</tr>
<tr>
<td><strong>External zero</strong></td>
<td>Part of total offset resulting from voltage sum at offset adjustment block</td>
</tr>
<tr>
<td><strong>Board</strong></td>
<td>Address of conditioning board</td>
</tr>
<tr>
<td><strong>Output</strong></td>
<td>Output channel of conditioning board</td>
</tr>
</tbody>
</table>
Analog channel configuration parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>External gain</td>
<td>Gain adjustment on signal conditioning board</td>
</tr>
<tr>
<td>Channel type</td>
<td>Type of conditioning channel connected to the analog input</td>
</tr>
</tbody>
</table>

1.4.2. Signal data structures

Signal records are kept in memory in two arrays, namely:
- Signal data;
- Signal properties.

The signal data for one record is an array with the acquired values, scaled to the unit of the measured variable. To hold several data records, the array is introduced into a cluster, and multiple clusters (multiple signals) are gathered in an array.

The data contained within the arrays may not directly originate from acquisition. It can be the result of calculation over the original signal.

A second data structure holds the signal properties. A cluster for each signal is formed, and multiple “property clusters” are gathered in an array. Each signal data cluster has an associated signal properties cluster.

The signal properties cluster is structured as shown in Table 4.

Table 4: Signal properties cluster

<table>
<thead>
<tr>
<th>Signal properties</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition date/time</td>
<td>Date and time of acquisition</td>
</tr>
<tr>
<td>Sewing speed</td>
<td>Average sewing speed during acquisition</td>
</tr>
<tr>
<td>Acquisition board gain</td>
<td>Acquisition board gain used in the acquisition</td>
</tr>
<tr>
<td>External gain</td>
<td>Gain of the conditioning channel used in the acquisition</td>
</tr>
<tr>
<td>Channel number</td>
<td>Index of acquired channel</td>
</tr>
<tr>
<td>Name</td>
<td>Signal name</td>
</tr>
<tr>
<td>Type</td>
<td>Signal type (time, power spectrum, amplitude spectrum, phase spectrum, derivative or discrete values)</td>
</tr>
<tr>
<td>Record length</td>
<td>Number of samples contained in the signal</td>
</tr>
</tbody>
</table>

3 A 2D-array (matrix) in Labview does not allow signal arrays (columns) to have different length. This is the reason for clustering the signal array and inserting them into a 1D-array.

4 An array of discrete values is the result of calculation over the original signal, for example peaks)
<table>
<thead>
<tr>
<th>Signal properties</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sample frequency</strong></td>
<td>Sample frequency used in the acquisition</td>
</tr>
<tr>
<td><strong>Window</strong></td>
<td>Type of time windowing function used for spectrum calculation</td>
</tr>
<tr>
<td><strong>m</strong></td>
<td>Gain of measurement chain</td>
</tr>
<tr>
<td><strong>b</strong></td>
<td>Total offset of measurement chain</td>
</tr>
<tr>
<td><strong>External zero</strong></td>
<td>Part of total offset resulting from voltage sum at offset adjustment block</td>
</tr>
</tbody>
</table>
2. References

