Automatic calibration with character recognition software

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Abstract. This work presents the development and implementation of a character recognition software of digital displays with serial communication for the automation of the readings, registry and transcription of measurement instrument's indications during calibrations. The software proved to be flexible, allowing calibrations with automatic registry, reducing transcription errors, improving the work conditions and organizing the registers, besides allow remote calibrations.

Keywords. Automation; character recognition; software; data acquisition; calibration.

1. Introduction
The constant need for calibration and measurement processes growth, particularly agility, productivity and efficiency, motivate the improvement and innovation of the various activities of the laboratories. In this sense, the automation of calibration processes plays a fundamental role, since it allows obtaining more reliable results with less variability and does not require the full attention of the employee to record the instrument indications, allowing him to perform other activities.

In a typical calibration process, the skilled technician is responsible for assembling the equipment and collecting the results in each of the measurement cycles. In more specific cases such as thermohygrometer calibration [1], which require long times for stabilization of the involved systems and instruments, it demands technician dedication up to 16 hours, depending on the range and calibration points, and limiting calibration to business hours. In addition, errors in manual data transcription during calibration pose a risk to the reliability of the results. When they are detected, it is very difficult to determine the correct value it forces the technician to perform new measurements, implying rework.

One of the main difficulties in the development of an automatic data collection system is the wide variety of measuring instruments available on the market. Most of them do not have an open communication interface that allows automatic readings of the indications. For these reasons the Mechanical Metrology Laboratory of the Institute of Technological Research of São Paulo, is committed to the automation of its calibration processes and began its work developing software for automatic acquisition, either by recognition of the numbers presented in the instrument indicators or by serial communication.

2. State of the art
There have been several papers published since 1988 addressing methods and systems for automation not only of calibrations but also of laboratory activities in general, such as Ringeard [2] and Kruh [3]. However, these developments only automated instrument calibrations that already had some form of digital communication.

In 1994 came the work of Sablatnig [4] showing techniques of image processing. This was a development specifically for analog instrument pointer recognition. Subsequently, from the year 2000, works on digital dial image recognition techniques, such as the works of Alegria [5 and 6], Donciu [7] and Andria [8] began.
Automation and image recognition techniques are widespread today, as the works cited above. In this sense, the work proposed here goes beyond these, it covers a wide range of measurement instruments and deals with digit recognition algorithms, from the development phase to the implementation of the most important software for error identification and repair.

3. Development
Initially the software was developed using the LabVIEW programming language [9]. In this version, the program was developed for calibration exclusively of thermohygrometers and was limited to capturing and recording the indications through a camera that focused the dial of the instrument in calibration.

Figure 1 shows the mounting scheme for the first software application.

![Figure 1 - Assembly diagram for the first software application.](image)

The climate chamber was controlled by the manufacturer's software. Temperature and relative humidity levels were previously configured, regardless of the acquisition software. The reference data were collected through digital communication via Modbus protocol. Until this time in development, the program communicated with only one instrument. Each instrument addition would require a new software revision.

The process of analyzing the results was somewhat lengthy as the software recorded several recognized photos and values and not just the discrete points required for calibration. This problem has been remedied by establishing tolerances on the variability of results for recognition of stabilization levels during calibration and automatic transmission of such discrete points to the calibration results calculation software.

Due to technical and commercial limitations, the second version was developed with the Python programming language and the OpenCV library [10].

In this version, the form of collection through digital communication via RS-232 and GPIB protocols was included so that the user interactively could register the communication parameters, without the need for software revision.

In addition, to facilitate the visualization of results, they start to be recorded in a spreadsheet in the software itself. This spreadsheet was design so that automatic or manual transfer to the software used to generate the calibration certificate was easily possible.
In this release a new algorithm for character recognition has been introduced. This technique uses digits previously trained by the user to compare with digits to be recognized. Figures 2 and 3 show respectively, common Arial and Italic Arial font digits being compared with the trained digit in a common Arial font showing the difference between one font and another.

So that the software could meet the widest possible range of services offered by the laboratory, this second version was structured to meet various forms and calibration methods. The user defines between the instruments (customer or laboratory standard) which will be monitored and which will monitor, and the way of automatic acquisition of results; can be at established levels, automatic command (sent by the generator, the standard or the instrument itself) and continuous recording.

In exceptional cases where recognition is not possible (currently in cases such as analog instruments), recording can still be done only by photos, without recognition, and the operator will need to type the results later in the software spreadsheet.

Finally, it was implemented the possibility of installing cameras working simultaneously to meet the demand of instrument calibrations that require two or more readings at the same time.

4. Deployment
As described by Chan [11] there is often strong resistance to deploying automated systems. In order to reduce such resistance, the deployment process sought to involve several users by opening possibilities for software improvements and bug fixes.

During this phase, users monitored the evolution of calibration in full time, in order to compare and evaluate 100% of the collected results. The software was implemented simultaneously for calibrations in Temperature, Humidity, Force and Torque. Figures 4 and 5 show an example of a system assembly for load cell calibration.

Figure 2 - Example of Arial Font Recognition Compared to a Trained Arial Font
Figure 3 - Example of Italic Arial Font Recognition Compared to a Trained Arial Font

Figure 4 - Load Cell Calibration System Assembly
Figure 5 - Camera detail for indicator digit recognition
Since then, several revisions were needed improving design, reading reliability, user interface and user experience among other things.

One such review, drawn from user experience, has improved the 7-segment digit recognition process, the most common types of digital indicators.

It was noted that the digit training technique used implied the need for every indicator to undergo specific training as the shape and aspect ratio of its digits could differ from the previously trained digit. This step caused unnecessary complications and delays in the process.

For this reason an algorithm has been developed to identify this type of digit by means of a 5x3 matrix. This algorithm identified the lit segments in each element of the matrix, as shown in Figure 6.

![Figure 6 - Example of 7 segment font recognition by matrix method](image)

Another review proved the necessity of mitigating the chances of occasional misrecognition by the software. An algorithm for automatic recognition of punctuation and signs (points, commas and negative sign) has been programmed and two possibilities for choosing the region of interest, single or individual selection as shown in Figures 7 and 8, have been inserted. These possibilities allow the user to choose best option for automatic application of filters [12]. This review included the dilate and corrode technique [13] that minimize noise and dilate digits, often important, to increase recognition efficiency by joining digits with widely spaced segments.

![Figure 7 - Example of uniquely selecting the region of interest](image)

![Figure 8 - Example of selecting the region of interest individually](image)

Finally, an important revision was put in use for the traceability of the collected data. In order to mitigate data loss due to communication failure with the laboratory server, the software started to have redundancy of the records. The record is saved in a folder on the user's computer and in another folder on the lab server. In addition, all numeric and photographic records are stored, even when a calibration is performed again. Previous data is saved in a backup folder.
In addition, it was also difficult to trace the causes of misrecognition and to relate each result to its respective photo.

For this reason, the photos are now related in the software itself to their result. A color standard has also been introduced that relates the reading accuracy level and the type of acquisition identification (manual, camera, RS-232 etc.). Figure 9 shows the software spreadsheet with four results and their respective colors and the photo of one of the results.

![Spreadsheet and photo in software with color pattern](image)

The reading accuracy level is defined as the degree of similarity between the trained digit and the read digit, as can be seen in Figures 2 and 3.

5. Validation

For software validation, results were collected automatically and manually and both values were compared with the photos taken by the software. Initially it was found faults in the recognition of digits of 7 segments. After analyzing the recognition methods, it was concluded that the matrix method was not the most appropriate since the same lit segment could be in more than one element of the matrix, especially when the digit was slightly inclined (italic).

Then a new revision was elaborated implementing the line recognition method as shown in Figure 10. This method uses only one vertical and two horizontal lines to evaluate the lit segments. In this way recognition becomes more reliable as it would take a too slanted digit to distort the result.

![Example of 7-segment font recognition by line method](image)
Another problem presented in the validation was the speed of recognition by the software. As the registration and recognition took place with the image of just a moment, several times the reading was performed in the digit transition, causing errors in the recognition. The problem was solved using the mode of 10 values collected.

6. Results
With all algorithms and revisions in place, validation achieved a 100% accuracy level out of 274 data collected. Table 1 shows some results of the various validations performed.

| Photos | Log   | Manual Registry |
|--------|-------|-----------------|
| 901.2  | 901.2 | 901.2           |
| 1200.2 | 1200.2| 1200.2          |
| 240.03 | 240.03| 240.03          |
| 179.82 | 179.82| 179.82          |
| 06.130 | 06.130| 06.130          |
| 00.000 | 00.000| 00.000          |
| 48.11  | 48.11 | 48.11           |
| 24.12  | 24.12 | 24.12           |

For applied case studies, during the beginning of the software use, the results obtained in random calibrations were evaluated. The success level of each study is given in Table 2.

| Study | Readings | Success | Errors | Errors (%) | Photo         |
|-------|----------|---------|--------|------------|---------------|
| 1     | 750      | 710     | 40     | 5.33       |               |
| 2     | 25       | 25      | 0      | 0.00       | -60.18 -60.18 |
| 3     | 33       | 31      | 2      | 6.06       | 7996079620    |
| 4     | 82       | 82      | 0      | 0.00       | 0.15997       |
| 5     | 24       | 24      | 0      | 0.00       | 009200992     |
| 6     | 34       | 34      | 0      | 0.00       | 1414604146    |
| 7     | 32       | 32      | 0      | 0.00       | 12.05         |
Each recognition error has been evaluated to analyze possibilities for improvements. In this analysis, some limitations on digit recognition were noted, such as camera resolution (for small digit indicators) and difficulties due to not using software resources. In the first case study, errors were due to the small size of the indicator digit. Even using the camera at its best resolution, the number 4 was confused with the digit next to it, as shown in Figure 11.

![Figure 11 - Error reading due to digit size](image)

In the third case study, errors were caused due to the individual selection of the region of interest. This was reflected in the incorrect reading of erased digits that had a different light intensity from the display background, as shown in Figure 12. If the single region of interest selection method had been chosen, the filter would be applied to the full display region and the deleted digits would be correctly recognized as an "empty" field.

![Figure 12 - Reading error due to light intensity of deleted digits](image)

In the studies performed and mentioned in Table 2, the recognition accuracy level was around 96%. Except for punctual errors, the level of accuracy obtained was 100% of the collected results, coinciding with the levels presented in the validation.

In addition to the high reliability shown in digit recognition, as a result of this work, a significant improvement in service flow has also been noted, allowing for shorter calibration times, as the technician can anticipate other activities during the recording period, as well as possibility of out-of-work calibration.

7. Future work
The next steps in the project involve expanding the use of analog indicator pointer recognition software.

In addition, the proposal is for software to be an integral part of a larger automation system. A system that works 100% autonomously.

Finally, the automation process needs improvements in support and facilitation steps in system assembly. Therefore, the next steps also involve improvements in the data transfer process for the issuance of the calibration certificate and the construction of devices that facilitate assembly and minimize the difficulties related to saturate lighting in the displays.

8. Conclusions
The program met the initial proposal with excellence and can be applied in various areas of laboratories. In addition, image recognition can be used across industry sectors for control and monitoring automation, further consolidating “industry 4.0” into processes.

By applying the software in the calibration process, it was possible to verify an increase in the number of calibrations without the need for labor increase, reduction of transcription errors of results, improvement in working conditions, possibility of simultaneous calibrations and performing calibrations remotely.

Another improvement refers to the records of the results. With the records manually inserted in the calibration worksheet, it was sometimes difficult to trace the data obtained,
especially when calibration series needed to be redone. With the software all images are stored neatly, making it easy to identify the history and traceability of measurement records.

As negative points, we can mention the difficulty of automation of equipment with closed protocols and the fact that the system configuration process becomes more complex.

However, the advantages demonstrated the feasibility of applying the software in the calibration processes, allowing a huge reduction of time even with the greater complexity for the parameterization.

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