

A Machine Vision for Automatic Hydrometers Calibration

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ABSTRACT

Due to the changes imposed by Industry 4.0, the service market has also been changing, including metrological laboratories, where this adaptation is increasingly necessary. And this evolution has been called Metrology 4.0, where the automation of calibration processes is necessary, and with this these processes become more agile and less susceptible to human errors. The calibration of Hydrometers (glass densimeters) is a point of extreme importance for various sectors of industry and commerce, with this equipment it is possible to check the quality of products such as alcohol, petroleum derivatives, oils, milk among others. This project proposes the development of a device (including hardware and software) described as a computer vision machine (MVS) for automatic calibration of hydrometers by the Cuckow method using computer vision techniques. The results showed robustness and accuracy for the calibration task of glass densimeters by the proposed MVS and the other point to be highlighted is the measurement speed, where each measuring point took an average of 6 seconds to stabilize and final reading of the value.

Keywords

Cuckow, density, glass densimeter, computer vision, hydrometer.

1. INTRODUCTION

Common problems found in metrological laboratories include repeatability of the results obtained during calibration processes, the productivity of technicians and the high possibility of human errors [1–3]. In some cases, the result shown on an issued certificate may differ from that obtained in calibration due to errors in manual data transcription. This problem is usually caused by the fact that the technician running the calibration service is different from the one that issues the certificate. In addition, the accuracy of the measurement process can be significantly affected when the instrument or device to be calibrated has no data communication interface. In this case, the probability of human error increases greatly, due to the need for several readings and transcripts of data, which constitute a stressful task [1, 2, 4, 5].

Recent studies report that the service area is also undergoing the transformation of Industry 4.0. In this scenario, the automation of metrological processes could minimize the impacts for industries, being possible, even with the use of appropriate equipment, to perform the calibration processes of measuring instruments with the minimum possible handling [6].

In the last two decades, computer vision systems (CVS) have been proposed in the literature for calibration of analog and digital measuring instruments end up being only in the academic environment not becoming products with real practical applications [1, 2, 13–16, 4, 5, 7–12].

This project proposes the development of a device (hardware and software) described as Machine Vision System (MVS) for automatic calibration of hydrometers by the Cuckow [17–19] using computer vision techniques. Hydrometers have several applications in the industry, the most common being for measuring the density of alcohol, petroleum derivatives, oils, milk, among others based on the principle to measure the liquids density of Archimedes. The measurement of hydrometers is by suspending the device inside a liquid, thus the weight of the liquid displaced by the submerged part of the hydrometers is equivalent to the weight itself. Therefore, given a depth that the hydrometer is in the liquid, the density of the liquid, as well as its concentration, can be measured directly with a scale [20, 21].

The development of automatic calibration equipment, still meet the expectations of Industry 4.0. The so-called fourth industrial revolution or Industry 4.0 was initiated by the German government in 2011 and spread very quickly throughout the rest of the world [22–24] processes in all areas, including metrology. This revolution is based on the implementation of automation and robotics in industrial and logistics processes [24].

Among the automated calibration systems proposed in the literature for calibration of hydrometers by the Cuckow method, devices using laser diode to measure the transferred power stand out. As an example, we can cite the device developed by NIST (National Institute of Standards and Technology) for this type of calibration, as shown in Figure 1.

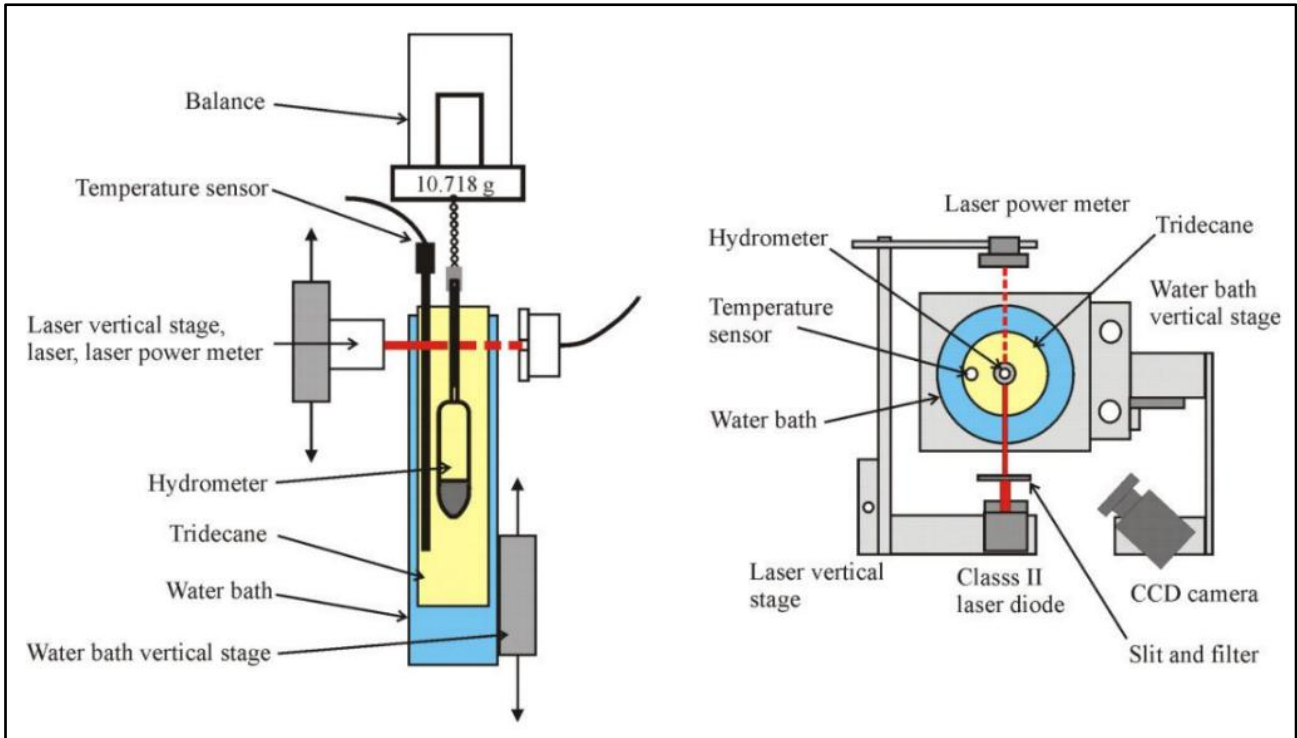


Fig 1: A schematic diagram of the NIST apparatus that applies Cuckow’s method [18]

2. PROPOSED EQUIPMENT

As mentioned, the proposed MVS is composed of a set of hardware (equipment) and software (computer vision system) responsible for acquiring the images of the meniscus point and performing the measurement. These components are described in the following subsections.

2.1 Equipment

The equipment proposed for the calibration of hydrometers has a compact structure when compared to those presented in the literature, another highlight is the use only of a digital camera, without the use of laser diode equipment, which significantly reduces the cost in the construction of the equipment. However, it is worth mentioning that this change in the project when compared to the equipment proposed by Aguilera et al. (2008) and Wright et al. (2008) [18, 19] did not change the accuracy for the measurements, since the proposed MVS has computer vision techniques, and the camera is not only for observation during calibration as in the systems mentioned.

The displacement of the jacketed vessel used in the structure of the project is carried out by a servo motor coupled to a ball spindle, thus having a smooth displacement without vibrations, which could hinder the measurement process. The use of the servo motor was adopted since the initial design had a step motor where this problem was found for a real-time measurement by cameras, as proposed in the project presented by Wang et al. (2021) [25]. The equipment developed is shown in Figure 2.

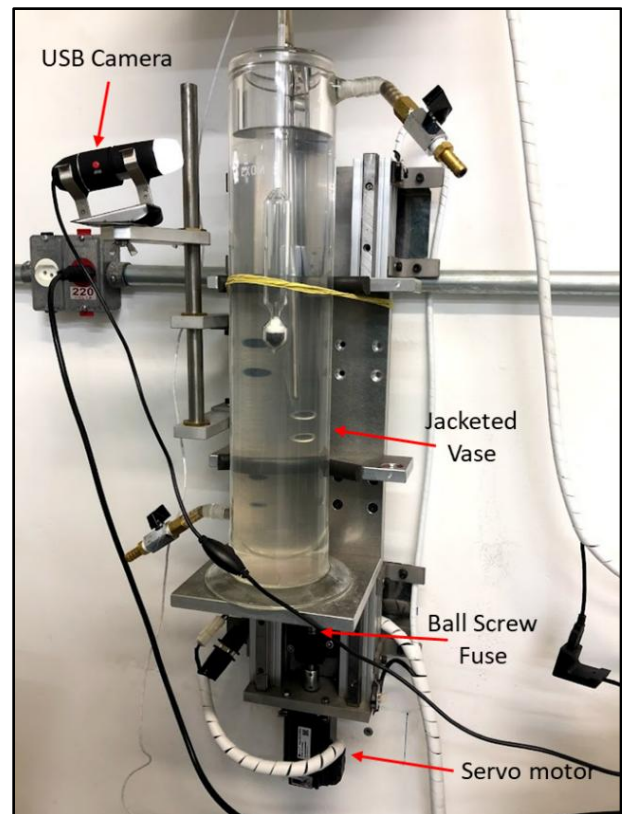


Fig 2: Proposed Equipment and its components

2.2 Computer Vision System (CVS)

The proposed system for automatic calibration of hydrometers proposed in this project consists of performing the reading of the selected meniscus and performing the adjustment of the height of the densimeter, since the measurement must be performed so that the top of the meniscus (reflection) must be

the same as the bottom (actual image). This area is called the region of interest (ROI) in the measurement process. Another point that should be highlighted is a slight inclination in the camera (Figure 2) so that the reflection of the meniscus trait can be read. This ROI is shown in Figure 3.

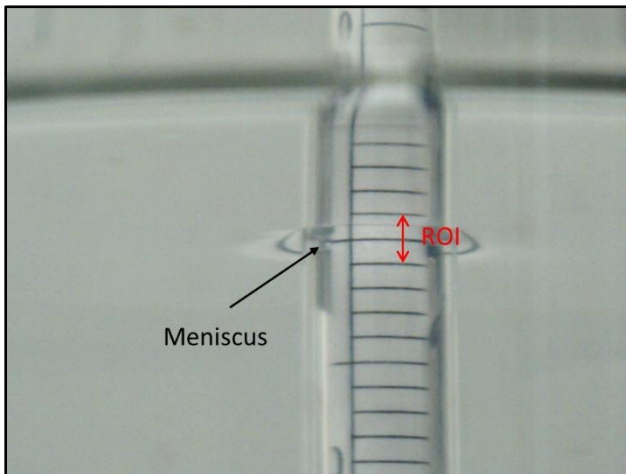


Fig 3: Region of Interest (ROI) and meniscus

The real-time measurement process consists of CVS measuring the distance (in pixels) from the meniscus to the lower point of the ROI (actual trace) and to the upper point of the ROI (stroke reflection) and controlling the servo motor so that this distance is identical. At the point where this egalitarian distance is obtained, the system finishes the measurement, and can collect the information of the balance, that is, the weight, which will be used to issue the calibration certificate.

CVS was developed in C/C++ using the OpenCV image processing library[26]. The software interface is shown in Figure 4.

Although the system was developed for automatic calibration, the user was also made available to the user the possibility of semi-automatic calibrations or manually, such functions were evaluated as useful by the technicians who perform the calibration. It is noteworthy that the proposed SVC was audited by the Accreditation Body of Brazil (INMETRO), going through all the necessary validations for its application, having a good measurement accuracy and also a low measurement uncertainty [3].

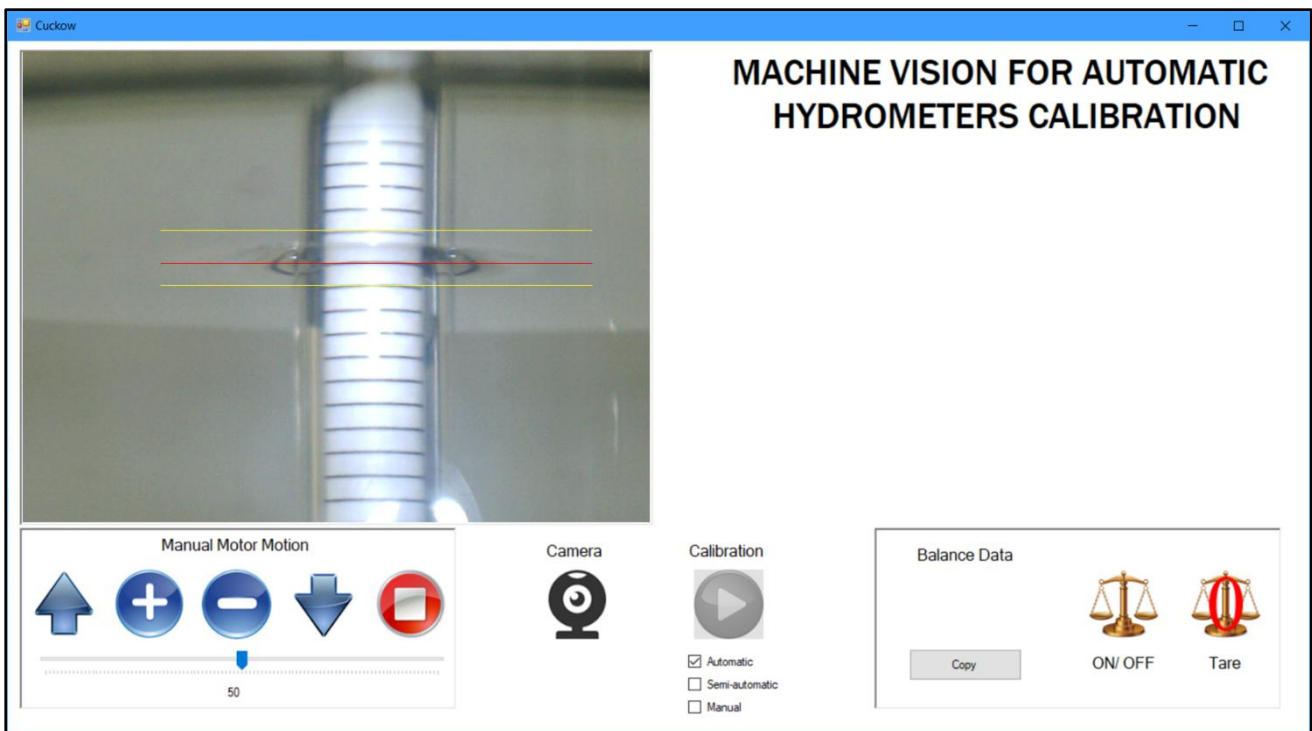


Fig 4: Proposed CVS interface

3. RESULTS AND DISCUSSION

To carry out the experimental validation with a safety margin in this project, comparative evaluations were carried out, thus validating the results generated by the SVC, so that all hydrometers that were automatically calibrated through the SVC proposed in this project followed all the rules provided for in ISO 649-2:1981, and after its completion were submitted to manual calibrations, which were performed by a technician qualified for this task, who has training and qualification to perform this task.

Another point to be highlighted in this validation process is that the calibrations performed by the technician were carried out in a metrology laboratory where there is authorization for

calibration of this product and were carried out in other equipment, this one completely manually and complying with all the rules of standard ISO 649-2:1981.

In the validation process, 100 hydrometers were used, where each one of them was checked at 3 different points, thus generating a total of 300 calibration points, with that there was a good sample, making the results safe and reliable. The sampling of the hydrometers chosen for validation was carried out so that the proposed equipment and the SVC could be tested with different rods could be tested, menisci with different colors and thickness.

The choice of these diversified hydrometers to carry out the experiments was essential to validate all the possibilities of

instruments available on the market, thus avoiding that in the future a specific type of hydrometer does not have support in the proposed SVC, thus also generating a reliable mass of data, allowing tests to be conducted under different conditions.

Among the sample of 300 evaluated calibration points, only 5 showed a small deviation when compared to the measurement performed manually by the technician, and these deviations did not exceed 0.3% of the measured point, thus not affecting the result generated by the MVS, this is because such error or deviation is covered by the measurement uncertainty for this calibration method as described by ISO 649-2:1981.

It is important to highlight that the results showed that the MVS has good accuracy and repeatability, thus ensuring its applicability not only as a theoretical improvement proposal, but in real environments in metrology laboratories. Another fact to be highlighted is that the MVS was submitted to the accreditation process for commercial calibration by INMETRO, which guarantees the metrological validity of the entire proposed system internationally.

As for the cost of developing the equipment, it can be considered that the proposed MVS is of low cost, since all the material used in its creation is lower than the cost of just the good quality laser emitting diode and receiver, such as those used in several studies proposed in the literature. The total cost of developing the MVS was approximately \$600. This cost makes the project accessible to smaller companies, increasing its applicability.

4. CONCLUSION

The results obtained in the experiments conducted by the proposed MVS showed robustness and precision for the calibration task of hydrometers. Another point to be highlighted is the measurement speed, where each measuring point took an average of 6 seconds to stabilize and final point reading.

In this work, no improvements, or adjustments in calculating measurement uncertainty or any other factor that could alter the results were addressed. As a reference for all calculations found in the calibration certificate, the standards described by Wright, Bean and Aguilera (2008) [18],

Only 1.67% of the results obtained by MVS suffered some type of distortion when compared to the manual process, however these values did not compromise the calibration result since they were within the deviation allowed by the calibration uncertainty for this type of measurement, making the MVS fully applicable to a metrological laboratory.

Another point of paramount importance was the approval of the system by the regulatory body of calibrations in the national territory, thus showing once again the robustness in the results presented. This approval together with the low production value shows its viability for metrological laboratories of any size, not only being available to large companies.

5. ACKNOWLEDGMENTS

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