Using triangulation method to address regression problems for measurements of ultra-high electrical resistance

ABSTRACT BOOK MATHMET 2025

Contents

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4. Statistical calibration and regression problems

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Abstract: The triangulation is widely applied in research and surveying and its application in metrology can support the choice of extrapolating measurement values through regression models, a practice that still encounters opposition among metrologists. Triangulation offers an approach to improve the accuracy and reliability of regressions by allowing for the verification of their results against independent measurement techniques or data sources. In general, triangulation involves using independent sources or methods to validate a conclusion or measurement. Within metrology, this means to compare measurements obtained from different instruments or techniques to minimize bias [1] and increase the overall confidence in the final measurement result. Our work focuses on extending the capabilities of high resistance measurement systems, specifically, applying the principles of metrological triangulation. This approach allows us to extend reliably the measurement ranges of these systems, particularly in areas where their performance is limited. First application of the method was on the dual source high resistance bridge (DSB) [2-4], to identify systematic or functional errors in of a commercial DSB [5, 6]. Software tools such as Calibration Curves Computing (CCC) [7] and Excel were employed. This research identifies a more efficient and reliable extrapolation methodology compared to conventional approaches (as extrapolation with Excel or other tools). The DSB method for high and ultra-high value resistance calibration can face limitations at voltages below 100 V due to detector sensitivity, when picoampere-level currents are involved. An example of the application consists of to measure the uncorrelated ratios r_1, r_2 and r_3, on a network of three high value resistors (higher than 1 TΩ R_1, R_2 and R_3 with R_2 circa 10 R_1 and R_3 circa 10 R_2, according to Fig.1 with the commercial DSB.

Fig.1. Scheme of the triangular ratio method on three high value resistors.

Being the values of R_1 at low voltages extrapolated, for example using the algorithm [7], the fulfilment of the following triangulation rule and allows to be confident that errors introduced with the extrapolation are within the standard deviation of the mean of the r_1, r_2 and r_3.

$$abs(1 - r_3 * r_2 / r_1) * 10^6 < sqrt(s^2_{r1} + s^2_{r2} + s^2_{r3}) \quad (1)$$

where s_{r1}, s_{r2}, s_{r3} are the lowest standard deviations of the mean, *sgrt* is the square root function and *abs* is the absolute value function.

This can support calibration services in compliance with ISO 17025:2018, concerning the risk assessment, and facilitate measurements of bulk resistors or insulation materials within composite thermal shields. Applying the triangulation to the regression analysis can be beneficial in evaluating relationships between different variables. In our case with this method, we can investigate the correlation between voltage and high resistance measurements, especially in voltage ranges outside the typical calibration range of the measurement system. This approach allows for a more robust assessment of the behaviour of the system under less conventional operating conditions. Our preliminary findings suggest that triangulation can be effectively used to validate a regression model by comparing its predicted values with measurements obtained through:

- Different measurement techniques comparing resistance values measured with well-established high resistance measurement methods [2-4, 8, 9];
- Different data sets: By analyzing measurements of resistance under varying conditions, it is possible to train several regression models and then compare their predictions. Consistency among the predictions from different models or techniques would significantly strengthen the reliability of the regression. Furthermore, comparing resistance values derived from the regression model with those measured by an independent and reliable measurement system can indicate the model's performance and the reliability of the measurement system, provided the values are within a reasonable tolerance, for example in the case of ultra-high value resistors with very low or negligible voltage coefficient. Recognizing certain limitations is essential. It is crucial to select independent sources or methods relevant with the specific measurement context and the characteristics of the regression model. Unfortunately, triangulation can be a time-consuming and resource-intensive process and obtaining multiple independent measurements of the same parameter (i.e. without covariance terms in (1)) may not always be feasible. In conclusion, although the triangulation does not fully solve regression problems, it can be beneficial for improving the reliability of regression models within the domain of high resistance measurements allowing to establish a sort of local multiple ultra-high value resistance standard. The periodical check of the fulfilment of the proposed triangulation rule among the ratios involved in the high resistors network can be a metrological confirmation of the validity of both the chosen regression model and the multiple high resistance standard.

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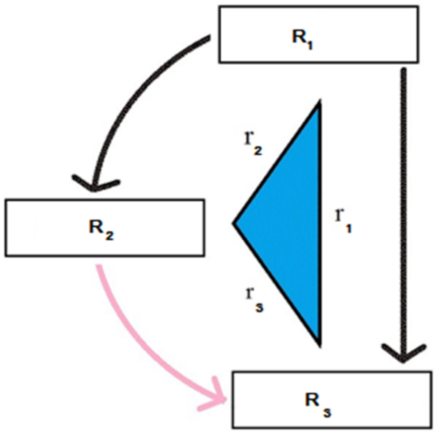

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