13th the 150th anniversary of the Metre.
New opportunities for Metrology
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Establishing the traceability of the var measurement results to the si units for more proficiently refereeing in the world cup events

Eng. Talaat A. Alrahali, Fahad A. AlMuhlaki (SASO / NMCC, KSA.)

T.Rahali@saso.gov.sa

Abstract

The FIFA World Cup attracts global attention, with refereeing decisions crucial for fair play. However, challenges like offside calls, goal-line decisions, and penalty fouls often cause disputes. To improve accuracy, the Video Assistant This research, motivated by Saudi Arabia's successful bid to host the 2034 FIFA World Cup, highlights the need for VAR device calibration and its linkage to the International System of Units (SI Units). Calibration will be conducted using optical and photometric measurement standards, with uncertainty assessments following globally recognized protocols such as NIST, CIE, and ISO GUM.
Referee (VAR) system was introduced, utilizing advanced imaging, tracking, and synchronized analysis.
The study develops calibration methodologies to facilitate proficiency testing (PT) programs for VAR calibration laboratories worldwide. This initiative enhances measurement accuracy, supports the growing calibration sector, and ensures standardized VAR technology in refereeing. Additionally, the research explores VAR technology's economic potential, identifying investment opportunities in sports metrology aligned with the International Bureau of Weights and Measures (BIPM) vision.
By integrating metrological principles into football officiating, this study strengthens transparency, precision, and credibility in refereeing while fostering technological advancements and economic growth in sports calibration.

Introduction

Importance of VAR Technology•

- Enhances refereeing accuracy in football using advanced imaging and synchronized analysis.
- Addresses disputes related to offside calls, goal-line decisions, and penalty fouls.

•Calibration for Reliability

- Essential to ensure precision and reliability of VAR technology.
- Requires adherence to global metrology standards.

•Saudi Arabia's Role in VAR Calibration

- NMCC at SASO serves as the national reference for VAR calibration.
- Calibration linked to the International System of Units (SI Units).

Calibration Methodology•

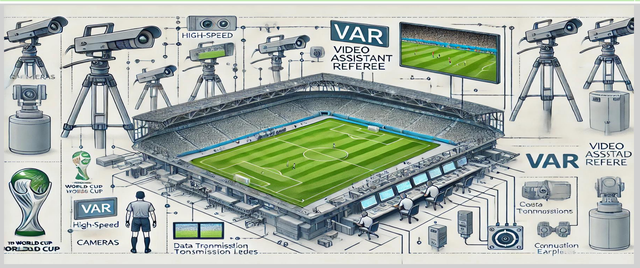
- Uses optical and photometric measurement standards.
- Follows internationally recognized uncertainty assessment protocols (NIST, CIE, ISO GUM).

•Objectives of the Research

- Develop national calibration methodologies for VAR technology.
- Establish Proficiency Testing (PT) programs to standardize calibration practices.
- Support the emerging calibration sector in Saudi Arabia.

•Impact and Economic Potential

- Enhances transparency and fairness in sports refereeing.
- Positions Saudi Arabia as a leader in sports metrology and refereeing technology.
- Opens new investment opportunities in sports metrology and technology.





Key points in applying the methodology of calibrating VAR systems and devices

❖ Types of errors in calibration:

- ❑ -Random Error: It arises due to unexpected random changes in the measurement.
- ❑ -Systematic Error: It occurs due to fixed factors that lead to distortion of measurements in a specific direction.
- ❑ Noise: Random fluctuations that affect the readings.

- Calibration Techniques Using Mathematical and Statistical Methods

- Equations for Calibration Correction

The correlation between measured values and actual values is expressed through a linear equation structured as follows: Y = aX + b

- Y represents the calibrated output.
- X denotes the measured input.
- a and b are the calibration coefficients established through experimental methods.



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Results and graphs

❖ Correction equation graph

Graphs are included to illustrate the relationship between measured values and true values according to the correction equation.

❖ - Analysis of variance and linear regression

A graph showing the analysis of variance between measured and reference values using linear regression

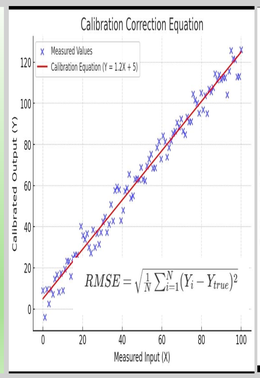
❖ Modeling and simulation for calibrating VAR systems

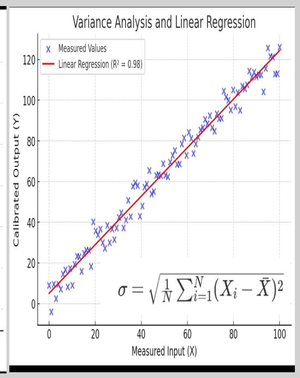
- Digital calibration models

- ❑ Advanced algorithms are used to analyze data and calibrate sensors and cameras:
- ❑ Kalman Filtering to improve the accuracy of measurements taken from VAR devices.
- ❑ Machine Learning to identify and correct deviations in measurements.

- Physical simulation of sensors and cameras :

- ❑ Specialized programs such as MATLAB and ANSYS are used to simulate the performance of VAR devices and analyze the impact of changes in the environment.





The standard deviation, signal-to-noise ratio (SNR) and root mean square error (RMSE) of the calibration data were calculated, to review the values and analyze the accuracy of the VAR system and calibrate it based on these indicators in the attached table:

#	Metric	Value
1	Standard Deviation	35.1591457569555
2	Signal- to- Noise ratio (SNR)	23.35053251
3	Root Mean Square Error (RMSE)	5.01596159615904566

$$\begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix} = \mathbf{T} \begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix}$$

Conclusion

This study proposes standardized calibration techniques for VAR systems, ensuring global measurement precision and compliance with NIST, CIE, and ISO GUM standards. By integrating metrological principles into sports officiating, the research enhances the accuracy, transparency, and reliability of football refereeing, while maintaining a robust link to SI base units and reference units, thus improving measurement reliability. Additionally, it highlights investment opportunities in sports metrology, aligning with BIPM's objective of achieving measurement excellence. These advancements contribute to the progression of VAR technology, foster economic growth, and stimulate innovation within the calibration sector, ultimately reinforcing the future of high-precision sports officiating in accordance with international measurement standards.

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