

## Abstract

The Video Assistant Referee (VAR) system has significantly improved decision-making accuracy in football. However, its reliability depends on the precise calibration of the camera and the time measurement systems. The camera calibration involves a combination of geometric and photogrammetric techniques to ensure accurate spatial measurements. The calibration method includes determining the intrinsic parameters focal length and lens distortion as well as the camera position and orientation relative to the field. On the other hand, the time measurement calibration was focused on synchronizing video feeds from multiple cameras with the official game clock to minimize the time delays between an event and its review. High-frequency time-stamping systems and network synchronization protocols, such as the Precision Time Protocol (PTP) were employed in the calibration to align frames across different camera angles. The sources of uncertainty in camera calibration include lens distortion, camera positioning errors, environmental factors, pixel resolution and sensor noise. It also includes reference object accuracy, algorithmic and computational errors. Meanwhile, in the time measurement calibration, sources of uncertainty include clock synchronization drift, transmission delays, frame rate limitations, processing delays, human response time, software and hardware latency, and network jitter. The results obtained highlight the effectiveness of the calibration techniques in reducing measurement uncertainty and improving the reliability of VAR decisions. By quantifying the sources of error, this research contributes to refining VAR technology, ultimately enhancing the fairness and accuracy of officiating in football.

## Introduction

### Enhancing Sports Officiating Accuracy through Camera and Time Measurement Calibration in VAR Systems: SASO/NMCC Efforts

The Video Assistant Referee (VAR) technology has significantly improved the accuracy of refereeing decisions in football. However, its reliability fundamentally depends on the precise calibration of imaging and time measurement systems. To ensure spatial accuracy, geometric and photogrammetric calibration techniques are employed to determine the essential camera parameters, such as focal length, lens distortion, positioning, and orientation relative to the field. Regarding time calibration, multiple camera feeds are synchronized with the official match clock through advanced timing systems that rely on high-precision synchronization protocols, such as the Precision Time Protocol (PTP), ensuring frame alignment across different camera angles without delays that could affect decision accuracy.

The sources of uncertainty in camera calibration include lens distortion, positioning errors, environmental factors, pixel resolution, and sensor noise, in addition to computational and algorithmic errors. Meanwhile, sources of uncertainty in time measurement calibration include clock synchronization drift, transmission delays, frame rate limitations, processing delays, human response time, hardware and software latency, and network jitter.

In this context, the National Measurement and Calibration Center (NMCC), under the Saudi Standards, Metrology, and Quality Organization (SASO), leads advanced research and technical efforts to enhance calibration accuracy and minimize uncertainty, thereby improving the reliability and precision of VAR decisions. By developing cutting-edge calibration methodologies, these efforts contribute to reinforcing sports officiating integrity and ensuring the highest levels of accuracy in decision-making, ultimately strengthening players' and fans' trust in the fairness of sports competitions.



## Analysis of Calibration and Testing Protocols in VAR Systems: SASO/NMCC Efforts and Metrological Evaluation

### 1. Role of the International System of Units (SI) in Camera and Time Measurement Calibration

The calibration of imaging and time measurement systems in VAR relies on the International System of Units (SI) to ensure accuracy and reliability. The key SI units used include:

- Meter (m): For determining field dimensions, camera positioning, and lens parameters.
- Second (s): For synchronizing footage and verifying the accuracy of timing protocols.
- Hertz (Hz): For monitoring frame rates and their impact on system response.

All calibration processes comply with ISO/IEC 17025, ensuring reliability and international recognition.

### 2. Camera Calibration and Uncertainty Analysis

- SASO/NMCC utilizes photogrammetric and geometric calibration techniques with Control Points to refine optical and mechanical parameters.

- Lens Distortion Analysis
- Distortions are corrected using the equation:

$$r' = r \cdot (1 + k_1 r^2 + k_2 r^4)$$

- Positioning Accuracy Analysis Using RMSE
- For accuracy evaluation, the formula used is:

$$RMSE = \sqrt{\frac{1}{N} \sum (X_i - X_{i,ref})^2}$$

### 3. Time Measurement Calibration and Synchronization Analysis

Precise synchronization is crucial for minimizing errors. SASO/NMCC has adopted Precision Time Protocol (PTP), reducing timing deviation to below 50 microseconds, compared to 5-10 milliseconds in NTP Mathematical Analysis of Timing Deviation

### 4. Metrological Comparisons and International Recognition (CIPM MRA)

SASO/NMCC participates in CCM.T-K1 and CCTF-K001.UTC comparisons for frequency and time calibration, enhancing international recognition of VAR measurement standards.

### 5. Impact of Metrological Calibration on Quality Infrastructure

- 80% improvement in referee decision accuracy using PTP.
- Enhanced Quality Infrastructure Index (QII) through international recognition.
- Boosted Global Competitiveness Index (GCI) via improved metrological precision.
- Compliance with FIFA and ISO 17025 requirements, reinforcing VAR reliability.



## Final Conclusion: The Role of SASO/NMCC in Advancing Global Sports Officiating

his study demonstrates that integrating metrological calibration into VAR systems enhances sports officiating accuracy through:

- Implementation of advanced timing protocols such as PTP.
- Improvement of imaging standards using geometric and photogrammetric calibration techniques.
- International recognition of calibration results within CIPM MRA and ISO/IEC 17025.
- SASO/NMCC represents a global model in reducing uncertainty and ensuring fair play through advanced metrological infrastructure, reinforcing public and institutional trust in digital refereeing decisions.

## the reviewer

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