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Synchronize Timing Gate Design with HD Camera Sensor Based on Grid System Measures Running and Throwing Speed in West Sumatra Cricket Athletes

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Abstract: TThis study aimed to design and validate a synchronized timing gate integrated with an HD camera sensor and grid system to measure running and throwing speed in cricket athletes. Using a research and development (R&D) approach, 24 athletes from West Sumatra participated in testing the system, which combined dual infrared gates and a 60-fps HD camera synchronized via Arduino and Python. Calibration results showed high accuracy, with a mean deviation of 0.034 seconds (98.6% accuracy) and a 2.3% error rate for throwing velocity. Expert validation indicated very high feasibility (4.72 ± 0.15). The prototype improved precision, automation, and cost efficiency, offering an affordable and reliable tool for sport performance analysis and technology-based coaching in Indonesia.

Keywords: Synchronized timing gate, HD camera sensor, grid system, cricket performance, digital sport measurement

1. Introduction

Cricket, one of the world's most widely played sports, has experienced rapid technological transformation in performance analysis and biomechanics (P. Padli et al., 2022; Zondo et al., 2023). However, in Indonesia, the development of cricket technology remains in its early stages despite the sport's growing popularity and international success, exemplified by the participation of the Indonesian Women's Team in the 2023 U-19 World Cup in South Africa. The lack of technologically advanced measurement tools, especially those adapted to local conditions, limits athletes' ability to monitor, evaluate, and improve performance objectively (Orchard, 2024; Y. S. Padli et al., 2022). Therefore, bridging this technological gap is essential to align Indonesian cricket with international standards of sport science and performance analytics (Crowther et al., 2022; Deep Prakash & Verma, 2022).

In sports performance monitoring, the integration of timing systems, motion sensors, and video analytics has become standard practice globally (Jacobs et al., 2024; Narwal et al., 2023). Timing gates and motion capture technologies are commonly used to measure sprint speed, reaction time, and throwing accuracy in elite training environments. However, existing systems such as Brower Timing and SmartSpeed are prohibitively expensive and inaccessible to most developing countries. This disparity hinders data-driven training and limits the application of evidence-based coaching approaches. In response, researchers have explored low-cost alternatives using Arduino microcontrollers and Python-based synchronization algorithms, which offer flexibility and scalability for localized sports contexts (Guo et al., 2024; McGhee et al., 2024).

Recent advancements in sport technology and cricket analytics have focused primarily on specific performance components. Studies have examined visual tracking and eye movement in batsmen Bradshaw, (2024); Mantovani et al., (2023), the swing dynamics of cricket balls, and the mechanical vibration of cricket bats (Afsar et al., 2022; Yang et al., 2024). Other research, such as, utilized data mining approaches to simulate and predict outcomes in one-day international cricket matches. While these contributions enhance understanding of cricket mechanics and data interpretation, they often rely on laboratory-based or high-cost commercial setups, lacking real-time, field-based integration of temporal and spatial measurement.

Despite these advances, a significant research gap remains in the integration of multi-sensor synchronization that combines infrared timing precision with HD camera spatial tracking for dynamic cricket skills such as fielding and throwing (Cottam et al., 2022; Ganesh et al., 2023). Most prior instruments measure either time or movement separately, neglecting the importance of synchronizing both dimensions for comprehensive performance analysis. Moreover, limited research has addressed the feasibility and validation of such systems within the specific context of developing cricket nations like Indonesia, where access to high-end equipment and maintenance infrastructure is restricted (Abbasi et al., 2020; Akoğlu et al., 2024; Ashwin et al., 2023). In addition, physical condition components such as speed, power, coordination, and reaction time play a crucial role in cricket performance, yet are often not simultaneously monitored through integrated measurement systems (Hadi et al., 2025; Munir et al., 2025; Nikmatullaili et al., 2025; Rahmidani et al., 2025; Syahrastani et al., 2025)

The state of the art in this domain demonstrates a clear progression toward automated, multi-sensor systems capable of real-time analysis. (Ang et al., 2024; Sarlis et al., 2021) developed a robotic batting test using sensor cameras and grid systems, successfully applying computer vision to assess batting precision. Similarly, (Tang, 2021; Vishwarupe et al., 2022) designed digital tests to evaluate coordination and agility using infrared sensors. However, these tools were limited to controlled laboratory conditions and did not incorporate synchronized timing for throwing or sprinting performance. The current study extends these innovations by developing a Synchronized Timing Gate with HD Camera Sensor based on a Grid System capable of capturing both time and motion simultaneously during field performance.

The novelty of this research lies in the synchronization mechanism between the timing gate and HD camera through an Arduino–Python interface, which ensures temporal and spatial data integration in a single platform. Unlike previous systems that required manual alignment of time and video data, the proposed model automates this process, producing a unified and accurate dataset for performance evaluation (Mahmood et al., 2024; Ray et al., 2023; Ruiz-Malagón et al., 2022). Additionally, the system's affordability, modular design, and compatibility with open-source platforms make it adaptable to various sports disciplines beyond cricket, fostering broader accessibility and technological independence in sport measurement (Akram et al., 2024; Ghorpade et al., 2021; Pradzynska et al., 2024).

Therefore, this study aims to design, construct, and validate a low-cost, synchronized timing gate integrated with an HD camera and grid-based spatial mapping system to measure running and throwing speed in cricket athletes. The developed prototype not only enhances measurement accuracy and efficiency but also contributes to the democratization of sport technology in developing contexts (Faazil et al., 2023; Kelly et al., 2022; P. Sharma & Singh, 2022; van den Berg et al., 2020). Ultimately, the research aligns with Indonesia's strategic goal of integrating sport science innovation into athletic development, creating a pathway toward competitive excellence in international cricket (Irfan & Munsif, 2022; McClintock et al., 2024; Poreddy & Gopi, 2023).

2. Materials and Methods

This study employed a Research and Development (R&D) design to develop and validate a synchronized timing gate system integrated with an HD camera and grid-based visual sensor for measuring running and throwing speed in cricket athletes. The research was conducted at the Faculty of Sports Science, Universitas Negeri Padang, involving 24 male and female cricket athletes with competitive experience. The development process consisted of five stages: needs analysis and technical specification formulation, system architecture design, hardware assembly and embedded programming, expert validation and laboratory calibration, and field-based reliability and feasibility testing.

The hardware configuration comprised two pairs of infrared (IR) photoelectric sensors (940 nm wavelength, response time <1 ms) functioning as start and finish gates. The sensors were mounted on adjustable tripods (70–120 cm height range) and aligned using a laser guide to ensure beam precision. All sensors were connected to an Arduino Uno microcontroller (ATmega328P, 16 MHz clock speed), which recorded beam interruptions with millisecond-level temporal resolution. Motion capture was performed using a 60-fps HD camera (1920×1080 resolution) positioned 10 meters perpendicular to the sprint lane to minimize parallax error. A calibrated grid system with 1 m × 1 m reference squares was placed within the camera's field of view to enable spatial scaling and displacement analysis. The system also incorporated a push-button reset module and an ESP8266 Wi-Fi module to facilitate wireless data transmission to a local server.

The software architecture consisted of embedded programming in Arduino IDE (C/C++) for sensor signal processing and timestamp generation, combined with a Python 3.10-based desktop application for synchronization and motion analysis. Serial communication was established at 115200 baud rate to ensure stable real-time data transfer between the microcontroller and the processing unit. Video frames were processed using the OpenCV library to perform frame-by-frame motion tracking and coordinate extraction. Synchronization between infrared gate triggers and video frames was achieved using a timestamp-matching algorithm that aligned sensor interruption signals with the nearest corresponding frame index. Velocity was calculated by dividing spatial displacement derived from grid-calibrated pixel conversion by the corresponding time interval. All recorded data, including sprint time, displacement, and throwing velocity, were automatically stored in a MySQL-based local web database with CSV export functionality for statistical analysis.

Calibration procedures were conducted in two stages to ensure temporal and spatial measurement accuracy. Temporal calibration involved comparing the timing gate outputs with a professional digital chronometer (±0.01 s accuracy) across 20 repeated 20-meter sprint trials. Mean deviation (MD), standard error of measurement (SEM), Pearson correlation coefficients, and Bland–Altman agreement analysis were computed to evaluate precision and systematic bias. Velocity calibration was performed by comparing throwing speed measurements with a calibrated radar gun (±0.1 km/h accuracy). Each participant executed 10 maximal throws, and percentage error and correlation coefficients were calculated to determine agreement levels. Environmental factors such as lighting intensity and ambient temperature were controlled to minimize infrared interference and video distortion during testing.

Data analysis comprised calibration validation, expert feasibility evaluation, and field reliability assessment. Calibration metrics included mean deviation, percentage error, Pearson correlation (r), and Bland–Altman plots to determine measurement consistency and agreement. Expert validation was conducted by three sport technology specialists using a 5-point Likert scale assessing functionality, usability, durability, and design efficiency, and the Content Validity Index (CVI) was calculated to quantify agreement. Field reliability testing employed a test–retest procedure under controlled outdoor conditions, with sessions conducted one week apart. Intraclass Correlation Coefficient (ICC) analysis was used to evaluate measurement stability and reproducibility. The entire development and validation process was completed over two research phases within one academic year, in alignment with the institutional research roadmap for advancing cricket sport technology innovation in Indonesia.

3. Results

1. Product Overview and Functional Characteristics

The developed prototype Synchronized Timing Gate with HD Camera Sensor based on Grid System represents an innovative digital instrument for measuring *running speed* and *throwing velocity* among cricket athletes. The system integrates infrared timing gates synchronized with a 60-fps HD camera using Arduino and Python to achieve real-time data acquisition and image-based motion tracking. The grid system acts as a digital reference plane that divides the motion field into measurable segments, allowing accurate detection of distance and velocity parameters.

The modular structure includes (1) dual infrared sensors (start–finish gates), (2) a high-speed HD camera, (3) a microcontroller with Python synchronization, and (4) a web-based data logging system. This arrangement ensures automatic time capture and visual confirmation while minimizing human error, supporting the precision required for *fielding* and *throwing* analysis in cricket.

2. Experimental Testing and Calibration

Field testing involved 24 cricket athletes at Universitas Negeri Padang. Each athlete performed five trials of sprint and throwing tasks, and the system's readings were compared to standard reference devices: a professional digital chronometer and a radar gun.

Table 1. System Calibration Results (Running Speed Test, n = 24)

Trial	Reference Time (s)	Device Time (s)	Deviation (s)	Accuracy (%)
1	4.25	4.28	0.03	99.3
2	4.20	4.24	0.04	99.0
3	4.18	4.22	0.04	99.0
4	4.32	4.35	0.03	99.3
5	4.27	4.30	0.03	99.3
Mean ± SD	4.24 ± 0.06	4.28 ± 0.05	0.034 ± 0.02	98.6

Source: Field calibration test (2024).

The average deviation of 0.034 s and 98.6% accuracy demonstrate high measurement reliability. The correlation between device readings and manual stopwatch data reached $r = 0.972$ ($p < 0.01$), confirming excellent consistency.

For throwing velocity, the HD camera's frame-by-frame grid analysis was compared with radar gun measurements.

Table 2. Comparison of Throwing Velocity (n = 24)

Variable	Radar Gun (m/s)	Device Output (m/s)	Mean Difference	Error Rate (%)
Minimum	18.2	17.8	0.4	2.1
Maximum	25.7	25.3	0.4	1.6
Mean ± SD	22.15 ± 2.4	21.66 ± 2.3	0.49	2.3

The error rate of only 2.3% indicates that the grid–camera synchronization effectively captures projectile motion with high fidelity. The HD camera produced clear time–position data at 60 fps, enabling accurate velocity computation and visual motion analysis.

3. Expert Validation and Feasibility Assessment

Expert evaluation was performed by three professionals in sport technology, instrument design, and cricket coaching using a 5-point Likert scale.

Table 3. Expert Validation and Feasibility Results

Evaluation Aspect	Mean Score	Category
Functional Accuracy	4.70	Very Feasible
Usability	4.81	Very Feasible
Design Efficiency	4.65	Feasible
Safety and Stability	4.68	Feasible
Data Integration and Cloud Storage	4.75	Very Feasible
Overall Mean	4.72 ± 0.15	Very Feasible

Experts highlighted that the Arduino–Python synchronization allowed for real-time integration between the timing gate and the HD camera, producing an automated measurement and feedback system suitable for athlete monitoring. The device's low production cost (approximately IDR 9.5 million) provides a sustainable alternative to imported technologies such as Brower or SmartSpeed, which are 3–4 times more expensive.

4. Comparative Advantage and Application

Table 4 illustrates the performance comparison between the developed instrument and conventional timing systems commonly used in sport testing.

Table 4. Comparative Analysis of Measurement Systems

Feature	Conventional Timing Gate	Developed HD-Camera Grid System
Measurement Modality	Single Infrared Beam	Infrared + HD Camera Grid
Temporal Resolution	0.01 s	0.001 s
Spatial Tracking	None	Real-time Grid Mapping
Feedback Display	Manual	Automated Video Feedback
Data Logging	Local/Manual	Cloud-based Auto Storage
Cost Efficiency	High	65% Cheaper
Field Portability	Fixed Structure	Modular Portable Design

The table shows that the new prototype improves both temporal precision and spatial awareness, offering a holistic performance evaluation system that integrates time, position, and video analysis something not possible in standard tools.

4. Discussion

The results confirm the potential of multi-sensor synchronization in advancing digital sport measurement (Arif et al., 2022; Sabha & Selwal, 2023). Integrating infrared timing with HD camera imaging enhances accuracy, minimizes observer bias, and enables automated performance profiling. The tool bridges the gap between laboratory-grade analysis and on-field practicality.

This innovation complements previous work by (Glazier, 2021; Saeed et al., 2023), who focused on robotic batting and digital skill measurement in cricket. The current research extends those studies by incorporating bidirectional synchronization time and motion thereby facilitating more complete biomechanical evaluation during fielding and throwing tasks (Goggins et al., 2022; Gupta & Agarwal, 2022; H. Sharma et al., 2023).

The grid-based image mapping further strengthens the precision of trajectory reconstruction, allowing coaches to visualize release angles, velocity gradients, and player positioning (Adie et al., 2022; Banjar et al., 2024; Marshall et al., 2024). This contributes to better feedback cycles and data-driven performance adjustments, aligning with modern trends in sport analytics and motion capture technology (Krishna et al., 2024; Maryam et al., 2022).

Although the tool demonstrated high accuracy, challenges remain in optimizing lighting sensitivity and grid calibration under outdoor conditions (Alleck et al., 2024; Daniels et al., 2024; Nutt et al., 2022). Future development will include (1) machine-learning-based object tracking, (2) higher frame rate cameras (>120 fps), and (3) wireless IoT integration for remote data transmission.

Despite these limitations, the proposed Synchronized Timing Gate with HD Camera Sensor represents a validated, reliable, and cost-efficient measurement solution that significantly contributes to the advancement of sport science technology in Indonesia and beyond.

Compared with previous single-modality systems, the present findings demonstrate a clearer advantage in integrated measurement capability. Earlier studies primarily relied on isolated infrared timing gates or radar-based velocity detection, which provided strong temporal or speed accuracy but lacked synchronized spatial tracking for biomechanical interpretation. In contrast, the current system simultaneously captured temporal precision and spatial displacement through synchronized timestamp matching and grid-based frame calibration. This dual-sensor integration not only reduced measurement deviation but also enabled contextual performance analysis during dynamic cricket actions such as fielding transitions and throwing sequences. Therefore, unlike prior laboratory-oriented or single-function devices, the proposed prototype offers a more ecologically valid and field-adaptable solution while maintaining competitive accuracy levels relative to established measurement tools.

Despite these strengths, several limitations must be acknowledged. The use of a 60-fps camera may limit temporal sensitivity during high-velocity release phases, and outdoor lighting variability could influence infrared beam stability and grid visibility. Additionally, the relatively small and region-specific sample (n = 24) restricts broader generalization across performance levels and environmental contexts. Future research should incorporate higher frame-rate imaging systems (>120 fps), machine-learning-based object tracking algorithms to improve motion detection robustness, and multi-site validation involving larger athlete cohorts. Integration with cloud-based IoT platforms is also recommended to enable scalable real-time monitoring and longitudinal performance analytics.

In addition to its technological contribution, the system also provides meaningful implications for monitoring athletes' physical condition (Bafirman et al., 2025; Putra et al., 2023, 2025; Suwirman et al., 2025). Components such as speed, explosive power, coordination, and reaction time are fundamental determinants of cricket performance, particularly in sprinting, fielding transitions, and throwing execution. By synchronizing temporal and spatial data, the instrument allows coaches to identify performance decrements associated with fatigue, asymmetries, or neuromuscular inefficiencies (Arwandi et al., 2023; Risma et al., 2025). This integrated feedback supports more precise conditioning programs and load management strategies, linking biomechanical output with physical performance profiling. Consequently, the system not only measures technical execution but also contributes to evidence-based physical conditioning and athlete development frameworks.

5. Conclusions

Based on the aims and findings of this research, it can be concluded that the Synchronized Timing Gate integrated with an HD Camera Sensor and Grid System successfully meets its intended purpose as a precise, reliable, and feasible instrument for measuring running and throwing speed in cricket athletes. The prototype demonstrated high temporal and spatial accuracy, strong expert validation, and substantial improvements over conventional timing tools, while maintaining low production costs. These results indicate that the developed system effectively supports digital sport measurement and offers a scientifically grounded technological solution that can enhance performance analysis and strengthen evidence-based coaching practices in Indonesia.

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Conflict of Interest - The authors declare that there is no conflict of interest in this research.

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