

A Review of Artificial Intelligence Assisted Shooting Training Simulators and Laser-Based Marksmanship Technologies

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Abstract - Firearms training is essential for military personnel, law enforcement officers, and professional shooting athletes. Traditional live-fire training requires specialized infrastructure, safety supervision, and large quantities of ammunition, which significantly increases operational costs and limits accessibility. In recent years, technological advancements in artificial intelligence (AI), computer vision, sensor systems, and immersive simulation technologies have enabled the development of advanced shooting training simulators. These systems provide safe and cost-effective training environments while offering detailed performance analysis.

This review paper examines the evolution of shooting simulation technologies, including laser-based training systems, virtual reality (VR) shooting simulators, augmented reality (AR) training platforms, and computer vision-based target detection systems. The study analyzes the architecture, sensing mechanisms, and data processing techniques used in modern training platforms. Furthermore, the paper highlights current challenges related to system accuracy, cost, and scalability. Finally, future research directions are discussed focusing on intelligent training systems that integrate AI-driven analytics and advanced sensing technologies. Despite significant technological progress, several challenges such as system affordability, portability, and real-time analysis remain open research problems.

Key Words: Shooting simulators, Artificial intelligence, Computer vision, Laser detection, Firearms training, Simulation systems

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I. INTRODUCTION

Marksmanship training plays a vital role in military preparedness, law enforcement operations, and competitive shooting sports [7]. Accurate shooting requires consistent practice and proper training techniques. Traditionally, firearms training is conducted using live ammunition in dedicated shooting ranges under the supervision of trained instructors. Although live-fire training provides realistic conditions, it also presents significant challenges related to safety, cost, and accessibility.

The cost of ammunition, weapon maintenance, and training infrastructure can limit the frequency of training sessions. Additionally, safety risks associated with live firearms require strict operational protocols. In many regions, limited access to professional shooting ranges further restricts training opportunities.

To address these challenges, researchers and technology developers have explored simulation-based training solutions. Shooting simulators replicate real shooting conditions without the need for live ammunition [3]. These systems allow trainees to practice weapon handling, targeting, and shooting techniques in controlled environments.

Recent technologies in artificial intelligence, image processing, and immersive simulation technologies have improved the effectiveness of training simulators [9], [14]. Modern systems can automatically detect shot placement, analyze shooting patterns, and provide real-time feedback to trainees [4], [6]. These features enable data-driven training approaches that help improve marksmanship skills.

This paper provides a comprehensive review of existing shooting simulator technologies and analyzes the key components that enable intelligent training platforms.

II. Literature Review

Several studies have explored the use of simulation technologies for marksmanship training. Girardi et al. [1] developed a virtual reality-based training simulator designed to improve military shooting performance. Soetedjo and Nurcahyo [3] proposed a cost-effective laser-based shooting simulator using optical detection methods. Similarly, Sun [4] investigated camera-based impact detection systems for firearms training environments. These studies demonstrate the growing importance of intelligent simulation platforms in modern marksmanship training. Kim et al. [6] investigated the use of virtual reality environments to improve rifle accuracy during military training exercises. Their research demonstrated that immersive simulation environments allow trainees to practice shooting techniques in controlled conditions while receiving real-time performance feedback. The study reported significant improvements in target accuracy and reaction time after repeated simulation-based training sessions.

TABLE 1 : COMPARISON OF TRAINING TECHNOLOGIES

Study	Technology	Application	Advantages	limitations
Girardi et al.	Virtual reality	Military training	Immersive environment	High cost
Soetedjo and Nurcahyo	Laser simulator	Indoor training	Safe & low cost	Limited realism
Sun	Camera detection	Shot detection	Accurate	Lighting sensitivity
Kim et al.	VR system	Rifle training	Real-Time feedback	Requires VR hardware

III. TRADITIONAL FIREARMS TRAINING

Conventional firearms training typically involves live-fire exercises conducted in specialized training ranges [7]. Trainees practice shooting at stationary or moving targets while following structured training protocols. These exercises focus on improving skills such as:

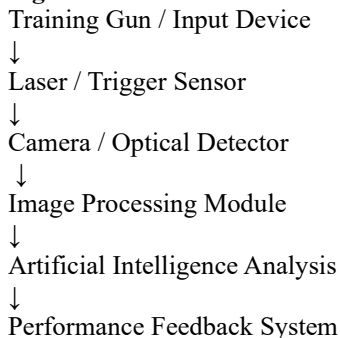
- Target acquisition
- Trigger control
- Breath management
- Shooting stability
- Recoil control

While live-fire training remains the most realistic training method, it also presents several limitations. One of the major challenges is the cost associated with ammunition and training facilities. Continuous training requires large quantities of ammunition, which increases operational expenses for organizations. Additionally, maintaining firing ranges and safety infrastructure requires significant investment. Safety is another major concern. Handling live ammunition always involves inherent risks, and strict safety procedures must be followed to prevent accidents. Environmental conditions such as weather and lighting can also affect training schedules. Outdoor shooting ranges may not always be accessible due to environmental constraints. These limitations have motivated researchers to develop simulation-based training technologies that can complement or partially replace traditional firearms training.

IV. SHOOTING SIMULATION TECHNOLOGIES

Shooting simulators are designed to replicate shooting scenarios without using live ammunition [3], [9]. These systems use various sensing technologies to detect shooting actions and evaluate performance.

Fig. 1. General Architecture of an AI-Assisted Shooting Training Simulator



Modern shooting simulators can be categorized into several technological approaches.

A. Laser-Based Training Systems

Laser-based training systems simulate firearm discharge using laser emitters [3]. When the trigger is activated, a laser pulse is projected toward a target surface. The point of impact is detected using optical sensors or camera-based detection systems.

These systems offer several advantages:

- Improved safety since no physical projectile is used
- Lower operational costs compared to live-fire training
- Ability to conduct indoor training sessions

Laser-based training systems are widely used by military and law enforcement agencies for marksmanship training.

B. Virtual Reality Shooting Simulators

Virtual reality technologies have enabled immersive training environments where trainees interact with simulated targets and scenarios [1], [6]. VR shooting simulators typically use headmounted displays and motion tracking systems to create realistic training experiences.

VR systems allow the simulation of complex environments such as urban combat scenarios or tactical operations. These environments help trainees develop situational awareness and decision-making skills.

C. Augmented Reality Training Platforms

Augmented reality combines physical training environments with digital overlays. AR-based training systems display virtual targets or information within the real-world environment.

These systems enhance traditional training exercises by providing additional visual guidance and performance feedback.

TABLE 2: COMPARISON OF SHOOTING TRAINING TECHNOLOGIES

Technology	Application	Advantages	Limitations
Laser simulators	Indoor shooting practice	Safe training	Lighting sensitivity
VR simulators	Tactical scenario training	Immersive environment	Expensive hardware
AR training	Mixed reality shooting	Real-time feedback	Calibration complexity
AI analytics	Performance evaluation	Personalized training	Requires large datasets

V. COMPUTER VISION FOR TARGET DETECTION

Computer vision plays an important role in modern shooting simulators [12], [18]. Vision-based detection systems use cameras to monitor the target area and identify shooting impacts.

Several image processing techniques are commonly used in such systems.

A. Image Thresholding

Thresholding techniques are used to identify high-intensity pixels in captured images [12]. This method is particularly useful for detecting bright laser spots projected onto target surfaces.

B. Edge Detection

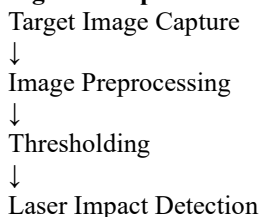
Edge detection algorithms help identify the boundaries of targets within an image [26]. These algorithms assist in determining the position and orientation of targets.

C. Coordinate Mapping

After detecting the impact location, coordinate mapping techniques are used to determine the precise position of the shot relative to the target center. This information is used to calculate scores and analyze shooting accuracy.

Computer vision technologies enable automated shot detection without requiring complex hardware installations.

Fig. 2. Computer Vision Pipeline for Shot Detection



↓
Coordinate Mapping
↓
Score Calculation

VI. ARTIFICIAL INTELLIGENCE IN MARKSMANSHIP TRAINING

Artificial intelligence has introduced new possibilities for performance analysis in shooting simulators [14], [15]. AI algorithms can analyze large datasets of shooting performance to identify patterns and evaluate shooter behavior.

Fig. 3. AI-Based Shooting Performance Analysis Framework Training Data

↓
Feature Extraction
↓
Machine Learning Model
↓
Pattern Recognition
↓
Performance Evaluation
↓
Training Feedback

Machine learning models can detect shooting inconsistencies and identify factors affecting performance [28], [30]. These systems can provide real-time feedback to trainees and recommend corrective actions.

Applications of AI in shooting training include:

- Shot grouping analysis
- Accuracy evaluation
- Shooter stability monitoring
- Performance trend analysis
- Personalized training recommendations

AI-driven analytics allows training programs to adapt based on individual trainee performance.

VII. COMMERCIAL AND MILITARY TRAINING SYSTEMS

Several advanced shooting simulators have been developed for military and law enforcement training [9], [10]. Examples include virtual marksmanship trainers and engagement skills training systems used by defense organizations.

These systems provide high-fidelity simulations and advanced analytics capabilities. However, they are often expensive and require specialized infrastructure.

As a result, access to such technologies may be limited to wellfunded institutions.

VIII. RESEARCH CHALLENGES

Despite significant progress in shooting simulation technologies, several challenges remain.

One major challenge is the cost of commercial training systems. Many existing solutions rely on specialized hardware that increases system complexity and deployment costs.

Environmental factors such as lighting conditions and reflective surfaces can also affect detection accuracy.

Another challenge is ensuring system portability and scalability. Training platforms should be easy to deploy in different environments without requiring extensive calibration.

Addressing these challenges is essential for developing accessible training technologies.

IX. FUTURE RESEARCH DIRECTIONS

Future research in shooting simulation technologies is expected to focus on intelligent training systems that combine advanced sensing technologies with AI-based analytics.

Potential research directions include:

- AI-driven performance evaluation systems
- Portable training platforms using modern computing devices
- Cloud-based shooting performance analytics
- Multi-user training systems
- Integration of augmented and virtual reality environments

Advances in sensor technology and machine learning algorithms will likely improve the accuracy and effectiveness of future training platforms [19], [21].

X. CONCLUSION

Shooting simulators have emerged as an important tool for firearms training in military, law enforcement, and sports shooting applications. Technologies such as laser detection systems, computer vision algorithms, and artificial intelligence have enabled new approaches to marksmanship training.

While current systems provide valuable capabilities, challenges related to cost, portability, and detection accuracy remain. Continued research in intelligent training systems will play a crucial role in improving accessibility and effectiveness of marksmanship training technologies.

Future intelligent shooting training platforms integrating artificial intelligence, computer vision, and immersive simulation technologies will play a critical role in improving accessibility and effectiveness of marksmanship training systems.

XI. SENSOR TECHNOLOGIES USED IN SHOOTING TRAINING SYSTEMS

Modern shooting training platforms rely on multiple sensing technologies to accurately detect projectile impact and analyze shooter performance. Sensors play a critical role in capturing training data that can later be processed by computer vision algorithms or artificial intelligence models.

Optical sensors are widely used in laser-based shooting simulators. These sensors detect light pulses emitted from laserequipped training firearms. When a trainee pulls the trigger, a laser beam is projected toward the target surface. Photodiodes or optical detectors capture the reflected signal and determine the location of the simulated shot.

Another commonly used sensing technology is high-speed imaging sensors. High-speed cameras can capture the exact moment of shot impact with high temporal resolution. These systems allow precise tracking of shot placement and are frequently used in research laboratories and professional training facilities.

In addition, inertial sensors such as accelerometers and gyroscopes are increasingly integrated into modern training weapons. These sensors measure motion and orientation during the shooting process. By analyzing motion data, researchers can evaluate factors such as weapon stability, trigger pull consistency, and shooter posture.

Combining multiple sensing technologies enables more reliable detection and more comprehensive training analytics.

XII. ROLE OF HUMAN FACTORS IN MARKSMANSHIP TRAINING

Marksmanship performance is influenced not only by weapon technology but also by several human physiological and psychological factors. Understanding these factors is important when designing intelligent training systems.

One of the most important elements is shooter stability. Even minor body movements can significantly affect shot accuracy. Professional training programs emphasize proper body posture, controlled breathing, and steady trigger operation.

Another important factor is reaction time and decision making. In tactical environments, shooters must quickly identify targets and respond appropriately. Simulation systems can help improve these cognitive abilities by presenting dynamic scenarios that require rapid decision making.

Visual perception also plays a significant role in shooting performance. Accurate target alignment requires proper eye focus and coordination between visual perception and motor actions. Training simulators often incorporate visual feedback mechanisms to help trainees improve aiming precision.

By studying these human factors, training technologies can provide more effective feedback and improve skill development.

XIII. DATA ANALYTICS IN SHOOTING PERFORMANCE EVALUATION

Data analytics has become an important component of modern training systems. Training platforms can collect large amounts of performance data during each training session. This data includes shot coordinates, reaction time, aiming stability, and shot grouping patterns.

Analyzing this information allows instructors to identify strengths and weaknesses in a trainee's shooting performance. For example, clustering techniques can be used to analyze shot grouping patterns on the target surface. Consistent clustering near the center indicates good accuracy, while scattered patterns may indicate instability or improper trigger control.

Statistical analysis techniques can also be used to monitor performance improvement over time. By comparing training sessions, instructors can evaluate whether a trainee's accuracy and consistency are improving.

Advanced training platforms may also generate automated performance reports that provide detailed feedback and recommendations for improvement.

XIV. TRAINING SCENARIO DESIGN IN SIMULATION ENVIRONMENTS

Simulation-based training systems often include various training scenarios designed to mimic real-world shooting conditions. Scenario design is an important element in improving the realism and effectiveness of training exercises.

Basic training scenarios may involve static targets placed at different distances. These exercises allow trainees to develop fundamental marksmanship skills such as aiming accuracy and trigger control.

More advanced training scenarios involve moving targets and dynamic environments. In these situations, trainees must adjust their aiming strategy while tracking target movement. Such exercises help improve hand-eye coordination and reaction speed.

In tactical training environments, simulation systems may replicate complex scenarios such as urban operations or defensive situations. These scenarios encourage trainees to develop situational awareness and decision-making skills.

Carefully designed training scenarios contribute to more engaging and effective training experiences.

XV. IMPORTANCE OF SAFETY IN SHOOTING TRAINING TECHNOLOGIES

Safety is one of the primary motivations for the development of simulation-based shooting training systems. Traditional live-fire exercises involve inherent risks due to the use of real firearms and ammunition.

Simulation technologies significantly reduce these risks by eliminating the need for physical projectiles. Laser-based systems and digital simulators allow trainees to practice shooting techniques in controlled environments without exposure to dangerous conditions.

Training facilities also benefit from improved safety management when using simulation systems. Indoor environments can be used without the need for extensive protective infrastructure typically required in live-fire ranges.

Additionally, training instructors can monitor trainee behavior and intervene when unsafe practices are detected. This controlled environment allows beginners to learn fundamental skills while minimizing potential hazards.

XVI. ROLE OF COMPUTER NETWORKS IN MODERN TRAINING SYSTEMS

Modern shooting training systems increasingly rely on networked computing platforms to support collaborative and distributed training environments.

Networking technologies allow multiple trainees to participate in synchronized training sessions. Training data collected from individual users can be transmitted to centralized servers where it can be analyzed and stored.

Cloud-based training systems provide additional advantages by enabling remote access to training analytics and performance records. Instructors can review training results and provide feedback even when trainees are located in different locations.

Networking infrastructure also enables large-scale training simulations where multiple participants interact within a shared virtual environment. These capabilities are particularly useful for military and law enforcement training exercises.

XVII. ADVANTAGES OF SIMULATION-BASED TRAINING

Simulation-based shooting training systems provide several advantages compared to traditional training approaches.

First, simulation technologies significantly reduce operational costs by eliminating the need for large quantities of ammunition. Training sessions can be conducted repeatedly without incurring additional expenses.

Second, simulation systems provide immediate feedback that helps trainees identify mistakes and improve their skills more effectively. Real-time performance metrics allow instructors to monitor trainee progress during each training session.

Third, simulation environments enable the creation of controlled training conditions. Environmental factors such as lighting, distance, and target movement can be adjusted to create different training challenges.

Finally, simulation technologies improve accessibility by allowing training to be conducted in indoor environments without the need for specialized outdoor shooting ranges.

XVIII. TARGET DESIGN AND SCORING MECHANISMS

Target design is a critical component of marksmanship training systems. The structure and layout of the target influence how performance is evaluated during training exercises. Traditional shooting targets usually consist of concentric circular zones, where each zone represents a different score value depending on the distance from the center.

Modern training simulators often use digitally generated targets that can be dynamically modified during training sessions. Digital targets allow instructors to change difficulty levels, target sizes, and scoring rules based on the skill level of trainees. For example, beginner trainees may practice with larger targets, while advanced shooters may train using smaller and more challenging target zones.

Scoring mechanisms in simulation systems are typically automated. Once a shot is detected, the system calculates the distance between the impact point and the center of the target. This distance is then converted into a score according to predefined scoring rules.

Automated scoring systems improve training efficiency by eliminating manual evaluation and providing immediate feedback to trainees.

XIX. IMAGE PROCESSING TECHNIQUES IN TARGET ANALYSIS

Image processing techniques are widely used to analyze target surfaces and detect shot locations in modern training systems. These techniques allow automated systems to identify the precise location of laser impacts or projectile marks on targets.

One commonly used method is image segmentation, where the captured image is divided into different regions based on pixel intensity values. This technique helps isolate the impact point from the background of the target.

Another widely used approach is blob detection, which identifies clusters of bright pixels corresponding to laser spots or impact marks. Blob detection algorithms can quickly locate the center of the detected region and determine its coordinates.

Morphological operations such as dilation and erosion are also applied to improve detection accuracy. These operations remove noise and enhance the visibility of detected impact points.

By combining these techniques, training systems can achieve accurate and reliable shot detection.

XX. PERFORMANCE METRICS IN SHOOTING TRAINING

Evaluating shooter performance requires the use of well-defined performance metrics. These metrics help instructors measure progress and identify areas that require improvement.

One of the most common metrics is shot accuracy, which measures the distance between the shot impact point and the center of the target. Higher accuracy indicates better aiming precision.

Another important metric is shot grouping consistency. Grouping refers to how closely multiple shots are clustered together on the target. Even if the group is slightly off-center, consistent grouping indicates good weapon control and shooting technique.

Reaction time is another performance indicator, particularly in tactical training environments. This metric measures the time required for a trainee to identify a target and respond with a shot.

Training systems may also evaluate weapon stability, which measures the amount of movement in the firearm before the shot is fired. Excessive movement often leads to reduced accuracy.

These performance metrics provide valuable insights into trainee skill levels and training progress.

XXI. HARDWARE COMPONENTS OF TRAINING SIMULATORS

Training simulators typically consist of several hardware components that work together to create a realistic training environment.

The first component is the training firearm or input device, which simulates the physical operation of a real firearm. These devices may include trigger sensors or laser emitters that generate signals when the trigger is pressed.

The second component is the target detection system, which identifies the position of the simulated shot. This system may use cameras, optical sensors, or specialized detection surfaces.

A processing unit is also required to analyze the captured data. This unit runs image processing algorithms and performs calculations required for scoring and performance evaluation.

Display systems such as monitors or projection screens are used to present training scenarios and feedback to trainees. These displays allow trainees to visualize targets, training environments, and performance results.

Together, these hardware components create an integrated training platform.

XXII. TRAINING DATA COLLECTION AND STORAGE

Training systems generate large volumes of data during shooting exercises. Each shot fired during a training session produces multiple data points including shot coordinates, timing information, and environmental parameters.

This data must be stored and organized for further analysis. Modern training platforms often use digital databases to store performance records of individual trainees. These records allow instructors to track long-term progress and identify performance trends.

Data storage systems also support the generation of training reports. Reports may include graphical representations of shot patterns, accuracy scores, and improvement over time.

Proper data management ensures that training information remains accessible and useful for future evaluation.

XXIII. LIMITATIONS OF CURRENT TRAINING TECHNOLOGIES

Despite significant technological advancements, current shooting training technologies still face several limitations.

One limitation is the dependency on environmental conditions. Optical detection systems may experience reduced accuracy under poor lighting conditions or in environments with strong reflections.

Another limitation is the cost of advanced simulation systems. High-end simulators often require specialized hardware, which may not be affordable for smaller training institutions.

System calibration can also present challenges. Accurate shot detection often requires careful alignment of sensors and cameras. Improper calibration may lead to inaccurate scoring results.

Finally, many existing systems lack portability, making it difficult to deploy them in different training environments. Addressing these limitations remains an important area for future research and development.

XXIV. INTERDISCIPLINARY NATURE OF MODERN TRAINING SYSTEMS

The development of advanced shooting training technologies requires collaboration between multiple scientific disciplines.

Electronics engineering plays a key role in designing sensors and hardware systems used for shot detection. Computer science contributes algorithms for image processing, data analysis, and system control.

Artificial intelligence and machine learning provide tools for analyzing large datasets and identifying performance patterns. Meanwhile, human factors engineering helps optimize system design to ensure usability and effective training outcomes.

By integrating knowledge from these disciplines, researchers can develop more effective and efficient training platforms.

25. GLOBAL DEVELOPMENT OF SHOOTING TRAINING TECHNOLOGIES

Over the past decade, the development of shooting training technologies has expanded rapidly due to advancements in digital simulation, sensor technologies, and artificial intelligence. Military organizations, law enforcement agencies, and sports training institutions have increasingly adopted simulator-based training systems to enhance training efficiency while reducing operational risks.

Many developed countries have invested heavily in simulation technologies for defense training programs. Modern military training facilities frequently use advanced simulators that combine immersive visual environments with precise shot detection systems. These simulators allow trainees to practice weapon handling and tactical decision-making without using live ammunition.

Commercial companies have also contributed significantly to the development of shooting training platforms. Several technology providers offer modular simulation systems that can be customized according to the training needs of different organizations. These systems often incorporate motion tracking, high-resolution displays, and advanced data analytics capabilities.

The growing demand for safe and cost-effective training solutions has accelerated research in this field. Universities and research laboratories continue to explore innovative approaches for improving simulator accuracy, portability, and usability.

26. EMERGING TECHNOLOGIES IN TRAINING SIMULATION

Recent technological developments have introduced several new possibilities for improving the effectiveness of training simulators. Advances in sensing technology, computational power, and artificial intelligence have enabled more sophisticated training systems.

One promising development is the integration of deep learning algorithms for analyzing shooter behavior. Deep learning models can process large volumes of training data and identify complex performance patterns that may not be visible through traditional analysis methods.

Another emerging technology is real-time motion tracking. Motion tracking systems use sensors or cameras to capture body movements and weapon orientation during training exercises. This information can help instructors evaluate shooter posture and stability.

Additionally, wearable technology is being explored as a tool for monitoring physiological parameters such as heart rate and stress levels during training. These measurements provide insights into how psychological factors influence shooting performance.

The combination of these technologies has the potential to create more intelligent and adaptive training systems.

27. POTENTIAL APPLICATIONS BEYOND MILITARY TRAINING

Although shooting simulators were originally developed for military and law enforcement training, their applications have expanded to several other fields.

In the field of sports shooting, professional athletes use simulation technologies to practice aiming techniques and improve consistency. Simulation systems allow athletes to analyze their performance without consuming ammunition during practice sessions.

Training simulators are also used in educational environments where students study weapon mechanics and safety procedures. These systems provide a controlled learning environment that emphasizes safe handling practices.

In addition, simulation technologies have been incorporated into entertainment and gaming industries. Interactive shooting simulations are widely used in virtual reality gaming platforms and arcade systems.

The diversity of these applications demonstrates the versatility and growing importance of simulation-based training technologies.

28. FUTURE OUTLOOK OF INTELLIGENT TRAINING SYSTEMS

The future of shooting training technologies will likely involve the integration of multiple advanced technologies to create highly intelligent and adaptive training platforms.

Artificial intelligence will continue to play a central role in analyzing training data and providing personalized feedback to trainees. Machine learning algorithms will enable systems to adapt training difficulty based on individual performance levels.

Cloud computing is expected to further enhance training systems by enabling centralized storage and large-scale analysis of performance data. Cloud-based platforms can support collaborative training environments where multiple users participate in shared simulations.

Advances in display technologies, including high-resolution projection systems and augmented reality devices, will improve the realism of simulated environments. These technologies will allow trainees to experience highly immersive training scenarios.

As research in these areas continues to progress, future training systems are expected to become more accessible, accurate, and cost-effective.

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