Precision Shooting Training System Using Augmented Reality

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Abstract. Precision shooting training is conventionally done at outdoor shooting ranges. There are also virtual training grounds that use weapons and scenarios that do not provide a completely real experience. When the practitioner begins training, the waste of ammunition represents an economic inconvenience both for him and for the training center. For this reason, this research analyzes the factors and tactical strategies involved in precision shooting practices, developing a virtual augmented reality system that implements three-dimensional objects that facilitate training with short-range weapons. The panorama of vision in the sights of the weapons is expanded, to have a better alignment between the three key points that intervene in the shots. Thus, the training method is modernized, but the reactions caused by the recoil force generated by a shot are preserved, without affecting the practitioner's cognitive process. When acting within a combat environment, it is necessary to recreate a situational awareness that allows generating a perception, understanding, and anticipation of all the elements of the environment. Experimental tests show a 116.67% increase in effectiveness when compared to the traditional method. Thus, there is a reduction in the consumption of resources, making it a sustainable proposal.

Keywords: Augmented reality · Precision shooting · Tactical training

1 Introduction

Augmented reality (AR) allows the introduction of computer-generated elements into the natural environment, improving the ability to detect, recognize and process objects and situations [1]. The ability to communicate with other devices has been made part of the daily life of users and facilitates operation in various interdisciplinary applications [2]. The entertainment industry has been one of its forerunners, although its importance in industry and in the professional sphere can also be highlighted [3, 4]. Besides being a tool to motivate consumers, with various marketing strategies [5]. In the military field, these systems are used to generate skills and abilities in personnel undergoing training

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[6]. This highlights the work of [7], where surfaces are used in high terrain using AR during the training of cadets in military tactics, encouraging active participation.

The evolution of military technology has been developing as the needs in military confrontations have appeared. In this way, the use of firearms of all kinds has been part of the formative process of the soldiers, but over time, it is also a domain knowledge of the civilian personnel. For this reason, training grounds, known as firing ranges, are created all over the world. In these establishments, the skills of the practitioners are perfected through technical instruction, improving performance in the execution of precision shots and in reaction. Correct tactical shooting training includes mastery of drawing, grasping, and control of the weapon in rapid sequences and an adequate vision of the crosshairs. This last skill corresponds to the alignment of the weapon and the accuracy of the shot depends on it [8].

Conventional training is based on the practitioner's eyesight and considering that only one clearly visible reference point can be focused on at a time, a problem is created. The problem with the height of the reference sights of a short-range weapon is that the observer must pay attention to three key points to make a precision shot: the rear and front sight located on the weapon, plus the target at a distance [9]. This causes the entire surrounding environment to become diffuse so that the script becomes the main object of observation and an important point for taking a precision shot. With this, the effectiveness of the shot is focused on the view and posture of the user, which, at distances greater than 15 m generates inaccurate results and is one of the limitations when training progresses towards the practice of reaction shots [10]. The alignment of the crosshairs depends on the posture adopted, according to the situation in which he finds himself and the recoil caused in the body by the inertia of detonation.

As an alternative proposal that reduces the amount of ammunition used and additional expenses during practice, sessions at a physical firing range, laser-guided firing simulators, and virtual ranges are used. These commercial systems represent a high economic investment since having laser weapons, virtual target projection systems, and video cameras. For this reason, shooting simulators have been developed at a lower cost as part of research related to virtual reality (VR) [11]. In [12] the changes in the cardiovascular responses of police officers in the training routines of a virtual system are evidenced. While in the work of [13], the virtual environment includes a device for the feedback of forces, allowing to evaluate the generation of force, the firing reactions, and the experimental results. In [14] a prototype is created that replicates the properties of a commercial VR device (i.e., adjustable shape, weight, and force feedback) and evaluates the effects of these parameters on user performance, obtaining good results.

Although most applications are made using VR, augmented reality proves to be a valid technological tool for training and the educational process. In the work of [5], several bibliographic sources are reviewed and the usefulness of RA in education and sports training is described, as well as suggestions for the design of training scenarios. Military tactics also benefit from AR, in [15] a system is described that using three-dimensional objects and audiovisual resources, simulates the environment of a real war conflict. Applications involving the execution of shots are prevalent in entertainment, as shown in [16], where a mobile AR game is developed where the player can walk in any environment and hunt ghosts [17].

Although the literature review is found not relevant articles, which are made tactical training with augmented reality, which has led to the present research. In this context, it is proposed to develop a virtual system for the practice of precision shots using AR. In the hardware, a smartphone has been coupled to a helmet for military use, which is safe and non-invasive for the user. In software, Unity, Vuforia, Blender, Adobe Illustrator, and Visual Studio have been used for the development of three-dimensional objects. The functional tests validate this initial proposal.

The document consists of six sections, including the introduction (Sect. 1). Section 2 describes the previous context on the use of weapons and Sect. 3 the development of the proposal. The tests and results obtained are set out in Sect. 4 and Sect. 5 respectively. Finally, the conclusions are shown in Sect. 6.

2 Previous Context

A firearm is a mechanical or semi-automatic object that is always under the control of a wearer. For the development of this proposal the initial analysis, implementation, and experimental tests have been carried out in a private establishment. Different physical and technical factors go into the effectiveness and accuracy of a shot. These can be external environmental factors or at the same time tactical strategies that require constant correction and training.

2.1 External Factors

There are those physical factors that can affect or distort the trajectory of a projectile from the point of origin to the destination (target).

Distance. It is relevant in firing precision since the longer the projectile travels, additional factors such as gravity and wind direction must be taken into account. This when used long-range weapons such as rifles, ammunition that reach n up to 3000 m of track, while short - range weapons are considered negligible.

Moving Target. It is the factor of greatest difficulty in shooting since the speed and variable position of the final target intervenes. It is necessary to anticipate the position of the target by observing through the sights and thus establish the necessary compensation interval to bring the shot closer. This is done through the use of visual tracking techniques for short-range shots (ideal for airsoft) or momentary hold for longer ranges. For this case study, the objectives are static, so this factor is also neglected.

Wind. The force of the wind is not constant and could destabilize both the projectile and the shooter. The direction and intensity of it must be taken into account, and it is advisable to shoot downwind to gain distance. When taking a shooting position, to have an empirical measurement of wind speed, the following ranges are established. (i) imperceptible wind: less than 5 km/h; (ii) gentle breeze that is perceived on the face: 5–9 km/h; (iii) leaves constantly shaking: 9–12 km h; (iv) flight of leaves and dust: 12 to 20 km/h. (v) shrubs and small trees oscillating: 20–27 km/h.

It must be taken into account that the wind affects the flight direction of the projectile, having to make drift corrections for the shot. The 9:00 a.m. wind blows the bullet to the right and the 3:00 p.m. wind blows it to the left. The factor that is considered for distances greater than 50 m. During the practice, it must wait for the wind intensity to be as low as possible, and in this establishment due to the location, it is very low.

Brightness. The reflection of sunlight or artificial light can n have disruptive effects on the field of view and affect directly the alienation of view for shooting. Therefore, it is required to use sunglasses to reduce the unnecessary reflections and contrast in a change of environment.

2.2 Tactical Strategies

There are those techniques that facilitate and improve shooting training, establishing coordination between the elements that intervene when shooting. To achieve an effective interaction of the proposed system, the most relevant tactical aspects are analyzed and summarized in Table 1.

3 Proposal Development

With the implementation of a precision shooting training system using augmented reality, the aim is to totally reduce the waste of ammunition and take advantage of the instructional time. Training times would focus solely on rounds of fire, reducing instructor time by 40%. This percentage of the practice is destined for the training and correction of the shooting posture of the practitioner to achieve efficiency and precision in the shots.

1. The environmental conditions under which the system must operate correspond to those of an open field, with full exposure to natural light. This environment has a hot dry climate, with the presence of dust and without direct connections to electricity.
2. The system must not have elements that interfere or present an obstacle when performing target practice in any of its stages. This should not have immersive hardware, as it would alter the safety standards for the shooter.
3. Personal protection elements can be used for the system, complying with the ANSI standard. This includes elements of visual protection, hearing protection, or external elements that are to be used for the protection of the shooter.
4. The sighting, projection, and alignment images should conform to the generally used internationally used tactical shooting characteristics.
5. The training, performance tests, and validation will be under supervision.

Based on the analysis of external physical factors that influence the accuracy of the shot, the tactical strategies used, and information on the facilities, it is inferred that only the external factor of luminosity is taken into account. The other external factors are not considered since the variations are negligible at distances less than 30 m (distance from the runways).

Table 1. Analysis of tactical shooting strategies.

Strategy	Analysis in training	Conclusion
Position	There are established positions; however, the physical constitution of each shooter makes it impossible for them to be final. Every posture must provide to the shooter: stability, balance, flexibility, and comfort	The shooting instructor must have access to the field vis ion of the shooter to correct the posture and achieve better results
Grip	The grip of the weapon must cover the largest possible surface of the weapon, without leaving free spaces, with rigid and straight wrists. It must allow a correct alignment of sights and objectives	This is relevant to the effectiveness of the reaction shots, the control of the recoil movement and the alignment of sights
Alignment	Shooter must have accurate rear and front sight alignment. It is must focus solely on the front sight of the weapon to have a proper sighting frame with the dominant eye	It is key in a precision shot. This depends on the vision of the shooter and the ability to form a focus box between the view and the target
Breathing	The rib cage is in constant motion due to inhalation, and exhalation, so a relaxed breath should be maintained	It is recommended to take the shot at the moment of apnea so as not to affect the precision
Trigger control	Of this depends on most of the effectiveness of a shot. It is necessary to have an effective recovery after each execution, to shoot again	Works in conjunction with weapon alignment

Figure 1 shows the architecture of this proposal. Here it can be seen that the input corresponds to the gun, sight, and target alignment by the shooter. On the weapon and on the target there are augmented reality tags on which AR elements are superimposed aimed at providing a better focus on the sights of the weapon and the target to be shot. These are developed on different platforms and are viewed by both the shooter and the instructor on different screens so that erroneous postures can be corrected and thus improve the accuracy of the shot. This information is stored on a server to have a training history of the shooters.

It is essential that each shooter receives prior technical instruction on shooting fundamentals and tactical strategies to achieve precision shots. So that the student is related to the type of weapon to be used, positioning strategies, alignment of sights on the weapon, and current safety regulations. The system should not present obstacles in the development of the practice, therefore, the strategic points for the development are:

- Shooting targets located 20 m from the shooter's starting position.
- The targets to shoot are silhouette targets at the height of the average person.

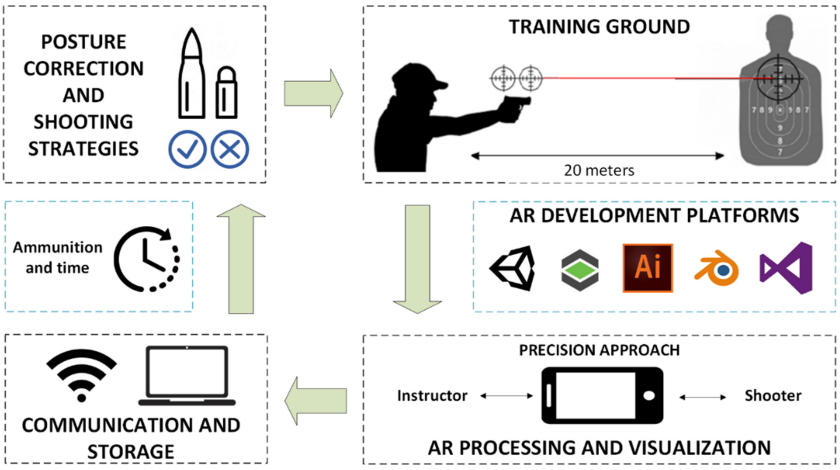

Fig. 1. General diagram of the system.

- The location of the shooter starts from an outdoor area with direct exposure to natural light, there are five training courts.
- The instructor's location is at a safe and prudent distance from the shooter, but adequate enough for him to appreciate the techniques used.
- The server is stored locally within the institution, in a secure area.

3.1 Hardware

Smart Device for AR System Visualization. It needs a display screen that is not invasive, that does not have problems with the brightness and dust of an open field. The use of augmented reality glasses because despite the good features in image quality, have discarded vibrations and software required paid. It is also considered that in the case of glasses, the location of the camera is not central, since there are two (one for each eye), which does not allow it to be used when handling short-range firearms. For this reason, it is decided to use a Smartphone, following strict visual safety regulations.

Smartphone. Quality graphics display depends directly on the smartphone where it will run the application. The intrinsic requirements of the application require a medium or high-end device, to guarantee visibility in an outdoor environment. In addition, since it is an application for a private institute, this system has been conditioned to the smartphones that the instructors of that place have. Therefore, technical analysis of each of the devices and satisfactory performance tests of the AR application is carried out.

Computer. To develop a system that uses AR requires the use of a computer with a graphics development engine and a compatible software development kit. Therefore, the computer where the system develops requires specific characteristics recommended for a good performance, avoiding slowdowns. These are:

- OS: Windows 10 64 bits.
- Android SDK Development Kit, Java (JDK), Vuforia SDK, Unity Hub.
- 16 GB RAM memory.
- CPU: Intel Core i7-7700HQ 2.8 GHz–3.8 GHz.
- 15.6″ (1920 × 1080) IPS LED screen.
- NVIDIA GTX 1050 Ti 4 GB Graphics Card.

In the case of the server, it must be on a local computer and since the amount of data is not that high, it does not require further considerations. It is recommended to install an OS: Windows 7 64 bits and an Intel Core i5-2450M @ 2.80 GHz 4 GB RAM processor.

Tactical Helmets. A fastening system is required to be attached to Safe Guard brand tactical incursion helmets, with security level IIIA ballistic protection. Thus, the absolute vision of the student is not obstructed and at the same time, it can have a screen where the alignment of sights is displayed.

Shooting Targets. Targets with human silhouettes, rings, and poppers are available. Taking into account that the system focuses on close-range shooting, silhouette targets have been chosen. These are the height of an average person locating the thorax.

Short-Range Weapons. The weapons made available for training and validation tests are Pietro Beretta and Glock model pistols. The projectiles are 9 mm caliber and the speed reached is 360 m/s. These are chosen for ergonomics, performance, and proper weight. It should be noted that the institution has the necessary permits for handling weapons.

3.2 Software

Unity. It is a graphics engine for the development of multiplatform videogames that has an integrated development environment (IDE). In the field of augmented reality, it offers tools to create fully enriched AR experiences, which interact intelligently with the real world and a unified workflow for all devices. The version used in this application is 2019.1.11 and for the installation, it is required to have previously Unity Hub. A desktop interface that streamlines the installation process and access to the different versions of Unity and its add-on packages. It also has compatibility with Vuforia.

Vuforia. It is a software development kit (SDK) for building mobile applications with AR. To do this, use the main camera of the mobile device and the screen to view the superimposed objects. An application made in Vuforia consists of the following components: camera, image converter, tracker, and application code.

The most robust AR development platforms are Vuforia, ARKit, and ARCore. The latter is robust for the design of applications but has incompatibilities with certain smartphones so it is ruled out. ARKit is focused on iOS, so the Vuforia SDK is chosen for its strengths and compatibility. As AR targets that are supported by Vuforia, Mult Target has been chosen, which works as an image target but with multiple images. These must be different for the system to recognize them.

Adobe Illustrator. It is a vector graphics editor, where the AR tags are developed for the development of the system. This software is used since these must be vectorized images with the best possible image quality.

Blender. It is a multiplatform software focused on modeling, lighting, rendering, animation, and the creation of three-dimensional graphics. In the development of the project, it allows to elaborating the 3D modeling of the silhouette that is superimposed on the target to be shot and the AR alignment sight as seen in Fig. 2.

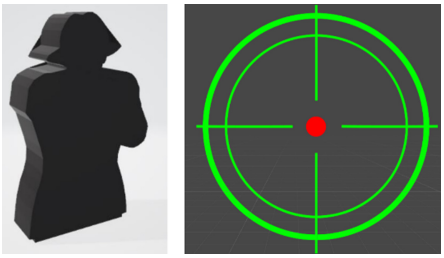

Fig. 2. Developing three-dimensional elements in Blender.

Visual Studio. t is the software selected for the development of the programming code of the scripts. This program has a link with Unity to go to the code development interface from the inspector panel. It allows the creation of a script in several programming languages such as Java, C++, C#; In this case, C# programming has been used for image stabilization.

3.3 Interface Design

Initial Tests: Above the markers that are located in the scene panel, the 3D elements that are going to be visualized in the final mobile application must be placed. For this, 3D assets can be downloaded as packages from the Unity online store. As the system is applied in a real environment, the 3D elements are a crosshair whose tag is located on the front sight of the weapon and a silhouette with scores that are superimposed on the target located at a distance. Each element is modified in a blender, thus obtaining a file with a compatible *.blend extension. It is necessary to take into account the size of the elements, due to the distance at which the markers are located. This optimal size is adjusted according to observational and error tests.

At this point it is necessary to perform functional tests for the AR elements added through the Unity panel, using the computer camera for marker recognition. In this test, it is evident that the AR crosshair tends to be confused by the color of the final objective, so the design is changed to a more interactive green color without background with the firing center in a red tone. In this way, the precision point towards which the projectile is directed when the weapon is fired is distinguished. Figure 3 shows this change, which is the definitive one in terms of element design.

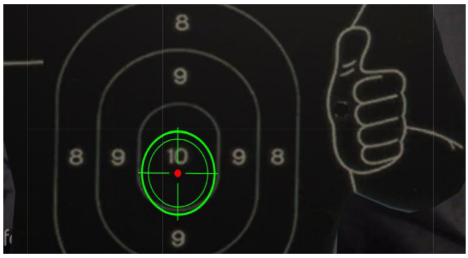

Fig. 3. Functional tests of AR elements in Unity.

To generate a mobile application in Unity through the use of the Vuforia SDK, the location and brightness parameters to which it is exposed must first be configured. Then the Android platform is added, as shown in the flow chart in Fig. 4. So that the system does not present problems when being rendered in an outdoor environment and with direct natural lighting. This object is configured in Unity in the inspector panel.

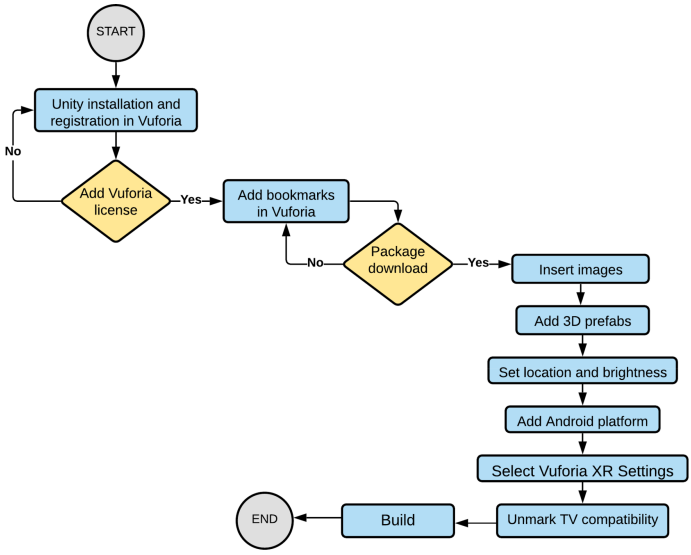

Fig. 4. Functional tests of AR elements in Unity.

Scripts Development. A script in Unity allows it to edit the source code of the elements placed in the scene to make the actions fit the user's needs. For this Unity has a partnership with Visual Studio for code editing. This is later attached to the project with the import of packages. The process for the development of a script is observed in the flow chart of Fig. 5. In the system, the luminosity is an important factor and the configuration of the directional light carried out and the AR elements are not enough. This involves using too many resources on the smartphone, causing overheating. For this reason, it proceeds

to edit the scripts for the shooting silhouette and the crosshairs, to add luminosity to each one, independently. In addition, the general lighting conditions of the system are improved by increasing the brightness that Unity assigns to the application, changing the texture of the shooting silhouette that is superimposed on the target.

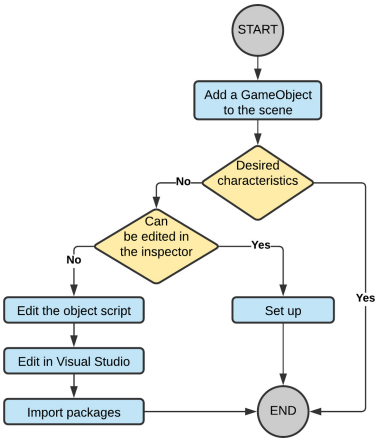

Fig. 5. Flowchart for developing a script.

The AR sight has a green tone, to make it clearer, editing the source code of the script that contains it, for it's clicked on the object and within the Unity inspector and add a Script type component. A new element is created within the inspector, to edit it in Visual Studio just open the script editing tab. All the parameters that want to be improved of each game object present in the scene can be edited through the use of scripts. Most of them already come with a source code, in which the exact variables must be edited. In case there is no direct script for necessary parameters such as texture, lighting, percentage of brightness, and optimal rendering with a low consumption level, the source code of the elements is edited. This programming is done in the C# language.

3.4 Dual Screen Display

The system requires that the instructor be able to have the vision of the shooter to correct misalignments and postures and achieve greater precision in the shot. Unity offers the ability to create a multiplayer environment, so in the augmented reality section, the camera of the second device is activated as well. For this proposal it is not ideal, that is why it's access to remote control of the Android device on which the application is running. In this way, the two screens display the same environment in real-time and the instructor can thus identify what the student is doing.

3.5 Server

The system requires that the videos of the use of the system in each training be stored on a computer. This way, it has a training history for each shooter and it can identify

trends in the most frequent mistakes that are made. For this reason, an FTP server is implemented in the main computer of the establishment. (File Transfer Protocol). In the configuration, there is a port value assigned for instructors to connect to initiate the file transfer. Also has access to the stored videos of the practitioners, respecting the respective access codes granted to the sta.

All instructors are enabled to access the server and to add videos of each training to specific folders from smartphones, by connecting to the establishment's network. Through the AndFTP application (compatible with the server) they access only using a link with the IP address of the computer and a personal password. The server interface is shown in Fig. 6.

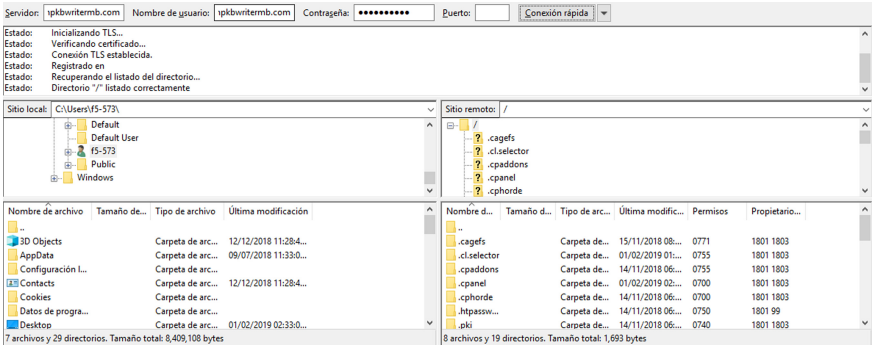

Fig. 6. Flowchart for developing a script.

4 Tests

Before starting the testing stage, the environmental conditions under which the system must operate are defined (which have already been mentioned previously). The system must not have elements that interfere or represent an obstacle when practicing, in any of its stages. Personal protection elements that comply with ANSI standards must be used, this includes elements of visual protection and hearing protection. Viewing, projection, and sight alignment images should conform to the tactical shooting characteristics used internationally and locally. Also, the physical characteristics of each of the five training courts and the signage present in the facilities.

Conventional shooting targets are used to assess the level of accuracy of the shooter. Scores are awarded, where the maximum is 10 points in the center, the contiguous areas with 9 and the most dispersed with 8 points respectively. When all shots that have not reached the target have a score of 0. There are integer values and very close precision data, obtaining variance is not justified. The number of wasted ammunition in the established series is reviewed and the percentage of efficiency is calculated. Figure 7 shows one of the targets used for the shooting session with the AR system and the instructor in the posture correction stage.



Fig. 7. Counting shots on target and posture correction.

Figure 8 shows the Safe Guard anti-ballistic helmet, which has additive support for mobile devices. It is made of metal alloys and presents an absolutely secure and stable grip for both the shooter and the smartphone. The design is adaptable according to the required size and has a fabric covering over the polymer to avoid scratches, without obstructing the view of the shooter. The measurement is exact so that the camera captures the augmented reality marker located in the front sight of the weapon to be shot when a stable shooting position is adopted.



Fig. 8. Ballistic protection helmet with support.

During practice, when acquiring a shooting stance, the shooter observes the superposition of two objects on the screen. First, the target to be shot with numbers for the proximity of the shots with the center of the thorax and then the firing point in green. This alignment is key to making precision shots since it represents the point that the projectile reaches when it is fired. Figure 9 shows the screen with the AR overlays, where the gun script contains the first marker and the firing target contains the second marker.

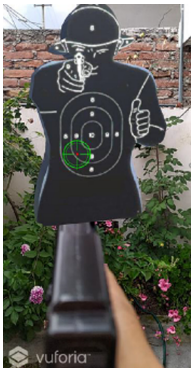

Fig. 9. Viewing AR items during testing.

5 Experimental Results

5.1 System Efficiency

To measure the effectiveness of the system, experimental tests have been carried out with three amateur shooters, a number reduced by the available budget. Series of five shots each are executed. First under the traditional instruction, to count the number of successful shots. After that, a new series of shots are fired, but this time using the proposed system together with the shooting instructor. The results are observed in Fig. 10. The arithmetic mean of the system's efficiency shows that there is an improvement of 116.67% when compared to conventional training.

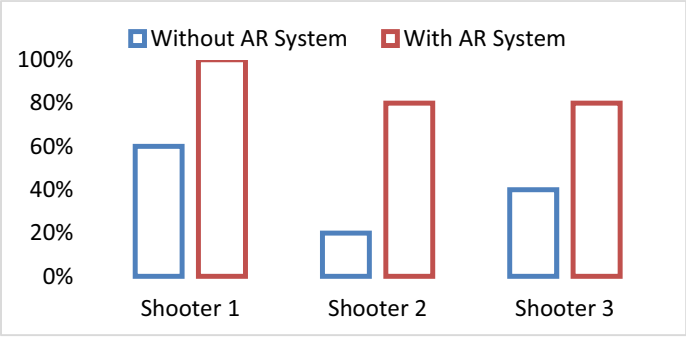

Fig. 10. Comparison chart of successful shots.

When using the AR system, hitting the target is much more likely to happen as the instructor has full access to the shooter's view and corrects misalignments and postures. In the first round, nine ammunition of the fifteen occupied is wasted, while in the second there are only two.

5.2 Subsequent Results

Then the closeness of the shots to the center of the board is evaluated, using the previously established scores. Figure 11 shows a comparison of the scores obtained according to the precision of each shot. The highest percentage of missed shots are directly related to the posture of the shooter, for which the instructor corrects it, adjusting them to a combat posture. After using the system, shooters improve posture and control of the weapon, in addition to reducing training time and ammunition used Practitioners show greater retention of the corrections made by the instructor, maintaining correct postures, even when no longer use the system.

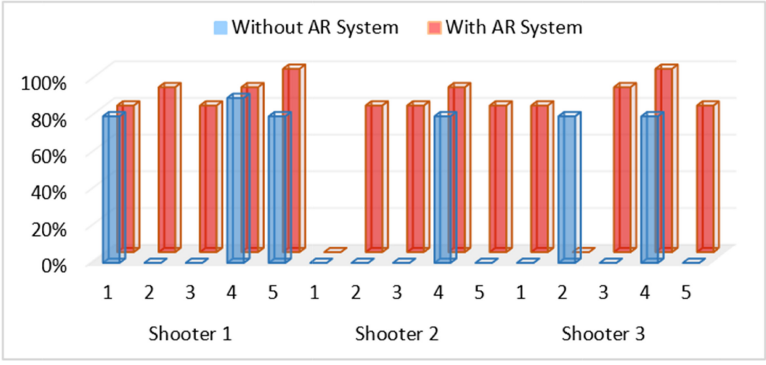

Fig. 11. Shot accuracy comparison chart.

5.3 Comparison with a Virtual Firing Range

When comparing the operation of this proposal with a virtual firing range, the conclusions shown below in Table 2 are obtained.

Table 2. Comparison of characteristics of the AR system with a virtual polygon.

Augmented reality system	Virtual shooting range
Allows the use of real weapons and ammunition	Air guns and ammunition are used, the characteristics of which do not resemble real conditions
The training can be in an outdoor environment, subject to climatic variations and in contact with the environment	The training takes place in a closed place, there is no interaction with external factors
The trajectory of the ammunition and recoil force of the weapon in the detonation is real and requires adequate tactical strategies	Lasers are often used to simulate the path of ammunition and there is no recoil force from a firearm
The vision and the environment are not completely invaded by virtual elements, but there are coupled in a non-invasive way	The environment becomes completely digitized, the immersion in a virtual system removes the real reaction conditions

6 Conclusions

During the analysis of external factors, tactical strategies, and information on the facilities used, it is inferred that the system must only take into account the external factor of luminosity. This since the system is constantly exposed to an outdoor environment with a dry hot climate. The other external factors are not considered, since the distance from the training tracks does not exceed 30 m. Variations in the trajectories of the 9 mm projectiles are also neglected since there are tiny when operating with a speed of 360 m/s.

The proposed system is non-invasive and makes up for the limitations that the shooter has at the moment of sight alignment. It supports tactical instruction and enables training under real physical conditions, which distinguishes it from a laser beam weapon present in virtual ranges. The practitioner should be trained in shooting fundamentals before using the system. Given these fundamentals: posture, alignment, and framing of sights.

During the tests, the instructor is located a few meters away, which allows for correcting erroneous shooting postures. Using the AR marker placed on the front sight improves the targeting focus for the ammo. This allows having a constant correction on the systematic errors that the shooter commits, due to the limitations of vision in a focus frame and inadequate shooting position. This is corroborated with the experimental tests that showed an increase of 116.67% of effectiveness when compared with the traditional method. Which shows that there is a reduction in the amount of wasted ammunition. This also improves the cognitive abilities of shooters, correcting the postures and precision after using the system, which allows time to be optimized.

Several proposals have been developed but in the field of VR, which shows that immersive environments are a trend that is increasing. By implementing this prototype, the use of AR in the field of tactical training can be appreciated. This research seeks to create a sustainable training process that reduces waste production, optimizes times, and offers lasting results over time. Finally, the authors of this document propose as future work to develop an improved version of this system, to improve the service provided.

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