Development of a cost effective simulator for small arms shooting training

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Thesis Acceptance Certificate

Approval Page

To

Certificate of Originality

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205190

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First and foremost, I would like to thank Almighty Allah for giving me the the opportunity and capability to undertake this research study and complete it satisfactorily.

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Lastly, a special thanks to all the students who participated in the testing phase of this project.

Contents

List of Abbreviations

Abbreviations

ILI	Invisible Laser Infrared
3D	Three Dimensional
2D	Two Dimensional
OpenGL	Open Graphics Library
FATS	Firearm Training Simulators
JUST	Judgement Under Stress
OpenCV	Open Computer Vision
HMD	Head Mounted Display
AR	Augmented Reality
ANOVA	Analysis of Variance
PSI	Pounds per Square Inch
SMG	Short Machine Gun

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Abstract

Shooting simulators for firearm training are effective in improving the marksmanship of personnel in different law enforcement agencies like police, armed forces and also in shooting athletes. In order to achieve the best training quality in these training simulators, the weapon's shooting process needs to be replicated to provide the perception of a real shot being fired. A user friendly shooting simulator should provide reliable and accurate information about impact time and hit location at the target of the shot fired from the weapon. Desirably shooting process should display the margin by which a shot missed the target. The impact time at the target is based on the direction and speed of weapon as well as the target and also on the delay time of projectile. We propose a shooting training system with accurately modelled recoil usable for indoor training. It consists of three basic components: a graphic component for visualization, a haptic component for recoil simulation and a tracking component for simulation of shot trajectory. Graphics component displays a moving object to firer. The haptic component uses a custom designed haptic device that works on pulses of compressed air. It contains pneumatic valves that provide rearward pressure consistently to provide recoil. The tracking module includes visible laser mounted on a weapon that is activated by a trigger press. A stationary camera captures the position of laser pointer on the projector screen using image processing. Various different training scenarios are designed to evaluate the efficacy of the proposed shooting training system. A user study was conducted on subjects from different backgrounds to check the accuracy of our system and of user marksmanship. Subjective analysis indicates high resemblance to live shooting training indicating that the designed haptic device is a reasonable option to provide immersion of real shot fired and system is helpful in improving the

Chapter 1

Introduction

1.1 Background

Training simulators are extensively used for training personnel in different areas like police, armed forces and law enforcement agencies. The use of these simulators causes significant reduction in ammunition expenses, reduces the time for preparation of a skilled shooter and also improves quality of training. Ideally, in shooting simulators all aspects of shooting should be reconstructed precisely. This is important for developing the methods of accurate targeting and skills and strong mental condition to behave under different combat scenarios.

To measure a simulator's effectiveness, the ability of the system to reconstruct the psychological and physical impact of firearms on shooter is considered.

Shooting a firearm is a complex process that takes place in a biomechanical system (i.e. shooter-weapon). When a shot is fired from a real weapon, it is followed by a recoil force that affects the shooter. Recoil is the backward movement of a weapon when it is fired. There is a difference between kick and recoil. This can be differentiated as user or shooter gets kick while weapon recoils. The recoil of a weapon is purely a mechanical process while kick is the result of recoil and its nature is physical and psychological. The effect of kick due to recoil acting from the weapon onto a user's body is linked with the weapon weight and the way the weapon is handled e.g. whether it is held tightly or loosely.

To create realistic perception of a shot the simulator should produce conditions like recoil and sound, and realistic visual shooting scenarios should be integrated with these conditions. In addition to this there should be a tracking system to track the position where weapon is pointed at during aiming. So in order to achieve high realism in shooting simulators all these conditions and aspects are necessary.

Development in the field of computer graphics is helping in achieving more immersive interaction between a computer and a human. To make user experience more interesting various innovations have been made. Latest in these efforts are augmented and virtual reality. This development in the field of human computer interaction is useful in a variety of fields especially in shooting training simulators.

When training either on simulated rifle or small arms, the user must be able to aim and fire and also to hold the weapon accurately. Each one of these tasks causes difficulties and different devices and techniques have been designed to help novice users to accurately hit the desired target repeatedly and accurately.

Holding weapon steady is difficult but the main problem is for instructor to determine the reason for unsteadiness. When trainee is able to hold the weapon steady then trainee is shifted to the dry firing where the trainee uses unloaded weapon at target. Lastly, he/she is asked to aim at the target and his performance is measured by checking the number of shots hit at the target accurately and his/her response time.

The main intention of firearms simulator is that these can be used for training in classical aiming scenes where viewpoint is fixed i.e. that the plane of screen does not move with the movement of weapon as in the case of shooting games the plane of screen moves with the movement of mouse. So it is required in these simulators that precision is punctual with no cursor displayed on screen. In our system, mathematical modeling of forces and vision-based tracking has been used along with a calibration process to provide our system with high accuracy in determining the aiming point on screen using coordinates of laser pointer and of the target.Three basic modules in the shooting system are:

1. Tracking: Goal of tracking is to determine where weapon is pointed at during the shooting training. This is very useful for instructor to indicate and correct the mistakes of the trainee shooter. For tracking there exist various methods that help user to improve his/her shooting skills.

2. Haptic Feedback: Haptic feedback is necessary in the shooting training simulators to mimic the firing of a real shot. It improves the level of immersion together with the sound input. Multiples techniques have been used in this regard to provide the force feedback to the user's shoulder, like electric guns [1], customized weapons with compressed gas capsules placed inside the magazine of a weapon.

3. Visualization: Different shooting scenarios can be designed and displayed on a visual display. The virtual scene is simulated where different types of targets can be displayed using computer graphics techniques. The trainee shooter can train and practice in different scenarios that he/she may come across during their service. In outdoor shooting training it is not possible to provide different scenarios as it becomes more expensive and takes more time for preparation. Different display technologies can be used to deliver the trainee with simulated visual information.

1.2 Motivation

Training simulators have proved to be effective for training a wide variety of skills. This is especially true for scenarios where live training is expensive and/or infeasible. For a simulator to be an effective tool for training, it must replicate the real life scenario as accurately as possible, making it more realistic. When it comes to military training, such simulators are of great importance, providing a soldier real life shooting scenarios that he may face during live combat operations. A simulator for shooting training broadly comprises three subsystems i.e. a tracking system, a recoil generation system, and a scenario generation system [1]. Various methods of tracking a simulated weapon exist including using computer vision techniques, inertial measurement units

[2] etc. Electrical, mechanical or customized gas-based systems are usually employed to provide haptic feedback for recoil. Haptic feedback of these simulators is often insufficient to provide the user with the sensation of recoil of an actual bullet. In this work, we focus on modeling accurate haptic feedback of the weapon to provide better immersion to the user. This will be integrated into a system with laser-based tracking and simple learning scenarios will be used to assess the fidelity of haptic feedback and the overall shooting experience. Given the geopolitical situation the need for low-cost effective training methods for law enforcement is obvious. Commercial shooting training systems being very expensive necessitate indigenous development of such systems. Realistic simulation systems will enhance the preparedness of security personnel. Moreover, the recoil system of the proposed training simulation will also be suitable for other applications such as first person shooting games.

1.3 Scope

This simulator will provide haptic feedback to the user when he/she shoots at the target. A laser light source is attached to the to detect the spot where user is aiming the weapon. Accurate tracking of laser is important to improve the necessary skills required for shooting training. Various shooting scenarios that represent different situations that shooter may face during live combat can be developed and integrated into the proposed system. Such a simulator can be used by military and law enforcement agencies. In first person shooting games, haptic device developed for this project can be used by mounting it on the toy weapons to provide immersion to gamers in their shooting experience.

1.4 Problem Statement

Shooting with conventional firearms is risky and there are greater chances of accidents in live firing training. Shooting simulators are suitable for providing a risk free and safe environment for shooting training and improving a learner's shooting skills. Moreover, present shooting simulators provide haptic feedback using customized weapons and costly camera system to track the bullet impact point. The idea is to develop a cost effective training system for small arms shooting training that provides the users accurate and realistic firearm shooting experience similar to a live firing range in terms of recoil and different shooting scenarios that resemble real life combat situations.

1.5 Objectives

The objective of this thesis is to design and implement a low-cost shooting training system that includes accurately modeled haptic feedback, real-time tracking subsystem, and a visualization module that delivers realistic virtual shooting training.

1.6 Approach

As mentioned earlier that live shooting training does not provide a risk-free training environment and requires a wide area allocated to shooting training. So there is a need to develop an indoor simulator that replicates the conditions of live training like recoil, shooting targets and different scenarios. Efforts have been done in this area where personnel from different areas of life can train and improve their marksmanship. Problems with such simulators are that these are very expensive, require the development of customized weapons, and often the available recoil is insufficient to provide realism of shot fired. So in this research, a cost-effective shooting training simulator has been developed that provides effective recoil to trainer's shoulder when the bullet is fired making the shooting experience realistic. Accurate detection of the bullet hit point with a simple web-cam based makes it a low-cost solution. Furthermore, subjective analysis has done in this study on a different group of users from military, gaming and educational backgrounds to test the effectiveness of this proposed system.

1.7 Thesis Organization

The rest of the thesis is organized as follows. Chapter 2 presents the literature review on the shooting training simulators and the techniques that have been used to develop these systems. Chapter 3 explains the methodology of the research work that has been used to develop the proposed simulator and procedures to validate its effectiveness. Chapter 4 presents the results of the experiments and their analysis for the evaluation of the proposed system. In chapter 5, conclusions and future work have been discussed.

Chapter 2

Literature Review

This has been a desire for a long time to provide training to personnel in improving their skills in shooting and firing using different firearms like handguns, shotguns, and rifles. Several methods and devices have been developed in the past to improve the marksmanship and methods to improve the aiming and shooting skills of a user. Most of the devices designed for this purpose, use emission of light to simulate the shooting of a gun. These devices help in training and instructing the user to practice aiming either indoor or outdoor without the use of actual bullets fired from the weapon. Studies have shown that are three basic types of simulators that are GAMMA, FATS(Firearms Training Simulator) and JUST(Judgment Under Stress Training) [3]. These simulators include real time, life sized, computer controlled projected images that do not present any threat to the user. Actual firearms are used with a laser or an infrared emitting device, along with the sound of a shot, to provide a safe shooting environment that includes no accidental shooting of a bullet. The sound if provided by speakers installed in the environment to provide "surround sound" for enhancing realism.

1. GAMMA: The GAMMA training simulators use life sized video based images that are projected onto screen at high spatial resolution. When a trigger is pressed, a video screen sensor on the screen detects the shot and causes screen to freeze and shot location is identified on that fixed frame. A computer database manager determines time by number of the frames between presentation of threat and screen sensor operation. Continuous bullets fired are located in the same way.

This helps the system operator to provide feedback to the user about reaction time of their first and subsequent response.

2. FATS: These systems are technologically advanced and are generally used for small arms shooting training by military and other law enforcement agencies. These simulators present shooting scenarios via a videotape. These are controlled by a computer in order to provide seamless branching where user can switch to another scenario after completing the task. Subjects face situations through life sized video that present different personal threats. The user has a laser equipped weapon and videos are shown in a seamless sequence through computer where user action or inaction lowers or raises the threat presented in the video. The sequence of video is important to study the realistic consequences of real time shooting. For instance, if the user hits the target on a lethal area, the target will fall otherwise on missing target will move forward and hit the user in real time simulation. FATS firearms use simulated recoil to provide force feedback of the weapon during shooting as shown in Fig. 1.2. Shotguns, machine guns, rifles with simulated action use CO2 operated recoil that makes FATS more realistic [1].

Figure 2.1: CO2 cartridges used for recoil [4]

3. JUST: JUST simulators were designed to provide the trainer with flexibility to customize the scenarios according to their need. In these systems judgment and accuracy of the individual shooter can be measured. For these systems, a high speed video player provides user information about the shooting score and accuracy just after finishing the task. JUST simulators allow the use of a real firearm modified to fire with infrared beam that is captured by IR based sensors. When the user shoots at the target, the coordinates of the shot fired are identified and a cross hair is used to mark the position of shot fired. One advantage of this system is that the trainer can access the raw data and can change parameters like point of threat. In addition, these systems provide flexibility to trainer to make the scenarios customized on relatively cost.

2.1 Shooting Simulatotors

In most systems where shooter uses a gun that emits light to project luminous mark on the screen, a shot is considered to be successful when the light emitted from the weapon aligns with the target on a screen. A successful shot is indicated by the cancellation of a target or by displaying the simulated object that was hit. Electronically controlled audio and visual indicators are also used to indicate the hit [2]. When a light beam gun is used to project the concentrated light such a laser beam, the target apparatus is used to indicate the position of impact of the simulated projectile. One of the target apparatus comprises a light-receiving element like a photo-diode and photoconductive cell. When it is used alone, this light-receiving element is only capable of detecting light rays emitted from the gun that have landed in a specific range on the target defined by an area of the light-receiving surface but does not indicate accurately the impact area of the light beam [2].

2.1.1 Electronic Display of Target

There is another technique that has been introduced that uses electronic apparatus to display targets with multiple light-receiving elements arranged in the plane to indicate which light-receiving element has detected a light beam. Light beam guns project the light mark in the form of the small circle and its diameter is in millimeters. To indicate such a small circle, it is necessary to emit light to correspond to the impact of the simulated projectiles [2].

2.1.2 Clay Shooting

Another example of prior shooting devices involves clay shooting that utilizes the light emitting gun and flying pigeon target is provided with the light-responsive element. The light-responsive element is provided in clay and the hit occurs when an element that is responsive to light detects light beam from a gun. The disadvantage of this device leads to a sighting problem that is also required in real clay shooting and it cannot be simulated by the system. Training devices have previously been developed for various operations including guided missile launcher, rocket launcher, handguns, shoulder weapons and other similar weapons by providing options/scenarios close to those that are likely to have happened under real shooting conditions. There has been interest in using these systems for firing from combat vehicles, guns of tanks or other moving units [5].

Traditional methods for training in firing and marksmanship for police, military, hunters and others leave too much for desire in terms of realism, practicality, and cost. Most of the firing ranges have limited capacity. Moreover, many ranges for shooting do not provide safety to a user from natural elements like rain or snow. Due to the level of noise that is related to firing ranges these shooting ranges are normally located in remote areas and people have to drive to these ranges making such training expensive [6].Most of the ranges have fixed targets. Furthermore, using live ammunition has its own problems like administrative, safety issues, and above all government rules and regulations are burdensome. For initial training in aiming it is preferable to use indoor shooting ranges where users can shoot simulated bullets on simulated or computer targets [7]. In some systems shooting targets are displayed on a screen from a motion film and laser beams are aligned with the barrel of the weapon to simulate the shooting of real projectiles. A trainee aims and hits the displayed target on the screen [8].

Over the past few years a number of weapon simulators, devices for training and other equipment have been introduced, as well as methods and techniques to determine their use. These methods, equipment, and devices have fulfilled the requirements of a user to some extent but these usually cost more, are difficult to use and lack the internal delay of the projectile when it passes through the weapon [9].

2.2 Augmented Reality

Augmented reality, hugely popular nowadays, is a combination of the real world and the virtual world. It is a breakthrough that is helping to improve the experience of interaction of shooters with the system [10]. To build an augmented reality-based system for shooting training there are two different methods: marker-based and markerless. Broadly speaking components of AR applications are markers, cameras, and computers. The camera is used as a tool to capture an image which is sent to the computer which uses them to determine the location of objects to be displayed. A computer is used to help in the graphics part [11].The camera is a component used to take images from a real world that is forwarded to a computer system for video merging. The depth chart in the system creates virtual images, while video merging is used to mix the virtual objects with images of the real world captured by the camera. The monitor is used to display the output of the AR system.

2.2.1 Marker-less and Marker-based Tracking

To determine or identify the images that are displayed in the augmented reality system use two kinds of models that are marker-based and markerless [12]. Image which is a definition of the marker is a specific pattern that serves as a target for the detection of location of the virtual object to be displayed. The computer recognizes the orientation and position of the marker and creates a 3D virtual world that includes point (0,0,0) and three axes X, Y, Z. Once it is detected the correct position and right scale of the camera are defined. This method is known as marker-based object tracking [13]. Fig 2.2 is an image of an example marker that can be used in AR applications:

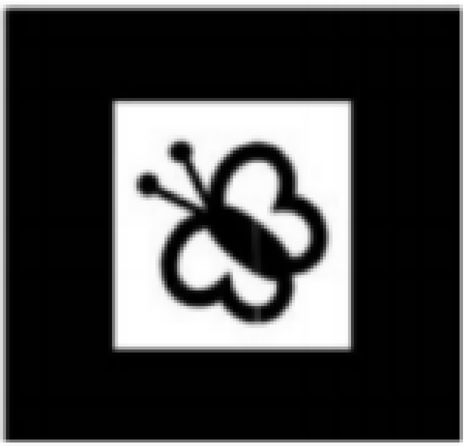

Figure 2.2: Marker used in AR application [14]

There are different options to display the simulation. These include monitor output or the use of HMDs (head-mounted displays). The use of HMD increases the immersion and give real effect as viewpoint experiences difference to when the user sees through a monitor [15]. There are two ways to display objects using HMD, named as video tracking and optical tracking [13].

2.3 Simulator using Haptic Device for Recoil

There is another system that has been designed that includes a physics engine, haptics, and techniques for motion capture [1]. This system provides force feedback using haptic technology and trigger pull weights and recoil has been rendered on user hands that achieve muscle memory training. The physics engine has been used to construct a shooting environment that provides realism and it also profiles shooting results of each user. To capture the motion of the user when he/she is shooting motion capture comes into play. The haptic term refers to incorporate the sensation of touch into a virtual world, that provides passive or active feedback to the user [16]. On the basis of the human perception of objects in the virtual world, there are two categories of virtual devices named as kinesthetic and tactile devices. Tactile devices when attached to human skin these provide a tactile sensation to skin that is responded to by skin receptors. A sensation that is perceived by joints and muscle by means of translation and rotation is provided by kinesthetic devices [17]. Force rendering in firearm shooting training is used:

- To calculate the various forces that are involved in shooting training for example recoil force and trigger weights. These forces are modeled based on physical and mathematical formulae.
- To increase the level of immersion in indoor shooting training by providing recoil forces and assisting with the training of muscle memory.
- To build firearm profiles that include their specifications. Profile of firearms includes weight, caliber, bullet type, barrel length, rate of fire, and trigger weights.

2.3.1 Trigger Pull Weights

Trigger pull weight is another force that is important with recoil during the discharge of a bullet. Different firearms offer different trigger weights, this force is larger for pistol and smaller for rifles. So, haptic devices have been used to render different weapon trigger pull weights [18].

The three different colors present different stages of shooting of a firearm shown in Fig 2.2, blue to green is called pre-travel, green to red is called break while green to red is called over travel [19]. Movement before the sear action is called pre-travel, this varies depending on the type of trigger i.e. single action and double action. Only one action is performed in a single action that is releasing the striker when trigger is pulled while in case of double-action the weapon is first cocked before the striker is released. A break is a critical stage in firearm shooting. It can be classified as a crisp break and soft break and it depends on weapon type. Soft break represents smooth travel of trigger

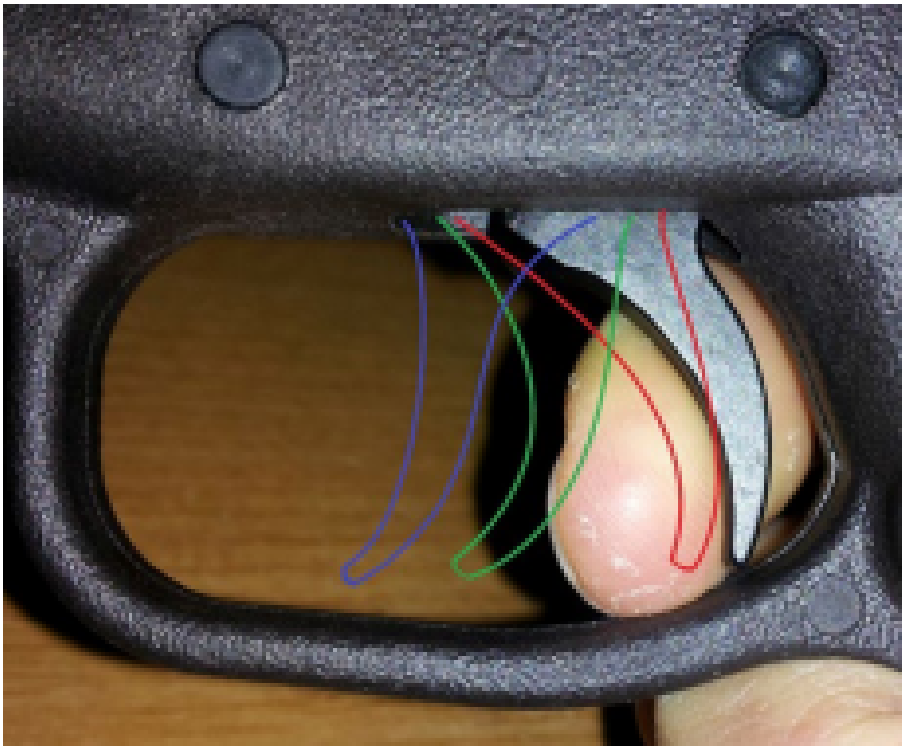

Figure 2.3: Image showing three phases during trigger pull [1]

while crisp break refers to a heavier weight. The distance the trigger travels after the release of the sear is called post-travel, because of inertia. In this movement, the bullet remains in a barrel while it has been fired.Fig 2.3 is the representation of x-ray image of over travel, when the bullet has been fired but actual is inside the barrel [20].Touch and vision are two dominant components for sensation [21]. Haptic and visual rendering is independent for computer systems but they can be linked and complement each other [22].

2.4 Use of ILI (Invisible Laser Infrared) in Training Simulator

Using invisible laser infrared with real scale weapon(dimension of custom made weapon is same as real weapon) and virtual shooting environment is another approach used for training simulators [18]. The challenge for most of these simulators is how to provide

Figure 2.4: X-Ray image of bullet travel inside the barrel [23]

the most effective shooting experience as compared to real life. Mostly real-world digital simulators use an invisible laser as their main technology. Although the laser path is different from the actual path of a bullet it is most suitable to simulate the bullet trajectory as in real-life firing training [24].Invisible laser tracking technology helps the user to learn actual shooting techniques in order to hit the target more accurately. ILI (invisible laser infrared) unit emits infrared laser on the target screen. This spot is captured by an image capturing system and then is further processed using data processing. 390nm to 700nm visible light is filtered from the screen using a light filter [18] The wavelength of the invisible laser is higher than the range of visible light. This helps to capture the IR spot on the screen easily and to capture it with precision. Four corner localization method is used for calibration in ILI based simulator, to adjust coordinates of the mouse on the screen. Coordinates of the mouse cursor are followed by a defined sequence to complete the calibration. The tracking process starts when the corner is captured by a camera, the system main loop starts when calibration is completed. The main loop consists of a series of image manipulation performed on each frame resulting in an array of coordinate points on the screen. When image acquisition and four corner localization are complete, then the system adjusts for the internal coordinates with the external coordinates conversion process. Then emitted ILI spot on screen from the muzzle is transformed into a mouse position (cursor) and a click command for guiding bullet impact. The second technology includes mounting the ILI and recoil device onto a customized weapon that in this simulator was a T91 rifle. This rifle has specifications from both the M-16 and AR rifles. Recoil is provided through the compressed gas-based system. On pressing the trigger gas inside the magazine of weapon provides recoil. Both the ILI unit and recoil device were synced to provide an immersive shooting experience.

Shooting training for law enforcement agencies, private citizens and military personnel increasingly includes ability to make decision in addition with marksmanship. These trainings mostly involve competing against players or to respond to a situation that is projected on the screen in front of the user/trainee. Self-healing allows the use of conventional firearms shooting, but this requires a location that is appropriate for the conventional firm shooting [25]. Moreover, these systems are very expensive and unreliable.

In order to increase locations where these trainings can be conducted safely, alternatives to conventional shooting have been developed including paintball simulations, and laser for showing the trajectory the bullet would have been taken upon firing [25]. The possibility of accidents that is present in live firing training can be reduced by training personnel in risk free environment [26].

Problems with these simulators are that they do not represent all these specifications/characteristics of bullet fired from weapon. Therefore, it limits the extent of training that can be given to user. Recoil is the most important and most difficult to provide in these simulators. Inability of getting user accustomed to recoil that is generated by weapon is the one of the biggest disadvantages of using these simulators. Recoil forces shooter to adjust the aim after shooting but also to adapt level of discomfort that is equal to energy of bullet for which weapon has been chambered. Recoil is difficult to handle that makes accurate simulation of recoil critical.

So to cope with the issues in shooting training simulators the proposed system provides a risk free environment for training with accurately modeled recoil and accurate tracking of laser spot emitted upon pressing the trigger.

Chapter 3

Methodology and Implementation

The idea of this research is to provide the realism of shot fired by developing a haptic device that provides realistic rearward force to user shoulder, and to improve the shooting skills of the shooter and making the shooting training possible in safe environment. To check the effectiveness and accuracy of this simulator, experiments and subjective analysis have been done so that this system can be used by law enforcement agencies, military training and also for gaming purposes.

3.1 Proposed Framework

First part of the research is to accurately model recoil and achieve real-time accurate tracking. Upon pressing the trigger, the haptic device is activated and a laser pointer emits the laser beam. A camera captures the laser spot on the projector screen then coordinate information of laser pointer is processed by a personal computer. At the same time, the user feels force feedback. The second part of it is to verify that indoor shooting training with the proposed system can replace conventional shooting training.

3.2 Structure of framework

Working of the proposed simulator has been shown in the Fig 3.1 . Laser is emitted from the weapon and projected on the screen. A webcam that has been attached with the laptop captures the laser spot, a projector has also been attached with the laptop to project shooting scene on the screen. Compressor provides air for the haptic device mounted on the weapon to produce recoil.

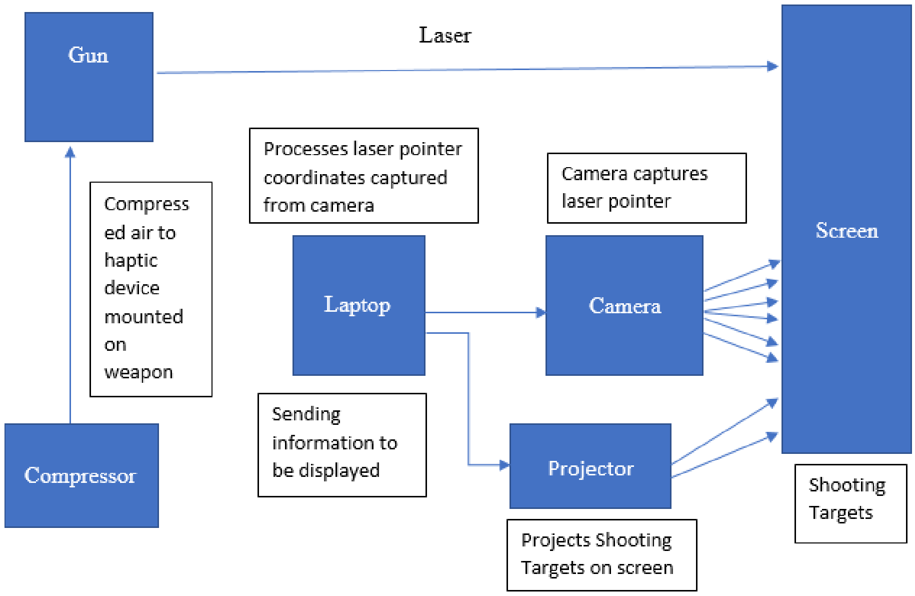

Figure 3.1: Working of the proposed simulator

3.3 Implementation Details

Development of the proposed simulator includes following steps:

- Laser Tracking
- Design of Custom Haptic Device
- Development of Haptic Device
- Development of shooting scenarios

3.3.1 Laser Tracking

Most of the shooting training simulators use laser tracking to detect the position where weapon is pointed so that to confirm if the target has been hit or missed. Furthermore, laser sight is the best way to represent the path or trajectory of bullet when fired from weapon [27]. So, a similar approach has been used in the proposed system. To track the laser, spot on the target scene image processing has been done using OpenCV.

A web-camera connected to a personal computer captures the image of the target scene. A green colored physical filter is added to the front of the camera to subtract all other components of light in the environment as a green laser light has been used in this system. Without this green color filter camera camera will capture all the components of white light in the environment including the green laser mounted on the weapon, and it is not possible to distinguish between laser spot and other light components. Fig 3.2 and Fig 3.3 shows target image captured by camera with and without colour filter respectively.

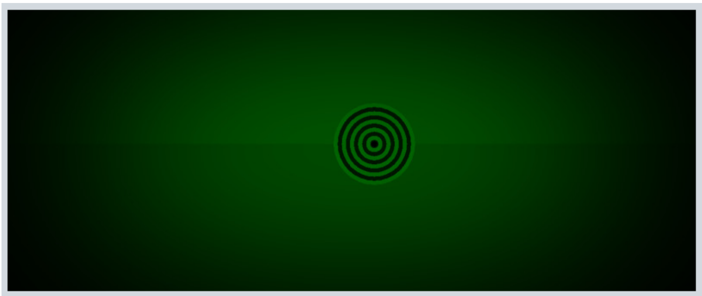

Figure 3.2: Target image with color filter

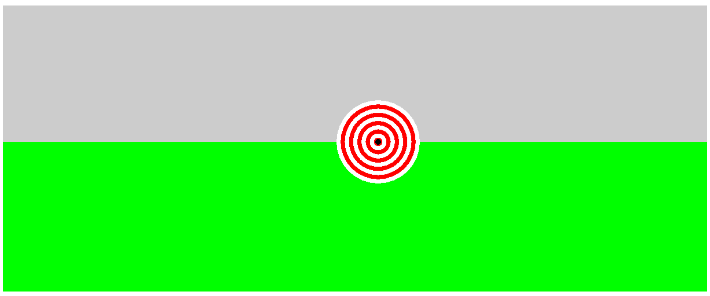

Figure 3.3: Target image without color filter

At the initialization of the simulation, calibration is first performed to specify the screen area where targets will be displayed by clicking on top left and bottom right corner of the screen as shown in Fig 3.4.

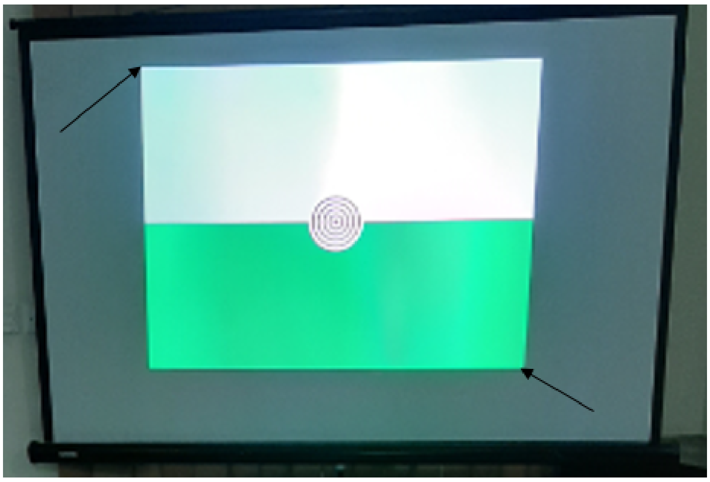

Figure 3.4: Calibration to specify the screen area by clicking top left and bottom right corner

After that target appears on the screen and user is allowed to start shooting. Push button mounted behind the trigger has been shown in Fig 3.5

Figure 3.5: Push button to activate the haptic device

When user presses the trigger that is controlled by a button attached to the trigger of weapon, a laser spot is emitted from the weapon onto the target screen. Camera attached to the personal computer captures the spot and then coordinates of that laser spot are analyzed by OpenCV.

Laser coordinates that are transferred for processing are then further transformed to OpenCV coordinate system, because resolution to display the targets varies based on what has been used to display the targets for instance a laptop screen or projector screen. So to solve this problem a generic code has been developed that itself detects the resolution of any display window/screen and then further processes display source resolution into OpenCV coordinate system. When laser spot is detected and further processed a virtual bullet is fired and displayed on the position where shooter pointed the weapon and pressed the trigger. Shots fired by a user during experiment when target is displayed at fixed location at the distance of 50m is shown in Fig 3.6

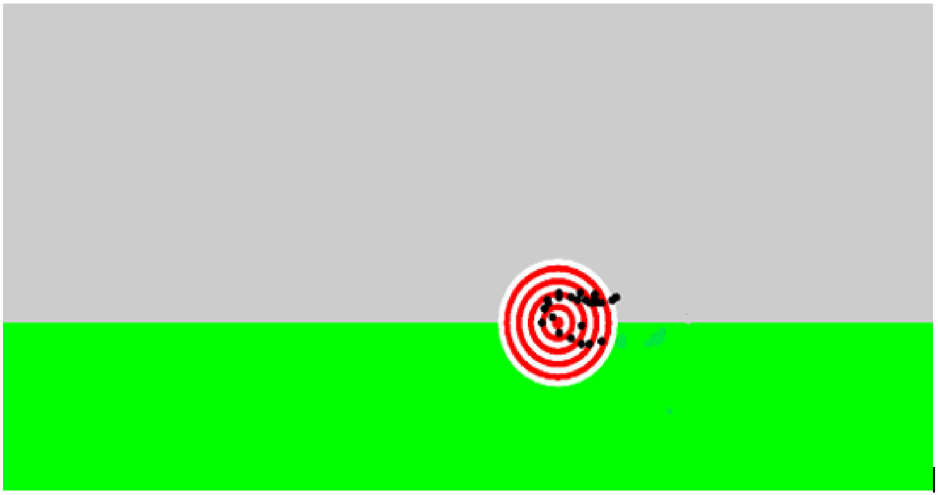

Figure 3.6: Shots fired by user at fixed target

3.3.2 Design of Customized Haptic Device

As discussed earlier, accurate recoil is one of the most important things for such simulators in order for these to provide a realistic shooting experience. So, the proposed simulator provides a unique and generalized solution. The approach is a generalized design in the sense that it can be used with a number of different weapons without the need to develop a customized weapon. This is in contrast to existing approaches where recoil is provided through compressed gas either from gas containers located inside the magazine or directly providing the air inlet from the muzzle of weapon.

In first case where recoil is provided through magazine, simulators require the development of customized weapon which is an exact replica of the original weapon in terms of shape. However, this approach is expensive and military personnel who train on conventional weapon find it difficult to adjust to these customized weapons usually having lighter weight and less recoil due to the limited capacity of the magazine to hold gas capsules. Moreover, these capsules provide limited pressure of gas to provide sensation of recoil [28].

In the latter case where compressed air from compressor or air bottles is provided to the weapon through the muzzle of an actual weapon, a control valve for air pressure needs to be installed inside the weapon that makes it impossible for the weapon to be reused in conventional firing. So there is a need to provide a solution that is cost effective and does not require damaging the weapon. The proposed haptic device provides a solution where there is no need to design and manufacture a customized weapon and weapon can be reused again after the simulation training and recoil that shooter experiences during shooting makes it realistic as the recoil that this device provides replicates the recoil of real shot fired. It is designed as an attachment that can be mounted onto any weapon and removed after use, thus eliminating the need for a customized weapon or modification to an actual weapon.

Calculations that are required for this device include the amount of force that is required to press the recoil spring inside the weapon to its maximum permissible distance when weapon is cocked [8]. This is calculated using the Hook's law [29]

$$F = kx \tag{3.1}$$

where k is the spring constant, x is the distance the spring travels from its equilibrium position when force is applied to it and F is the force required to stretch the spring to distance x.The weapon for this simulator is a Chinese manufactured SMG (Short Machine Gun) and the calculations for the haptic device are according to this weapon. So, when a bullet is fired from the weapon, as it exits the weapon it leaves a huge force behind it due to combustion of gun powder. This force pushes the bullet out of the gun barrel and to travel a specific distance and hit a target with high force, however when bullet and gun are considered together say when bullet has been fired from weapon but it is still inside the barrel of weapon it can be said there is no net force on gun-bullet system. So, momentum of gun plus bullet can be considered as conserved [30]. Consider that the bullet has speed vb and mass mb, momentum of bullet in forward direction can be calculated as [31]

$$P_b = v_b * m_b \tag{3.2}$$

For balancing this momentum and to keep the net momentum on gun bullet system zero the gun recoils in the direction opposite to the direction of bullet,Pg represents the momentum of gun and Pb the momentum of bullet.

$$P_g = -P_b \tag{3.3}$$

$$v_g * m_g = -V_b * m_b \tag{3.4}$$

vg and mg represents the velocity and mass of gun respectively.

As the mass of bullet is small but its speed is quite large so it releases with great momentum. Gun has a larger mass as compared to mass of bullet, so the recoil speed of gun is much smaller but enough to provide force feedback against the shooter's shoulder. The velocity with which the gun travels when a bullet is fired is calculated as

$$v_g = -v_b * m_b / m_g \tag{3.5}$$

For the weapon chosen for designing the proposed simulator i.e. SMG(Short Machinie Gun) the measurements obtained are shown in Table 3.1

Using these values in equation 3.5 , we obtain vg = (- 1.18 m/sec). This is the velocity gun recoils with when a bullet is fired where the negative sign indicates the velocity is in the negative direction to the bullet.

The pressure produced due to combustion of gun powder in the bullet is (45,000 psi)

Weapon Parameters	Values
Mass of Gun	4.78 kg
Velocity of bullet	71 m/sec
Mass of bullet	0.0079 kg
Spring wire diameter	0.070 in
Spring Outer diameter	0.472 in
Spring free length	38 in
Number of active coils on spring	90
Area of gas piston	2.16 in

Table 3.1: Measurements of weapon

[32]. This is the pressure that propels the bullet out of the gun muzzle to travel a distance in hundreds of meters and to hit the target with high momentum. It is not possible to produce that amount of pressure from an air compressor in a cost effective manner. In order to provide the force feedback to the shooter's shoulder, it is practical to produce the pressure or force that is enough to compress the recoil spring of the weapon to a specific distance. This is because the gas released during the combustion of gun powder does two things. First, it pushes the bullet with high velocity and forces it out of the chamber and secondly pushes the gas piston inside the weapon backwards that is used to load the next bullet inside the chamber during its forward stroke. The recoil spring attached to this piston also compresses and as a result gas piston makes its forward motion when spring extends loading the next bullet. Force required to compress the spring has been calculated and dimensions of gun recoil spring (Table 3.1) have been used for the compression spring in this haptic device [33].

Using the above dimension, the value of k for spring used in the haptic device is 5.900 lbs/in. Now, in order to calculate the distance that spring covers during the compression, consider the following distance:

- Un-cocked distance, $x1$, the distance the spring is compressed to when it is placed inside the weapon before the gas piston backward stroke [10].
- Cocked distance, $x2$, the distance that spring covers during the backward stroke of piston.

For the chosen weapon, the values for these distances are ($x1$= 10 in) and ($x2$= 25 in) respectively. Thus, using Hooke's law two forces are obtained as $F1$(un-cocked) = k* $x1$ = 5.90*10 =(59 lbs) and $F2$(cocked) = k* $x2$ = 5.90 * 25 = (147 lbs). Total force required to compress the spring to (35 in) is therefore:

$$F = F1 + F2 \tag{3.6}$$

$$F = 147 + 59 \tag{3.7}$$

$$F = 206lbs \tag{3.8}$$

Using the value of area of the gas piston of SMG from Table 3.1, the pressure required to produce the desired force can be calculated.

Now the pressure to be produced by the haptic device to provide the force feedback can be calculated easily using

$$P = F/A \tag{3.9}$$

Where

P= is the pressure required,

F= is the recoil force and

A= is the area of gas piston.

By using Eq 3.9

P = 206 /2.16

P= 95.37 psi.

Adding the safety factor of 10 percent as there is a pressure drop when compressed gas travels through the inlet pipe to haptic device due to wall thickness and length of a pipe we get

P = 95.37 + 9.537

P = 104.907 psi

So, the pressure required for the proposedis simulator to provide realistic recoilm of shot fired is approximately 105 psi. This pressure is produced using a single acting reciprocating compressor.

3.3.3 Development of Haptic Device

The custom device developed for haptic feedback consists of the following components shown in Fig 3.7

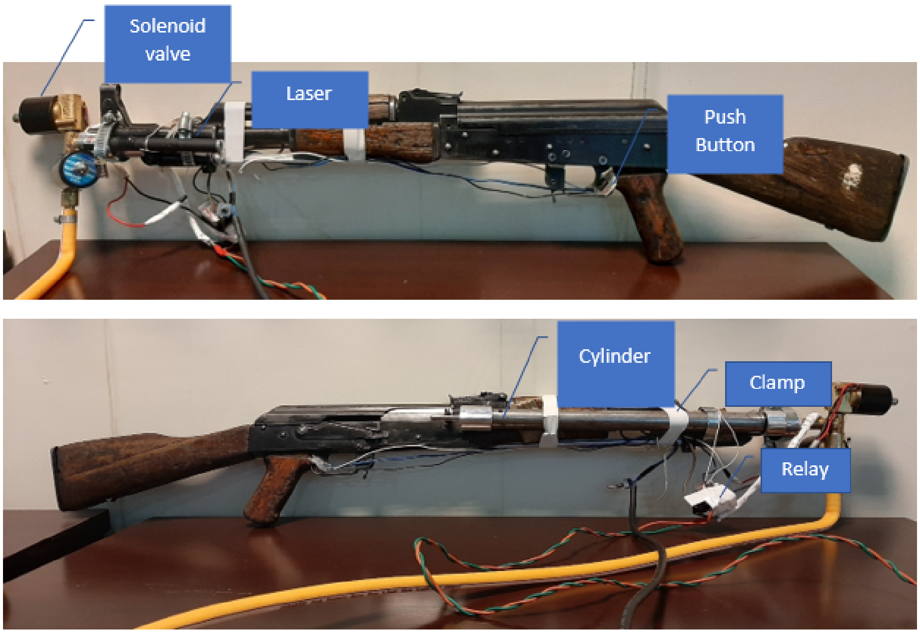

Figure 3.7: Components of Haptic Device

Solenoid valves provide air to cylinder for haptic force and these are activated upon pressing the push button. Two solenoid valves have been used, one is for air inlet and the other is air outlet. Green laser light has been used to help user aim at the target. Push button behind the trigger activates the solenoid valves when it is pressed. A spring piston assembly provides haptic force to the user when shot is fired and the cylinder provides space for the movement of the piston. Relay has been used to activate the solenoid valves separately, when trigger is pressed and the push button is pressed as a result of it, the air inlet valve operates and air enters the cylinder when trigger is released the inlet valve closes and outlet valve operates to remove the air from cylinder.

1. Working Principle: The proposed haptic device consists of a spring piston assembly enclosed in a cylinder. Two solenoid valves are attached to one end of the piston. Inlet valve to provide the compressed air inside the cylinder works on 220V while the outlet valve for the air on 12V. Reason for using 220V for air inlet is that it can allow more pressure to pass through than 12V solenoid valve because orifice dia of 220V is bigger. So when the push button that has been attached behind the trigger of the weapon is pressed, inlet valve operates through a relay switch and allowing air to enter inside the cylinder meanwhile outlet valve remains closed. High pressure compressed air pushes the piston backwards that provides the recoil force to the shooter's shoulder. When trigger/push button is released inlet valve closes through relay and outlet valve opens. Due to elastic potential energy stored in the spring when air is cut off it extends causing the piston to move to its equilibrium position and forces the air trapped inside the cylinder to move out through the outlet valve. The same cycle is repeated when user presses the trigger every time. Fig 3.8 repsents the circuit diagram for the haptic device. Positive terminal of the outlet solenoid valve is always connected with the relay that keeps this valve open unless push button is pressed. A common negative wire from both solenoid valves has been attached with the push button. When push button is pressed outlet valve's connection with the relay breaks and relay then connects with the inlet valve and then circuit completes with the air inlet valve.

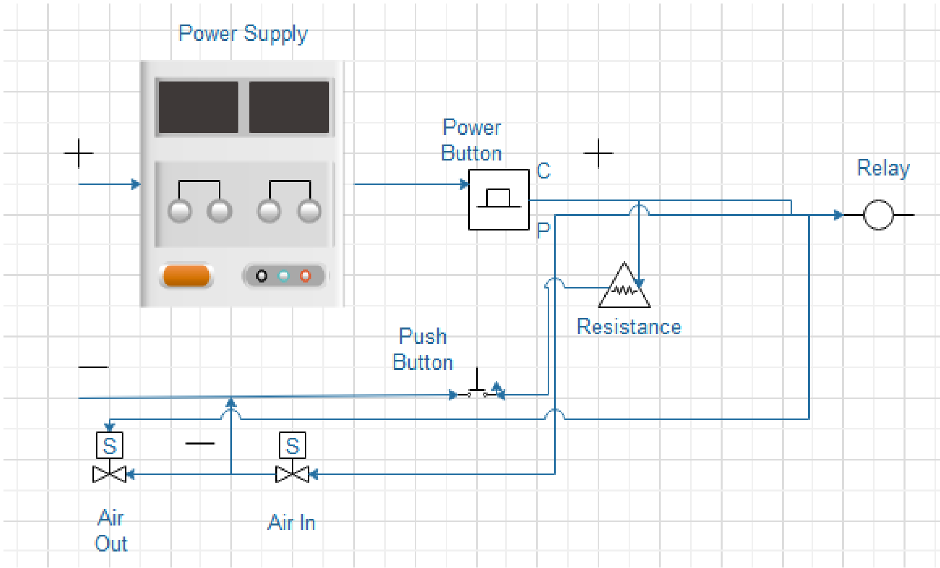

Figure 3.8: Circuit diagram for haptic device

3.3.4 Development of Shootnig Scenarios

Shooting scenarios for these simulators have been designed on different platforms like Unity, NVidia PhysX [34], etc. OpenGL has been used for this simulator to develop different shooting scenes.

Different target scenes have been designed that require high skill level in terms of accuracy and quick response, replicating the demands of real combat shooting. This has been achieved by displaying targets at different distances, with each distance difficulty of task increases as user has to hit in the center of the target to get maximum score.

There are six type of shooting scenarios developed for this simulator, in first three scenarios target is displayed at a fixed location by varying the distance i.e 15m, 25m and 50m. Aim of this scenario is to check the variance in accuracy of shooter by changing the target distance.In fourth scenario target appears at random location on the screen and when target is hit it reappears at different location on the screen. In this scenario user has to move and adjust the weapon position after every shot to get a successful hit unlike the previous scenario where target is stationary at a fixed position.In the scenario five the difficulty of task increases as the target continuously moves on the screen. At the start of the task target appears on the screen and starts to move in a random direction. The continuous movement of the task makes it difficult for the user to hit the target. A shot is considered to be successful only if the user can hit at the center of the moving target, when the shot is successful target reappears at a random location on the screen and the same cycle continues. This scenario is helpful in training the personnel to shoot at a moving target with high accuracy. Scenario six is the same as five but time constraint is applied to check the how many accurate shots user can shoot in a limited time.

Another feature of this simulator is that system records the impact point of bullet automatically. When target is hit camera captures the location of the laser spot at that point and its coordinates are determined. On the other hand, location of the target is known, so with the help of OpenCV this coordinates information is analyzed and using the Euclidean distance between the laser spot and the center of the target shooting score is assigned against each shot. In this case shooting target consists of ten circular disks. So based on the coordinates information of the laser spot user gets maximum score of 10 when he/she hits the center of the target. User gets score from 1 to 10 based on which circular disk has been hit. Using this information trainer can check about the shooter's learning status and can also correct their mistakes. System records the data of each user's shooting status and this can be used to develop strategies for teaching, correct the weak points, and also improve their essential skills. Fig 3.9 displays the proposed system for shooting training. Where target has been displayed on a screen using projector connected to a personal computer. Camera to capture the laser spot and compressor provides pressurized air for the haptic device.

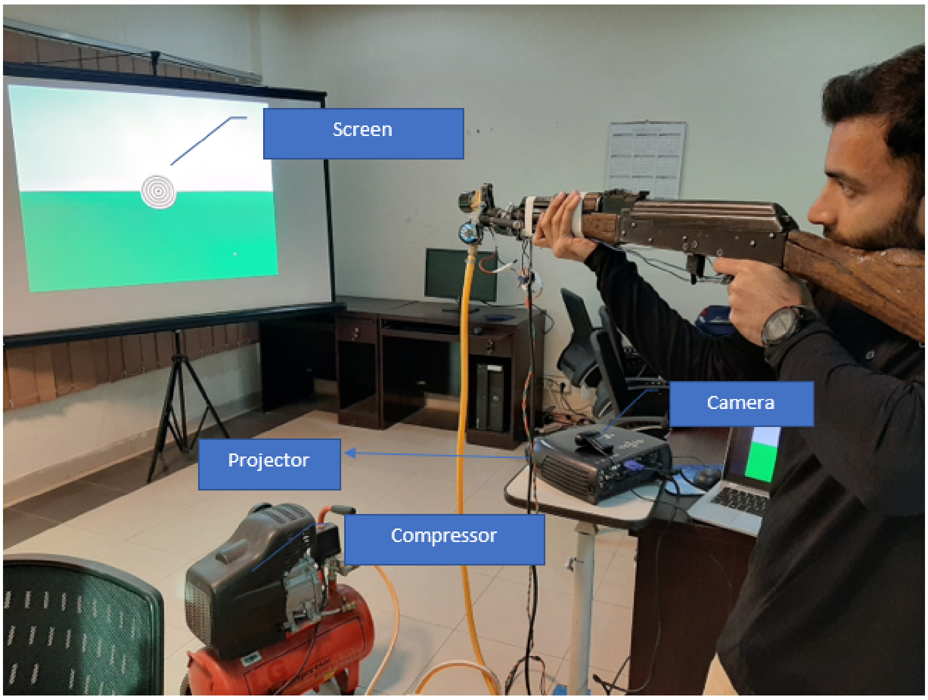

Figure 3.9: Simulator designed for shooting training

Chapter 4

Results and Discussion

4.1 Experiments

As it has been described earlier that the research work provides a solution for making the shooting training simulators immersive by providing accurately modeled recoil and making these simulators cost effective so that military personnel, law enforcement agencies and other users can improve their shooting skills. To check the effectiveness of this simulator six shooting scenarios have been designed to test the shooting skills of the participants.

- Target displayed at 15m distance
- Target displayed at 25m distance
- Target displayed at 50m distance
- Fixed target appearing at random locations on the screen
- Target moving continuously in a random direction on screen
- Shooting with time constraint at continuously moving target

The six shooting scenarios have been divided into four experiments. In first experiment target displayed at fixed location, in second experiment fixed target appears at random location, in third target moves continuously and in fourth target continuous movement with time constraint to complete the task. In each experiment participants shot the target with haptic feedback and without haptic feedback and analysis of experiments has been performed to check the accuracy of proposed system and subjective analysis for the overall system effectiveness. Total of 15 people between the age of 25 to 50 from military, educational and gaming background participated in this experiment. Participants fired 10 shots in each experiment except experiment 4 in which unlimited shots could be fired in a given time.

1. Experiment 1: In this experiment participants shot at a fixed target. OpenGL library was used as described earlier to design the shooting scene. Target displayed for this experiment is a circular disk that is also used in live firing range as shown in Fig 3.3. Diameter of this circular disk is 1m, using the object size to distance ratio targets are displayed at different distances at 15m, 25m and 50m. With each distance variation difficulty of the task increases as the participants have to hit the bullseye to get maximum score. When user hits at the target, a circle is drawn at the location where laser spot hits the target and score according to that location on target screen is displayed helping the user to adjust the aim after every shot. When user hits anywhere on the circular disk a green color circular disk appears on the top right corner and if participants fail to hit the target a red circular disk is displayed on the same location. After each shot, the hit score is stored in a text file to determine the shooting status of each participant.

2. Experiment 2: For this experiment participants were asked to shoot at a moving target (circular disk). At the start of simulation, the target appears at a random location on the screen, when the shooter hits at the center of target, it again appears on a random location on the screen. The process continues for the number of shots that hit the target, if user misses the target it remains on the same location. Shooting score for this experiment was recorded by calculating the Euclidean distance between the target location and the shot location. Accuracy is determined by the value of Euclidean distance.

3. Experiment 3: In this experiment, at the start of the simulation the target appears on a random location on the screen and moves continuously in a random direction. Same procedure has been followed here as for experiment 2, the target appears at some other random location after a successful hit and starts to move again. If the user misses the target and target escapes the screen boundary it reappears on some other location and repeats the same cycle. The aim of this experiment is to check the response time of user when target keeps on moving continuously on the screen. This also increases the difficulty of task as target is not stationary and the user has to hit at the center of the moving target. Euclidean distance between the continuous moving target and the shot fired helps in determining the accuracy of shooter.

4. Experiment 4: This experiment is same as experiment 3 but there is a limitation of time in this experiment. User has to hit as many shots as possible within 10 seconds on continuously moving targets. The idea of designing all these experiments is to replicate the situations that personnel from military and law enforcement agencies may follow during real life combat scenarios where shooting skills of a person and response time to any sudden situation matters a lot. All the scenarios of this simulator provide these combat situations to prepare a person for such conditions.

4.2 Evaluation of shooting

Graphical representation of the individual shooting score and all the fifteen users has been shown in Fig 4.1 and Fig 4.2 respectively. The x-axis represents the number of shots fired by a user and y-axis represents score against each shot. The trend shows that with increasing distance, accuracy of the shooter decreases similar to a real life firing range.Fig 4.1 represents the shooting score of one user of 10 shots fired in each scenario where target distance is 15m, 25m and 50m.

It can be seen from the Fig 4.1 that maximum points were scored when target was at

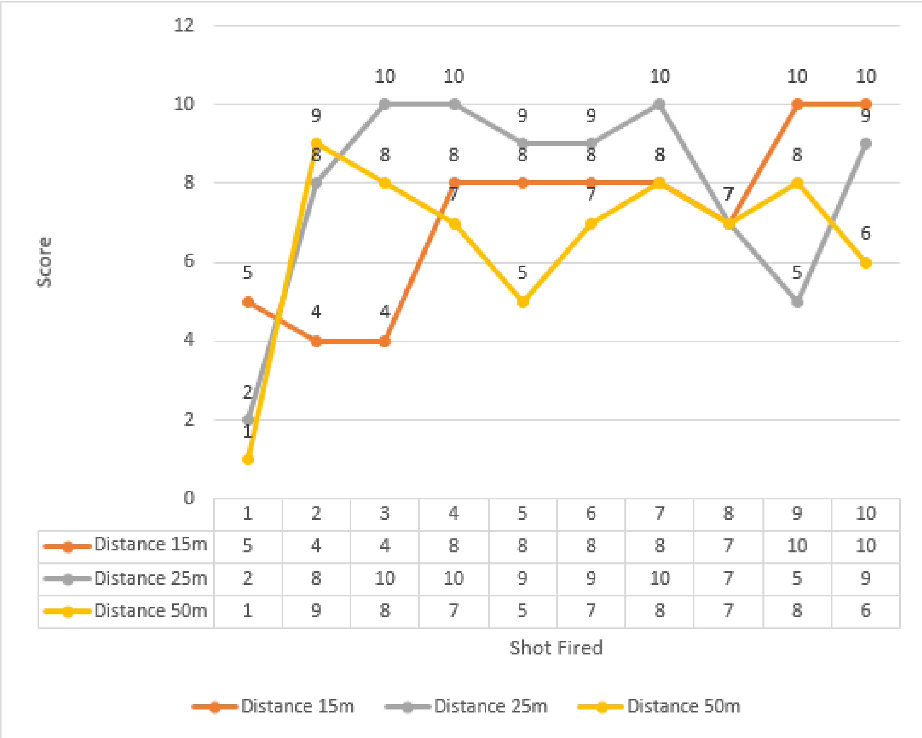

Figure 4.1: Shooting score of one candidate for fixed targets

15m and 25m. Yellow line represents that when target moved to 50m shooting points scored dropped to lower values and haptic feedback makes user to adjust the aim after every shot that causes variation in the shooting score with each distance.

Fig 4.2 represents the overall shooting score of 15 candidates in experiment 1 when each of them fired 10 shots at each target distance. Gradual decrease in shooting score at each target distance can be seen from the graph. Overall trend corresponds to the statement that with the increase in the distance of shooting target displayed accuracy is affected.

Fig 4.3 is the representation of experiment 2 when target moves to a random location on the screen whenever there is a successful hit. This is the data of all the users with each firing 10 shots during the experiment. x-axis represents the number of users and on the y-axis there are values of Euclidean distance calculated for each shot. Average Euclidean distance has been represented here against each user to show how close the target was hit by the user.When values of average accuracy on y-axis are small it means that overall shots fired by a participant were close to the center of target while larger

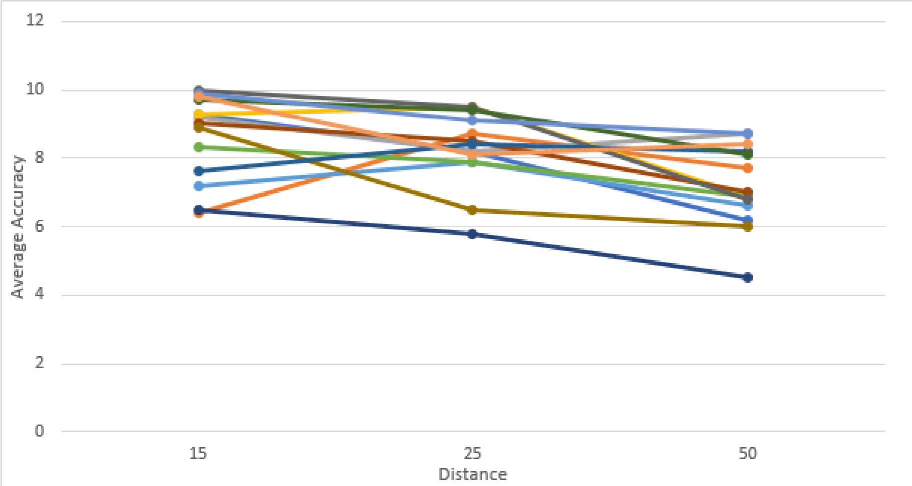

Figure 4.2: Shooting score of 15 candidate for fixed targets

values are the indication of shooting far from the center of the target. The results of experiment 2 show that accuracy of the participants in this scenario is less than experiment 1 as target is not at the fixed position it moves at the random location requiring larger aim adjustment from the user.

Figure 4.3: Average shooting score of 15 users for moving target

Shooting at the target that is fixed is much easier than shooting at a continuously moving target with a specific speed. For personnel from military and law enforcement agencies this is very important skill that is required in real life combat scenarios. They must be trained accordingly to improve this skill. In live firing training it is difficult to provide such scenarios for the obvious reason. So, the proposed simulator provides the solution for this problem and helps these personnel to train and improve their shooting skills to hit a moving target.

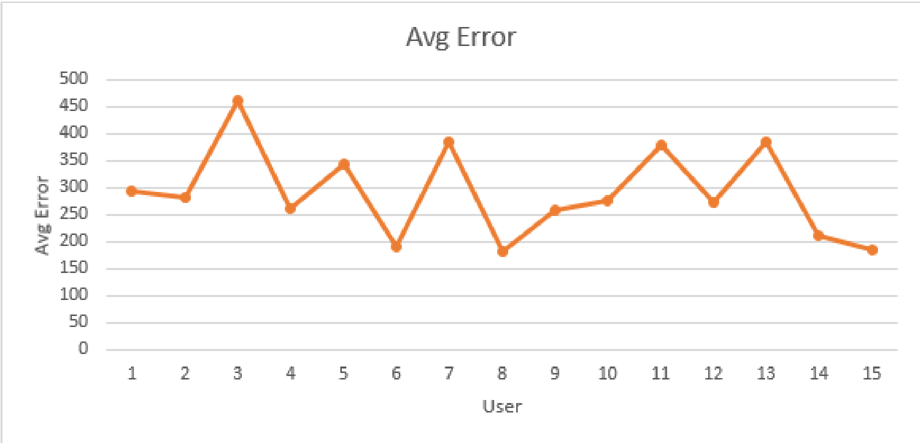

Figure 4.4: Shooting score of 15 users for continuously moving target

Fig 4.4 represents the shooting data of 15 candidates of experiment 3 where they were presented with the scenario where target appears at any random location on the screen and starts to move at a specific speed. Same procedure as followed before has been used here to determine the shooting results of the candidates. Average error is displayed on the y-axis and number of candidates on the x-axis. Values observed for this experiment are much larger than experiment 2 showing that hitting a continuously moving target increases the difficulty in aiming. Moreover, a candidate has to adjust the aim after every shot due to recoil provided by the haptic device.

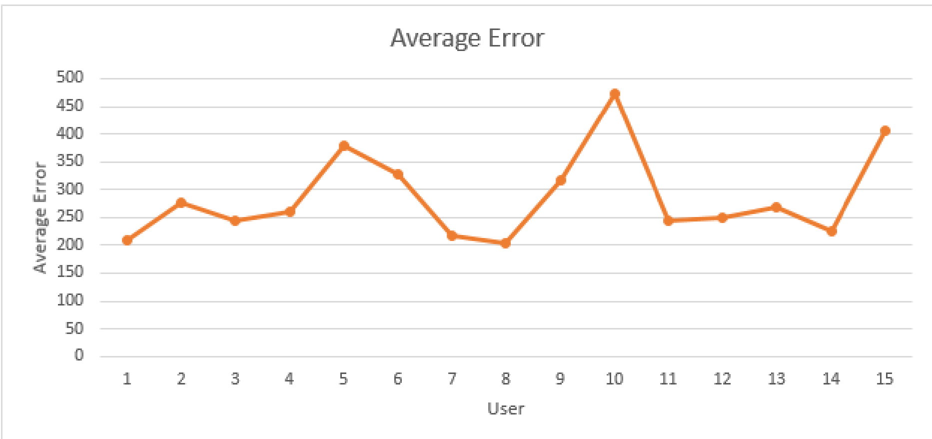

Figure 4.5: Shooting score of 15 users for continuously moving target with time constraint

Experiment 4 as described earlier is same as experiment 3 but with the time constraint. Fig 4.5 shows the result of experiment 4. The number of shots fired by the candidates vary depending on their shooting skills. The average accuracy of all the shots fired by individuals is presented in Fig 4.5 The aim of this experiment was to provide the scenario where a personal has limited time to respond and has to act fast in order to avoid any mishap. So this experiment trains the personal for this kind of situation. Graph shows that candidates were not able to hit the target as closely as they did in previous experiments.

4.3 Data Analysis:- ANOVA:For fixed target at 15m, 25m,50m

N	Sum	Average	Variance	Standard Deviation
15	129.6	8.64	1.441143	1.200476
15	125.7	8.38	1.257429	1.121351
15	106.2	7.08	1.510286	1.228937

Table 4.1: ANOVA results

Results of ANOVA (Table 4.1) shows that accuracy is effected when difficulty of task increases and haptic device developed for this simulator replicates the recoil of real shot fired as user accuracy is affected because user has to adjust weapon position after every shot and the effect is more when target is not stationary. P-value of 0.00162 for this experiment is less than alpha value (0.05) means there is a significant difference in the mean value of all three target scene shooting score [35].

Questionnaire analysis was also conducted to check the effectiveness of this training simulator. Fig 4.6 represents the rating of all individual responses to the questionnaire. Rating from 1 to 5 correspond to Likert scale [36]. Responses of all the candidates are presented here.

Q1. The shooting simulation reassembles my previous shooting experience in real life

Q2. Does using haptic feedback system provide more immersion?

Q3. Does provision of haptic feedback make you adjust your aim after every shot?

Q4. How accurate was the haptic feedback to the recoil of real shot fired?

Q5. Do you prefer shooting with haptic feedback?

Q6. The system is immersive and I enjoyed the simulation

Q7. Do you agree this method benefited for your shooting skills?

Q8. Do you agree this method increases your motivation for learning shooting skills?

Q9. Do you agree this method allows you to concentrate better?

Q10. Do you agree this method builds self-confidence in the true live firing range exam

Users	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Average	
1	4	4	2	5	4	5	5	5	5	5	4.4	88%
2	3	4	4	5	4	5	5	4	4	2	4	80%
3	2	4	4	4	4	5	5	5	5	4	4.2	84%
4	3	4	4	3	4	5	4	4	4	4	3.9	78%
5	4	4	4	1	2	5	4	5	5	4	3.8	76%
6	4	4	4	4	4	4	4	4	2	4	3.8	76%
7	3	4	2	3	4	4	4	4	4	4	3.6	72%
8	3	4	4	3	4	5	5	5	5	5	4.3	86%
9	4	3	4	4	2	4	4	4	4	4	3.7	74%
10	4	4	4	4	4	4	4	4	4	4	4	80%
11	4	2	2	4	4	4	5	5	4	5	3.9	78%
12	4	4	2	4	4	4	5	4	5	5	4.1	82%
13	4	4	2	4	4	4	4	4	4	4	3.8	76%
14	3	4	4	4	4	5	4	5	5	4	4.2	84%
15	4	4	3	4	4	5	5	5	5	5	4.4	88%

Figure 4.6: Questionnaire Results

Based on Fig 4.6 it can be observed that overall candidates provided positive feedback on shooting in this simulator. Also the statistical analysis has been done using SPSS to check the effectiveness of our system and also proves the hypothesis that proposed haptic device does not effect the performance of the user due to weight added to the weapon and recoil that device provides resembles the recoil of real shot fired as it can be seen from the SPSS result of questions 1 to 5 presented in (Table 4.2) to (Table 4.6). Results of questions from 6 to 10 in (Table 4.7) to (Table 4.11) shows that the overall user preferred shooting in this simulator to improve their marksmanship and also the proposed system is a reasonable option for indoor shooting training.

The resutls show that proposed system provides complete functionalities and requirements that are required for improving the shooting skills of a person and builds confidence in the people from outside the military background to train and improve their marksmanship.

Table 4.2 presents the overall response of 15 candidates to question 1 using SPSS, and it shows that 9 students (60 percent) agree that shooting in this simulator resembles the previous shooting experience.

	Frequency	Percent	Valid Percent	Cumulative Percent
Disagree	1	6.7	6.7	6.7
Neutral	5	33.3	33.3	40.0
Agree	9	60.0	60.0	100.0
Total	15	100.0	100.0	

Table 4.2: Shooting simulation resembles previous shooting experience

Table 4.3 shows that 86 percent candidates agree that haptic feedback that the system provides makes our simulator more immersive.

	Frequency	Percent	Valid Percent	Cumulative Percent
Disagree	1	6.7	6.7	6.7
Neutral	1	6.7	6.7	13.3
Agree	13	86.7	86.7	100.0
Total	15	100.0	100.0	

Table 4.3: Haptic feedback provides more immersion

Question 4 in (Table 4.4) has been asked to check if the proposed system provides enough recoil that user has to adjust the aim after every shot as it happens when firing the actual bullet. Results of the question shows that out of 15, 9 students agree with the statement.

Based on the calculation of recoil in chapter 3, (Table 4.5) presents the analysis of candidate's response to see how accurate was the recoil of the haptic device.

	Frequency	Percent	Valid Percent	Cumulative Percent
Disagree	5	33.3	33.3	33.3
Neutral	1	6.7	6.7	40.0
Agree	9	60.0	60.0	100.0
Total	15	100.0	100.0	

Table 4.4: Haptic feedback makes you adjust your aim after every shot

	Frequency	Percent	Valid Percent	Cumulative Percent
Strongly Disagree	1	6.7	6.7	6.7
Neutral	3	20.0	20.0	26.7
Agree	9	60.0	60.0	86.7
Strongly Agree	2	13.3	13.3	100.0
Total	15	100.0	100.0	

Table 4.5: Haptic feedback was accurate to the recoil of real shot fired

In some indoor training system there is no recoil of the weapon, user just presses the trigger without any force feedback. Table 4.6 shows that 86 percent candidates agree that indoor shooting training should be preferred with haptic feedback.

	Frequency	Percent	Valid Percent	Cumulative Percent
Disagree	2	13.3	13.3	13.3
Agree	13	86.7	86.7	100.0
Total	15	100.0	100.0	

Table 4.6: Shooting with haptic feedback is preferred

All the 15 candidates agree that proposed system provides immersion and they all enjoyed the simulation(Table 4.7).

	Frequency	Percent	Valid Percent	Cumulative Percent
Agree	7	46.7	46.7	46.7
Strongly Agree	8	53.3	53.3	100.0
Total	15	100.0	100.0	

Table 4.7: The system is immersive and i enjoyed the simulation

Basic purpose of the indoor training systems is to improve the shooting skills of the user and to train the personnel for any real life situation. All the shooting scenarios in this simulator enable the user to practise their aim by shooting at fixed and moving target. Candidates gave positive response in terms of the improvement in their shooting skills (Table 4.8).

	Frequency	Percent	Valid Percent	Cumulative Percent
Agree	8	53.3	53.3	53.3
StronglyAgree	7	46.7	46.7	100.0
Total	15	100.0	100.0	

Table 4.8: Do you agree this shooting simulator benefited for your shooting skills

Table 4.9 shows that the simulator provides motivation of learning shooting skills for all candidates from different backgrounds.

	Frequency	Percent	Valid Percent	Cumulative Percent
Agree	8	53.3	53.3	53.3
Strongly Agree	7	46.7	46.7	100.0
Total	15	100.0	100.0	

Table 4.9: Do you agree this shooting simulator increases your motivation of learning shooting skills

To check the shooting performace of the candidates they get a score from 1 to 10 after firing each shot. This allows users to concentrate completely on the task. Result in (Table 4.10) shows that 14 out of 15 candidates agree that the shooting scenarios developed for the simulator and the scoring system allow them to concentrate better.

	Frequency	Percent	Valid Percent	Cumulative Percent
Disagree	1	6.7	6.7	6.7
Agree	7	46.7	46.7	53.3
Strongly Agree	7	46.7	46.7	100.0
Total	15	100.0	100.0	

Table 4.10: Do you agree this simulator allows you to concentrate better

Table 4.11 presents the overall response of 15 candidates that they are keen to perform in live firing range exam.

	Frequency	Percent	Valid Percent	Cumulative Percent
Disagree	1	6.7	6.7	6.7
Agree	9	60.0	60.0	66.7
Strongly Agree	5	33.3	33.3	100.0
Total	15	100.0	100.0	

Table 4.11: Do you agree this simulator builds self-confidence in the true live firing range exam

Chapter 5

Conclusions and Future Work

5.1 Conclusions

In this research, we propose a cost effective system that can be used by people from different backgrounds like law enforcement agencies, military and gaming background to improve their shooting skills. Shooting with conventional firearms in live firing range is risky and there are chances of accidents. Moreover, it costs a large amount that is spent on bullets, shooting targets and open space required for training.

Presently there are many shooting simulators that are being used to improve the shooting skills of these personnel as shooting with conventional arms in live firing range is risky and there is a possibility of accidental bullet fired. So, indoor training simulators come in handy when it comes to providing shooting training without compromising the safety of personnel.

Recoil is one of the most important aspects of these simulators to provide immersion of real shot fired. Problems with existing recoil techniques are that they cause either damage to the weapon and weapon cannot be reused again for conventional firing or development of customized weapon that is not feasible for training large group of people like in military.

The proposed system provides a solution to these problems where a haptic device has been designed that is mounted on a conventional weapon to provide recoil in indoor shooting training reducing the cost of developing customized weapon and allowing the reuse of the weapon again in live situations. The proposed haptic device is a generalized solution as the device is not specific to one weapon and it can be mounted on any assault rifle by modifying the calculations for the desired weapon like recoil spring calculations, force required to cock the weapon and piston stroke length during its motion etc.

Experimental results of the simulator training where subjects from different background participated in the study show that this system provides accurate detection of bullet impact point and variation in shooting score in each scenario shows that accuracy is affected by increasing the difficulty of task. Furthermore, subjective analysis provides the positive feedback on the effectiveness of the system and it can be used for improving shooting skills.

5.2 Future Work

Experimental results and subjective analysis show the effectiveness of the simulator, but using virtual reality for visualization will help in increasing the level of immersion.

Force sensors can also be used to determine the amount of force that user feels during the recoil of weapon and compare it with the force of actual bullet fired that user feels and use the sensor data for comparison between the two. In this simulator visible light has been used for detecting the position where weapon is appointed at, it can be replaced by IR, with the help of IR camera IR spot on the screen can be detected.

Tracking the movement of participant and displaying it with the help of avatar in shooting scene will make the training more interesting and the provision to evade the enemy attack by moving in the scene. Shooting experience in such scenarios can also be improved if user feels haptic force when he/she gets hit during enemy attack.

Sniper training can also be incorporated in this simulator by including physical factors like gravity, wind speed and drag that affect bullet flight path when bullet covers a large distance that sometimes exceeds 1000m.

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