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Research Article

Design and Implementation of an Individual Shooting Simulation System and Software

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ABSTRACT

In this study, a software solution for the development of the Individual Shooting Simulation System is introduced. Shooting training for military and law enforcement is critical to mission effectiveness and safety. However, traditional shooting methods have physical, financial and safety limitations. The developed software offers a cost-effective solution to the user, thanks to its portable capabilities and user-friendly interface. The system includes laser-based targeting, image processing applications and real-time feedback. Designed in Python, the software offers easy installation and use with portable hardware. Tests have shown that the system is successful in terms of accuracy (%±1 pixels), speed (under 1 second processing time) and flexibility. Users and instructors expressed their satisfaction with the performance and ease of use of the system. Additionally, the system offers an effective learning environment for both individual and group training. In the future, it is aimed to implement the system in a wider application area with improvements such as artificial intelligence-supported image processing and mobile device compatibility. This study provides a solution that contributes to making shooting training safe, effective and accessible.

1. INTRODUCTION

All elements of the Armed Forces and the Gendarmerie General Command, the Directorate of Security and the Coast Guard Command, consisting of law enforcement forces, are of critical importance for the protection of the national economy and public order [1].

While the armed forces undertake the task of protecting the country against threats that could harm its sovereignty and territorial integrity, it plays a strategic role as a deterrent against possible external threats and, when necessary, as a striking force. Law enforcement forces, on the other hand, carry out their duty to ensure public security by ensuring social order, protecting the rights and freedoms of citizens, and fighting against crime and criminals. The fact that the personnel working in these institutions is effectively trained and equipped is the most fundamental element for the institutions responsible for security to fully fulfill their duties. The personnel to work in these institutions are selected and they begin training on weapons and weapon use simultaneously with the start of their training activities.

Shooting training ensures that Military and Law Enforcement personnel acquire the skills and weapon knowledge they need to use their duty weapons effectively and minimize the risks that may arise during use [2].

Shooting training of these personnel is a critical process to improve target accuracy, increase their ability to make quick decisions to neutralize the target by shooting it from the desired point, and reinforce their safe gun use skills. This process ensures the success of personal effectiveness and tactical field operations to destroy the target in any operation.

Traditional shooting training is a process that starts from the theory of basic gun use, continues with the introduction of weapons, and ends with the use of real bullets in the final stage. In this process, the safety rules against accidents and aiming principles for duty weapons are explained theoretically and they are informed before the actual shooting [3].

In this process, both physical conditions and ammunition costs prevent the trained personnel from providing sufficient practical training. Traditional training has many limitations, including security and shooting areas. Limitations such as preparing targets before shooting in open shooting areas or closed ranges, preparing physical security and protective measures for both the shooter and other observers, bringing and distributing ammunition also increase the duration of the training. Additionally, any carelessness during shooting may result in accidental injury or death [4].

Personnel who are not properly or sufficiently trained may cause an unexpected accident when using weapons or shooting to neutralize the target. This means the mission fails. For this reason, it is very important to properly and fully train military personnel authorized to use weapons and law enforcement personnel fighting crime and criminals.

Simulation-based shooting training systems are very flexible during training. By using these systems, ammunition and time are saved. In addition, the absence of ammunition increases the amount of shooting and allows the detection and analysis of the shooter's errors [5]. Simulations have evolved into a structure that is safer, faster and accessible to more people [6].

Simulation systems allow users to find more shooting opportunities, increase their aiming abilities, and be trained through realistic scenarios. It also ensures that security risks that may arise during real shooting are eliminated [7-9].

Shooting training through simulation attracts a lot of attention not only in military and law enforcement schools but also in the civilian field. As a result of this interest, many defense industry companies offer different software and systems to users to meet their needs. The developed systems are generally targeting military or law enforcement institution users. These systems aim to increase the success rate of users as well as increase their decision-making and scenario-based skills. For this reason, their costs are quite high. These types of systems, which are costly, are not preferred by individual users [8]. It is seen that studies on Shooting in the academic literature focus on virtual reality (VR) and augmented reality (AR) technologies. VR and AR technologies make shooting training more effective. [8,10]. In addition to the many benefits of virtual reality-based shooting simulations, their hardware requirements also require high costs.

The developed individual shooting simulation system software is designed to create an effective alternative simulation suitable for individual use apart from existing solutions and as a portable and cost-effective solution that will appeal to individual users. The developed software also allows effective personalization of shooting training. This article explains in detail the possibilities, capabilities and advantages of the developed individual shooting simulation system software.

2. MATERIALS AND METHODS

In this section, the components of the developed Individual Simulation System software and the working principles of the software are explained. In this context, the working logic of the developed software and the necessary hardware are specified step by step.

The system consists of the following basic components. The general view of the system is shown in Fig. 1.

Web Camera: Used to monitor the target and record images during shooting. Resolution and frame rate have been optimized to increase the accuracy of the system.

Computer: It is the basic hardware on which image processing algorithms are run and simulation results are analyzed.

Target Paper: Standard A4 size target papers were used to physically evaluate shooting hits and measure the performance of the system.

Laser: Two different lasers that can be mounted on the weapon or placed inside the barrel of the weapon are used. The trigger mounted on the gun flashes momentarily due to the shock that occurs during shooting.

The laser bullet placed in the gun barrel flashes momentarily as a result of the completion of the electronic circuit after the gun needle touches the laser bullet during the trigger.

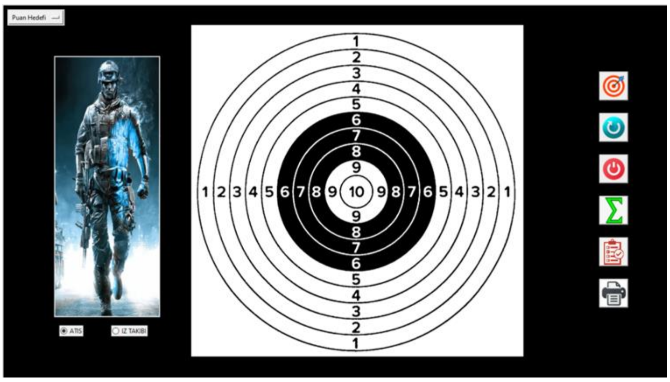


Figure 1. General view of the software

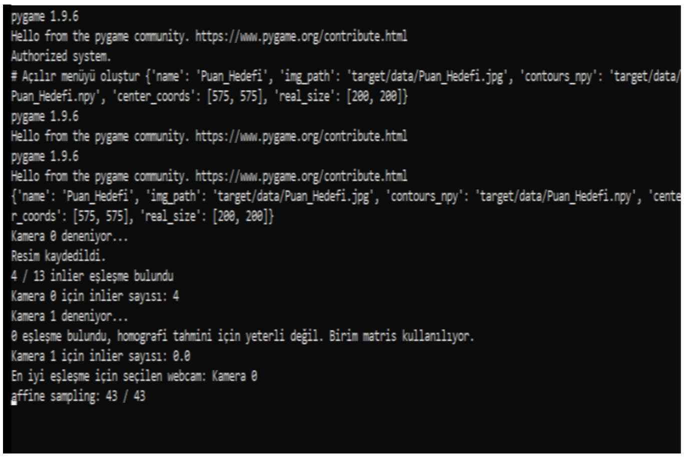
Simulation software: The software was written in Python software language using image processing algorithms and visualization interface. Python libraries used in the developed software are presented in Fig. 2.

```python
from doctest import master
from multiprocessing import Process, Queue, Value
from datetime import datetime
from PIL import Image
import numpy as np
import cv2
import time
from pygame import mixer
from gui import GUI, DialogRecalib
from utils import *
import os
import sys
import tkinter as tk
```

Figure 2. Python Libraries Used in the Software

Individual shooting simulation system usage includes the following steps.

System Setup: The web camera is fixed facing the target paper and positioned at a certain distance. The camera is positioned to completely frame the target paper with a linear alignment. The computer is integrated with the system to process images from the webcam in real time. The developed software automatically takes action to ensure that the right camera takes the right image during startup, as shown in Fig. 3. The reason for this is that the image of the externally attached webcam is transferred to the system, not the existing camera of the computer.



```
pygame 1.9.6
Hello from the pygame community. https://www.pygame.org/contribute.html
Authorized system.
# Açılır menüyü oluştur {'name': 'Puan_Hedefi', 'img_path': 'target/data/Puan_Hedefi.jpg', 'contours_npy': 'target/data/
Puan_Hedefi.npy', 'center_coords': [575, 575], 'real_size': [200, 200]}
pygame 1.9.6
Hello from the pygame community. https://www.pygame.org/contribute.html
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{'name': 'Puan_Hedefi', 'img_path': 'target/data/Puan_Hedefi.jpg', 'contours_npy': 'target/data/Puan_Hedefi.npy', 'cente
r_coords': [575, 575], 'real_size': [200, 200]}
Kamera 0 deneniyor...
Resim kaydedildi.
4 / 13 inlier eşleşme bulundu
Kamera 0 için inlier sayısı: 4
Kamera 1 deneniyor...
0 eşleşme bulundu, homografi tahmini için yeterli değil. Birim matris kullanılıyor.
Kamera 1 için inlier sayısı: 0.0
En iyi eşleşme için seçilen webcam: Kamera 0
affine sampling: 43 / 43
```

Figure 3. Camera selection and Sample Calculation

Image Processing: Image Acquisition, the webcam recorded high-resolution images of the target sheet after each shot. Pre-processing, the captured images were subjected to noise reduction and contrast enhancement processes. The image taken from the webcam is corrected by the software by following the correction steps. By correcting angular errors in the image taken on the webcam, the image is corrected to its actual size. In this way, it is sufficient for him to just see the target, without having to see the target directly in front of him. An image of scaling the image to its actual size is shown in Fig. 4.

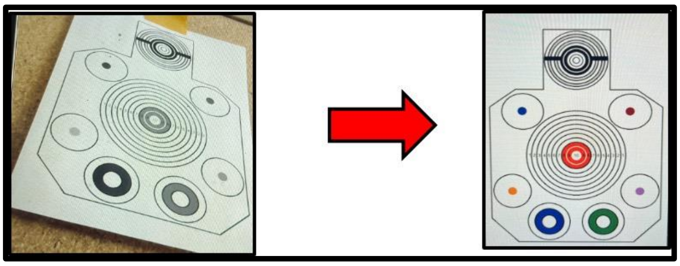


Figure 4. Scaling the image to actual size

Target Analysis: With the image processing algorithm, the position of the laser light on the target is calculated in pixels and its actual position on the aimed target is marked. Morphological operations and edge detection techniques have been used effectively in this process. Software Flow Diagram is presented in Fig. 5.

3. RESULTS

This chapter presents the findings from the implementation and testing of the Individual Shooting Simulation System software. The system was evaluated for its performance in image processing detection and analysis of shooting hits, as well as its general usability in simulating individual shooting applications.

Adding a system target; the desired target can be added to the system in A4 size. Before defining the target in the system, counter zones in the relevant areas of the target were selected and an npy. file was created for these regions.

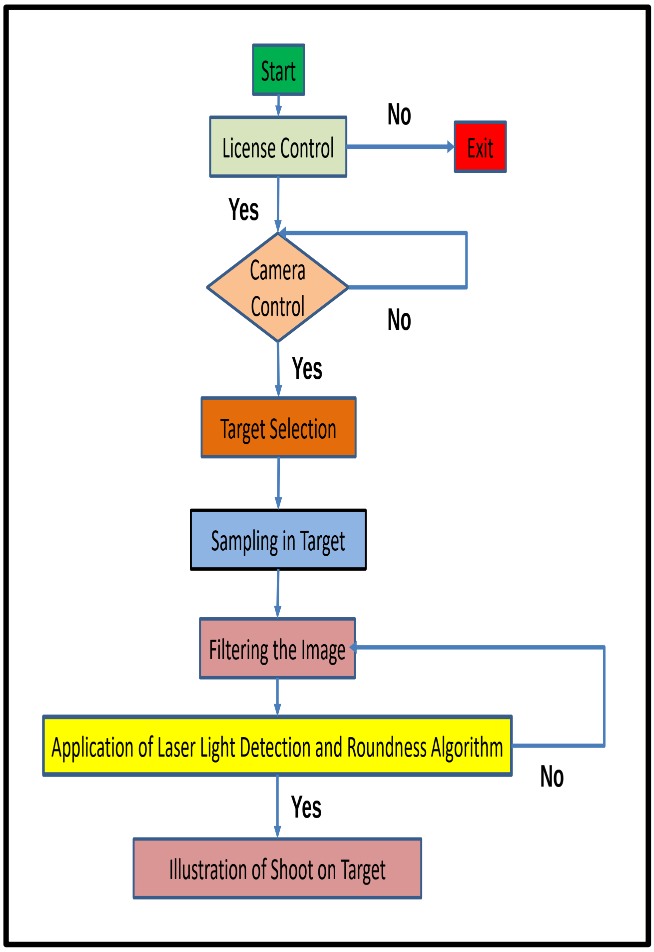


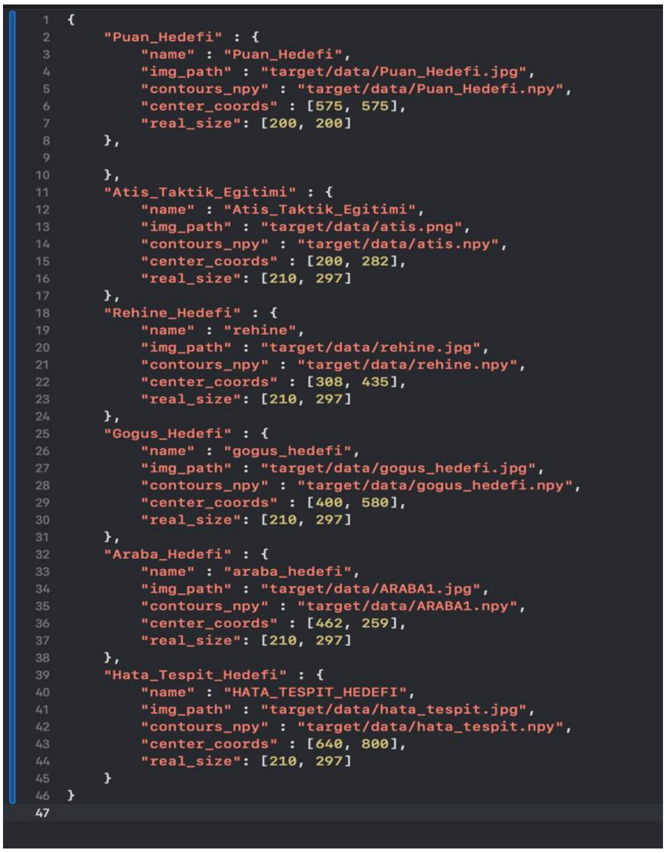
Figure 5. Software Flow Diagram

This created npy file is read from the target.json file, thus enabling the reading of descriptive information about the target after target selection from the software. The npy file created separately for each target has created target diversity and different evaluation opportunities. The codes of the target.json file, where attribute data and definitions for target selection are made, and the Target selection screen in the software interface are shown in Fig. 6.

The system was evaluated in terms of ease of use, installation and operating processes:

Positioning the camera and integrating it with the software was very simple. The automatic camera selection mechanism shown in Fig. 3 facilitated the installation process by ensuring that the correct external camera was used. The installation of the system (including turning on the computer and connecting the camera, attaching the target to the board and running the software) takes under 5 minutes.

The software enabled laser positions to be marked on the target image in real time. This feature allowed users to instantly evaluate their performance after each shot. Additionally, the system allows shooting as many times as desired without any limit. Additionally, the last shot is instantly shown in red and the other shots are shown in blue. Consecutive or serial shots are detected by the software in less than 1 second and displayed on the interface. In this way, the last shot fired can be quickly detected by the user.



```
{
    "Puan_Hedefi" : {
        "name" : "Puan_Hedefi",
        "img_path" : "target/data/Puan_Hedefi.jpg",
        "contours_npy" : "target/data/Puan_Hedefi.npy",
        "center_coords" : [575, 575],
        "real_size": [200, 200]
    },

    },
    "Atis_Taktik_Egitimi" : {
        "name" : "Atis_Taktik_Egitimi",
        "img_path" : "target/data/atis.png",
        "contours_npy" : "target/data/atis.npy",
        "center_coords" : [200, 282],
        "real_size": [210, 297]
    },
    "Rehine_Hedefi" : {
        "name" : "rehine",
        "img_path" : "target/data/rehine.jpg",
        "contours_npy" : "target/data/rehine.npy",
        "center_coords" : [308, 435],
        "real_size": [210, 297]
    },
    "Gogus_Hedefi" : {
        "name" : "gogus_hedefi",
        "img_path" : "target/data/gogus_hedefi.jpg",
        "contours_npy" : "target/data/gogus_hedefi.npy",
        "center_coords" : [400, 580],
        "real_size": [210, 297]
    },
    "Araba_Hedefi" : {
        "name" : "araba_hedefi",
        "img_path" : "target/data/ARABA1.jpg",
        "contours_npy" : "target/data/ARABA1.npy",
        "center_coords" : [462, 259],
        "real_size": [210, 297]
    },
    "Hata_Tespit_Hedefi" : {
        "name" : "HATA_TESPIT_HEDEFI",
        "img_path" : "target/data/hata_tespit.jpg",
        "contours_npy" : "target/data/hata_tespit.npy",
        "center_coords" : [640, 800],
        "real_size": [210, 297]
    }
}
```


Figure 6. Software Flow Diagram

The Capabilities and Interface of the Developed Software are shown in Fig. 7.

- Portable and Quick Installation,
- Target Selection,
- Shooting or shooting path display option (Fig. 8),
- Software calibration according to shooting (Fig. 9),
- Display of shooting score, hit success and total score by the system (Fig. 10),
- Serial and rapid shot detection,
- Unlimited shooting opportunities,
- Hit detection from different angles up to 30 degrees,
- Reporting and shooting recording (Fig. 11),

Figure 7. The Capabilities and Interface of the Developed Software

The Individual Shooting Simulation System has been comprehensively evaluated based on different criteria. System performance was examined under the headings of accuracy, speed, flexibility and user satisfaction.

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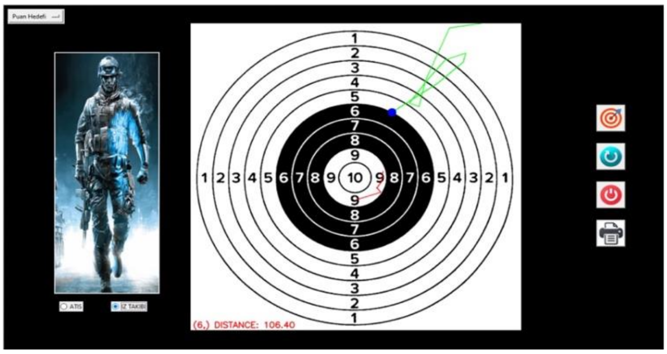

Figure 8. Shooting path display

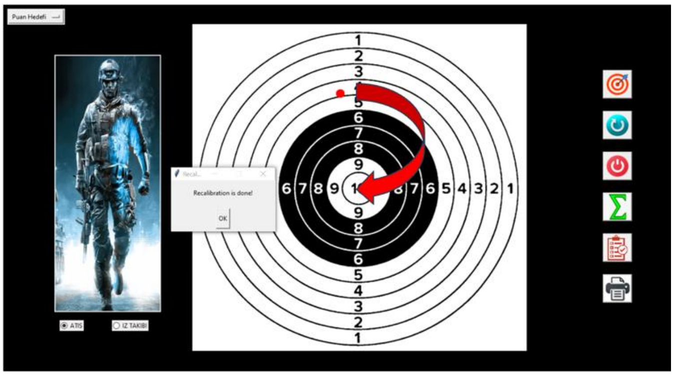

Figure 9. Software calibration according to shooting

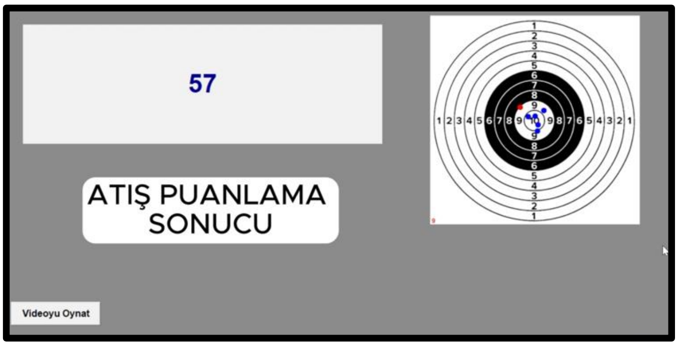

Figure 10. Display of shooting score

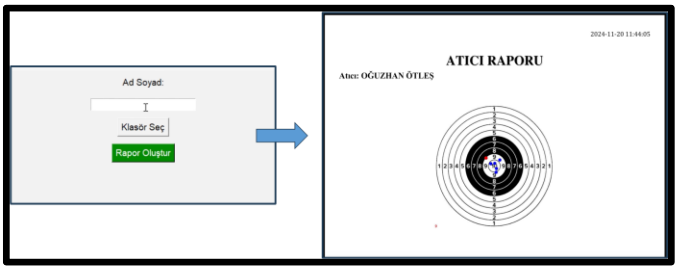

Figure 11. Reporting and shooting recording

The software showed high accuracy in detecting laser dots on the target paper. The main findings are:

The image processing algorithm detected laser points on the target consistently and with minimal error. Morphological operations and edge detection techniques enabled the laser hit points to be determined exactly and the error rate did not exceed the ±1 pixel limit. Preprocessing steps effectively corrected angular distortions in the acquired images and ensured accurate mapping of laser points to coordinates on the physical target. Scaling and alignment operations allowed accurate analysis regardless of camera angle differences, as shown in Fig. 4.

By optimizing the time from laser detection to result visualization, the system was able to process each shot in under 1 second. This speed has made training processes more efficient by allowing users to receive real-time feedback. The system was able to analyze consecutive shots with high processing speed and present the results to the user without any delay or data loss. The laser detection algorithm of the software worked successfully in trials conducted under different lighting conditions (low light, artificial lighting). Tests carried out especially in low light conditions have demonstrated the effectiveness of the software's image processing capabilities.

The system can detect the laser falling on the target paper. The software has been tested at distances ranging from 1 to 50 meters. At these distances, the accuracy of detection of laser points and their location on the target was preserved. It has been observed that the software will not be suitable for use in shots over 50 meters, as the appearance of the laser light on the target increases proportionally depending on the distance. If desired, the hit point can be marked by editing in the software, based on the pixel value of the center point, taking into account the size of the laser light. This means that the distance can be increased further. However, since the developed software in question was planned to be used in the classroom environment, such a need did not arise.

Instant visualization of firing points allowed users to quickly evaluate their performance. Users were able to effectively use this feedback in training improvement decisions. Users and Shooting Instructors stated that they were satisfied with the ease of installation of the system and the smoothness of the usage process. They also stated that real-time analysis and visualization features provide a significant advantage in shooting training. In the tests performed, the rate of cases in which the system could not recognize the laser points remained below 2%. These errors are generally seen in extremely bright environments or when the laser beam is directed to a point other than the target. Preprocessing steps successfully filtered out noise in the image, allowing laser points to be detected more clearly.

Individual Shooting Simulation System software has a structure that can meet the training and performance analysis needs of both amateur and professional users. The practical application potential of the system was examined under the headings of skill assessment and training flexibility. The software analyzed the position of the laser points on the target during shooting with millimetric precision. This analysis revealed the shooter's aiming accuracy and consistency. Users were able to use this data as a feedback tool to improve their shooting techniques.

The system provided the user with an overall performance evaluation after multiple shots. In the software, the total shooting score can be automatically displayed along with the shot-by-shot visual.

The system has an easily portable hardware structure. Essential components like the webcam, computer, and target paper can each be carried anywhere with a bag. The system becomes ready for use by running an exe file without requiring any special technical knowledge. The software automatically selects the camera and corrects the image of the target in the camera image, making it easier for the user to use it without any action The system instantly displays users' shooting results on the screen. This feature makes the education process more efficient and interactive. The software's reporting and recording feature allows the shooter's development and shooting success to be tracked over time. The results of the shooting studies conducted on different dates enable the analysis of the development of the users and the success of the training. The software is a suitable educational tool for students in military and law enforcement schools as well as professionals. While students use the system to learn basic shooting techniques, professionals use the software to maintain their performance and renew their training.

4. DISCUSSION

The developed Individual Shooting Simulation System software offers an innovative approach with its portable and cost-effective structure in both individual training. In this section, evaluations were made on the developed simulation software and its usage concept, its advantages, limitations, and the development potential of the software in the future.

The system offers its users various advantages during training:

- The system marks the position of the exact middle point of the laser circle on the target with high accuracy of ±1 pixel. Additionally, the software detected laser light under different lighting conditions and distances, providing consistent results.
- The system has a user-friendly structure with its simple interface and portable structure. Automatic correction of the target image obtained from the camera by the software and detection of the correct camera provide convenience to the users.
- Displaying the result of the shot on the screen at the time of shooting provides a dynamic structure to the training. This feature allows shooters to make instant improvements with repeated shots.
- The system, which offers users long-term performance monitoring, has enabled them to plan their training processes more consciously. Visualization and reporting of data made it possible to use the system as a guide for individual development.

Although the system works successfully, certain limitations have been observed:

- While the system showed high performance in low light conditions, it had difficulty detecting laser light in extremely bright environments. This may require taking additional precautions to reduce the effect of intense light sources such as sunlight in outdoor use.
- Although small errors in camera alignment were tolerated thanks to image correction algorithms, alignment errors above a certain limit negatively affected system performance.
- The system requires mid-level computer hardware and a mid-level webcam to run the image processing algorithms. Also, there is laser addiction.

This system provides advantages compared to other shooting training tools, especially in terms of portability, cost effectiveness and ease of use:

- Some commercially available shooting simulation systems often require expensive and complex hardware. This developed system offers a competitive alternative by providing similar accuracy and performance levels at lower cost.
- While existing commercial systems generally target professional users, this system is designed to appeal to both

amateur and professional users. This enables the system to reach a wider user base. Additionally, any target at any level can be added to the software. The only restriction is that this target must be scaled to A4 size.

The findings obtained in this study provide several opportunities for the development of the system and its dissemination to a wider application area:

- With the development of artificial intelligence-based image processing algorithms and advanced image filters and their integration into the software, the effect of light sensitivity in detecting the shooting point can be reduced.
- Integrating the system with the mobile application can reduce users' hardware needs. In this way, users can train even at home using the cameras of their personal phones.
- A module can be added to the software in which artificial intelligence-supported shooting errors can be automatically evaluated by the system according to the point of impact.
- In line with the developments to be made in the software, visuality can be increased with a barcovision device and a more advanced camera, and scripted shooting training can be given.

5. CONCLUSION

The evaluation results of the hit points on the target showed that the Individual Shooting Simulation System software marked the laser position on the target with high accuracy.

The user-friendly structure of the software and It shows that it can be used as an effective method in shooting training with its possibilities and capabilities. In addition, it was concluded that the real-time feedback feature of the software, together with its fast installation and portable structure and components, increased the effectiveness of shooting training. The fact that the desired target can be added to the software and the target image is on A4 paper shows that the system is an ideal option for individual shooting training with all its components and software. Users have the opportunity to report their performance after shooting, allowing them to track their progress.

The developed Individual Shooting Simulation System software increases the effectiveness of individual shooting training with its innovative structure and user-friendly interface. With future studies, it is expected that the system will reach a wider user base and become an important tool in education, research and commercial fields.

The results obtained confirm that the Individual Shooting Simulation System is a reliable and effective tool for simulating shooting scenarios, allowing users to improve their performance by providing accurate feedback.

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BIOGRAPHIES

Vedat YILMAZ obtained his BSc degree in system engineering from military Akademy in 2004. I completed Digital Communication Electronics Training at Hacettepe University in 2006. My master's degree in Management and Organization at Selçuk University in 2007, and PhD degrees in Biomechanics at Hacettepe University in 2022. Additionally, I received training on Principles of Communication from Cranfield University, Cyber Security from METU, and Training on Terrorists' Use of Cyberspace from the Center of Excellence in Combating Terrorism. I managed many technology projects within the Gendarmerie General Command. Currently, I continue my studies in the fields of cyber security, artificial intelligence applications in cyber crimes, security technologies and cyber security.