Journal of Computers Vol. 35 No. 4, August 2024, pp. 143-158
doi: 10.53106/199115992024083504011

An Evaluation Method for Steady Tracking Target Training and Its Engineering Application

Hong-Tian Liu, Yang Cao*, Chao Song, Dong-Jun Wang, Hui-Min Wang, and Hong-Wei Wu

Department of Weapons and Control, Army Academy of Armored Forces, Beijing, China
190233004@qq.com

Received 1 June 2024; Revised 31 July 2024; Accepted 15 August 2024

Abstract. In order to solve the problems such as the difficulty in obtaining the relevant data of the relative angular velocity of the target encapsulated in the fire control system in real time during training, the inability of single data points in the fire control system to reflect the relationship between the operator's operation and the changes in the target's position within the sight, low accuracy in evaluating steady target tracking training, and the lack of specificity in training guidance, this paper proposes to use the target recognition technology to measure the aiming deviation angle generated by the relative angular velocity of the target. By comparing this with the output voltage signal curve from the control console, a tracking stability curve is generated. Furthermore, by identifying the aimed target and comparing it with the center coordinates of the stored image, an aiming accuracy curve is produced. The tracking stability curve and aiming accuracy curve obtained from this study can be used to comprehensively evaluate the operation skills of the operator in the process of aiming and steady tracking target, and this is applied to the design of a training and evaluation system for steady tracking target, thereby improving the scientific evaluation and targeted effective guidance for operator training.

Keywords: steady tracking, training, aiming, accuracy, calculation, evaluation

1 Introduction

The ability to accurately aim at a target and maintain a steady tracking of it for an extended period is a critical skill for operators of image-stabilized fire-control systems. This capability is essential for the effective operation of these systems, which are pivotal in various defense and military applications. Evaluating this ability comprehensively involves assessing multiple factors, including the precision with which the operator can aim at the target and the stability with which they can track it. Additionally, practical operational tasks performed by the operator are also considered. The accuracy of aiming and the stability of tracking are crucial parameters that determine the likelihood of hitting the target. Currently, one of the primary methods for assessing an operator's ability to aim accurately and track targets steadily is based on the results of actual hits. This method involves analyzing the success rate of fired ammunition in hitting the target. However, the ability of the ammunition to hit the target is influenced by various random factors, such as dispersion, which can significantly affect the outcome. As the distance to the target increases, the impact of these random factors becomes more pronounced. This increased influence directly affects the probability of the projectile hitting the target, making it challenging to accurately evaluate the operator's skill based solely on hit results. Due to the difficulty in excluding these random factors, evaluating the operator's skill level based on the hit results can sometimes be imprecise. For example, even a skilled operator may have a poor hit rate due to adverse weather conditions, unstable munitions, or other unpredictable variables. Conversely, a less skilled operator may achieve better than expected results due to favorable conditions. Therefore, while hit results may reflect operator performance to some extent, they are not a completely reliable measure of an operator's true skill level. Another method for evaluating an operator's performance involves obtaining data on the relative angular velocity of the target within the fire control system. This data can be captured through voltage signals output from the control console. By plotting the aiming and tracking curves based on the angular velocity data, evaluators can assess the operator's training level and operational skills. These curves can reveal how well the operator can maintain steady tracking and precise aiming over time. However, relying solely on single data points from the fire control system does not accurately reflect whether the operator can consistently aim at and effectively track the target. Single data points can be affected by momentary

---

* Corresponding Author

lapses or anomalies, which may not be representative of the operator's overall performance. Therefore, both of these evaluation methods, hit results and angular velocity data, are often insufficiently precise when used in isolation [1].

2 Research Foundation

In an image-stabilized fire control system, the primary mechanism for tracking and aiming relies heavily on the target angular velocity sensor embedded within the image-stabilized sight [2]. The relative angular velocity of the target can be either an average angular velocity or an instantaneous angular velocity. To measure the average angular velocity, the method of measuring the instantaneous angular velocity of multiple targets and then taking the average value of the target can also be adopted, or the method of measuring the relative angular velocity of the target over a period of time and then calculating its average value. The main methods for measuring instantaneous angular velocity are measurement with tachogenerators, extraction of angular velocity signals from the aiming circuit, and extraction of angular velocity signals from the unloading torque motor of the sight servo mechanism [3-6]. Each of these methods has its advantages and specific applications within the fire control system. At present, there are no devices or technical means in image-stabilized fire control systems to evaluate the accuracy of an operator's aiming at a target. To comprehensively assess the skills of aiming and tracking targets, other methods must be employed. One such methodology involves the use of image recognition technology, which has become highly advanced and reliable in recent years. Image recognition technology can be utilized to evaluate an operator's proficiency in accurately aiming at and smoothly tracking targets. This technology is capable of accurately identifying various types of targets and can compare numerous different target samples using sophisticated methods. Through the application of specific algorithms, it is possible to evaluate both the accuracy of the operator's aim and the stability of their tracking performance during training sessions. These algorithms analyze data gathered by the image recognition systems, providing a detailed assessment of the operator's performance. The evaluation process hinges on two key components: target recognition technology and the methods used to calculate tracking stability and aiming accuracy. Target recognition technology enables the system to identify and differentiate between various target types, ensuring that the operator can correctly identify and engage targets under different conditions. The methods for calculating tracking stability and aiming accuracy involve analyzing the consistency and precision of the operator's actions over time. By integrating these advanced technologies, the fire control system allows for a comprehensive and accurate assessment of operator skills. This, in turn, facilitates more effective training and development programs to ensure that operators are able to fully perform their duties at the highest level of proficiency.

3 A Calculation Method for Tracking Steadiness and Aiming Accuracy

This paper proposes a novel method for evaluating the accuracy of an operator's aiming at a target and the stability of tracking the target. By using target recognition technology, the relative angular velocity of the target is measured, and the resulting aiming deviation angle is calculated. The calculated deviation angle is then compared with the voltage signal curve output from the control console to generate a tracking stability curve. The process begins with the identification of the aimed target through sophisticated image recognition algorithms. These algorithms compare the identified target with the center coordinates of stored reference images. This comparison is used to generate an aiming accuracy curve, which reflects the precision of the operator's aim over time. In addition, the methodology includes manual judgment to assess adherence to operating procedures during training sessions. This aspect of the assessment ensures that operators not only demonstrate technical proficiency, but also follow prescribed protocols and best practices. By integrating these different elements of assessment, a comprehensive assessment of an operator's skills can be made. The tracking stability curve is derived by comparing the angular velocity data with the voltage signals from the console and provides insight into the operator's ability to maintain steady tracking of the target. The aiming accuracy curve, on the other hand, provides a quantitative measure of how closely the operator's aim is centered on the target. By combining these objective measurements with subjective manual evaluation, the proposed methodology provides a comprehensive and detailed assessment of the operator's overall performance. This dual approach ensures a comprehensive assessment of the technical accuracy of aiming and the actual stability of tracking.

3.1 Image Recognition Methods

First, a substantial collection of images encompassing various target categories is compiled to serve as the training set for the system. The training set has been carefully designed to include multiple target types to ensure comprehensive coverage. A subset of these images from each category is designated as the validation and test sets to evaluate and fine-tune the performance of the recognition system. To improve the accuracy and robustness of image recognition, targets are painted in a diverse array of colors and are photographed under different lighting conditions, with different levels of occlusion, different shooting angles, and various shape distortions. This diversity in the training data ensures that the recognition system can automatically and accurately identify targets regardless of their colors, backgrounds, poses, angles, and occlusion scenarios [7, 8]. Prior to the commencement of training, the operator aims the sight at the center of the target statically. This initial alignment is crucial for establishing a baseline for the target's position. The target models from the image recognition training set are then used to extract essential target features, such as color and shape features. These primary features are further supplemented by texture and spatial relationship features, which provide additional context and detail necessary for accurate target identification. The extracted features are used to identify the target and its center. The recognition system's management module stores the images along with the corresponding target features. Additionally, the coordinates of the recognized target and the image center are recorded for subsequent comparison and analysis.

3.2 Calculation of Aiming Accuracy

First, the pixel angle of the system is calculated to establish a precise measurement of angular displacement per pixel. This foundational calculation is crucial for accurately determining the aiming deviation during training and operational scenarios. During the operator's training process, video data is captured in real-time to provide a continuous stream of visual information. Simultaneously, screenshots are saved to create a dataset for analysis. These images are then classified into positive and negative samples based on the presence or absence of the target within the frame. To ensure a balanced dataset, the positive-to-negative sample ratio is maintained at an optimal 1:1 ratio. This balanced classification is essential for training the image recognition system to differentiate effectively between target and non-target scenarios. The image recognition system calculates the offset of the target image center in the aiming field of view in real-time. This calculation involves sophisticated algorithms that continuously track the position of the target relative to the center of the aiming reticle. At the moment of shooting, the system notes the number of pixels of horizontal and vertical deviation from the aiming direction. Using these pixel measurements, the system computes the aiming deviation angle, which serves as an indicator of aiming accuracy.

$$\omega_{\text{pixel angle}} = \alpha_{\text{the field of view angle}} \div 360 \times 6000 \div \chi_{\text{the number of pixels}} . \tag{1}$$

$$\theta_{\text{aiming deviation angle}} = \omega_{\text{pixel angle}} \times \chi_{\text{deviation in pixels}} . \tag{2}$$

3.3 Tracking Steadiness Calculation Method

Based on the calculated aiming deviation angle, an aiming deviation angle curve is generated, as shown in Fig. 1.

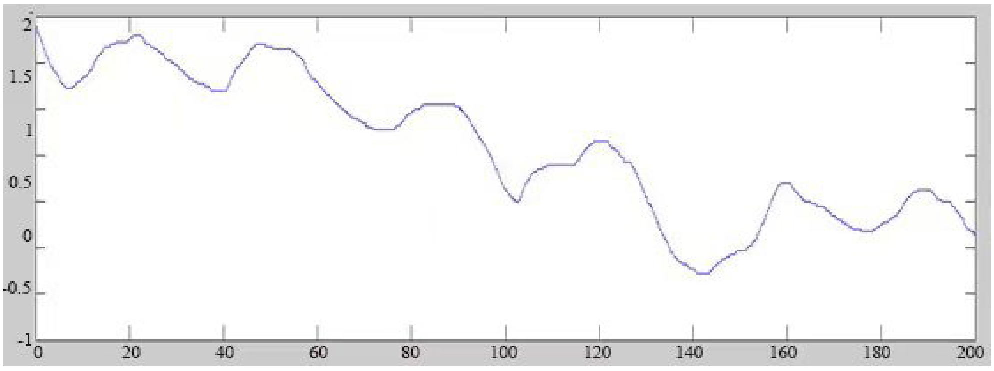

Fig. 1. Aiming deviation angle curve (mil)

The simultaneously collected output voltage signal curve from the control console is shown in Fig. 2.

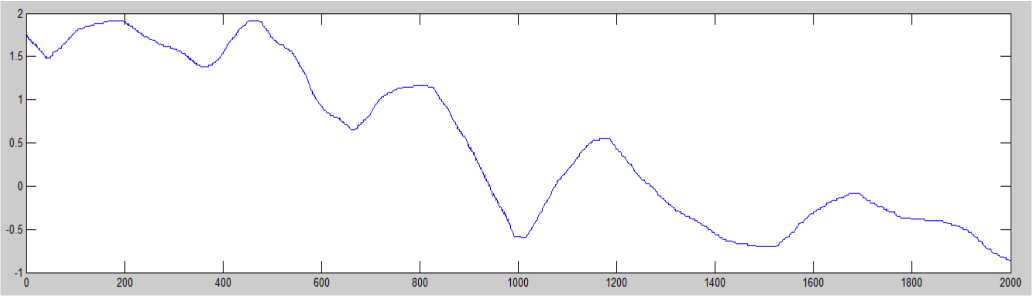

Fig. 2. Output voltage signal curve from the control console

If the collected data is directly compared, the inconsistency in the magnitude and dimensions of the two data sets will lead to calculation difficulties. To quantify the stability of tracking, the LIP (Line Integral Projection) method is used. The LIP method involves calculating the envelope area between the two curves—the aiming deviation angle curve and the output voltage signal curve. The principle behind this method is that the larger the area between the two curves, the poorer the operator's stability. Conversely, when the area between the two lines is zero, it indicates that the operator is capable of promptly and steadily tracking the target, as illustrated in Fig. 3.

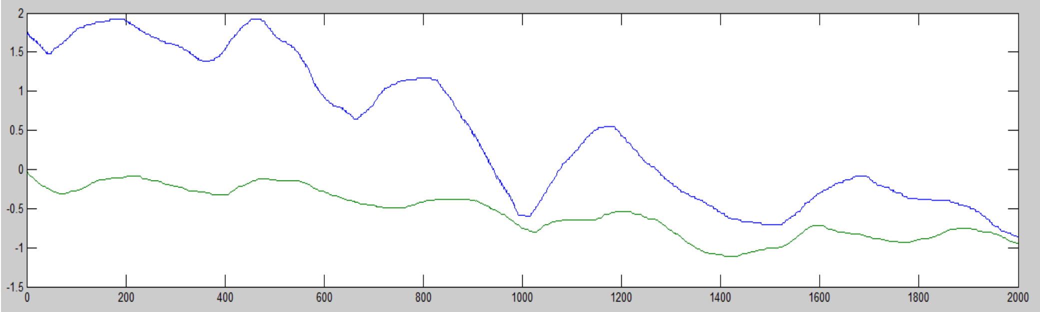

Fig. 3. Tracking stability curve - direct comparison

To facilitate this calculation, both waveforms need to be normalized. Normalization involves determining the maximum and minimum values of each curve and then applying these values to adjust the curves to a common scale. The formulas for normalization are as follows:

$$V_n = (V - V_{min}) \div (V_{max} - V_{min}). \tag{3}$$

$$\theta_n = (\theta - \theta_{min}) \div (\theta_{max} - \theta_{min}). \tag{4}$$

After normalization, the two curves will intersect at multiple points. The tracking curve for the 20 seconds before shooting is selected, and after normalization, stability is evaluated. The aiming deviation is calculated 10 times per second, totaling 200 comparison points (n ranges from 0 to 200), as shown in Fig. 4.

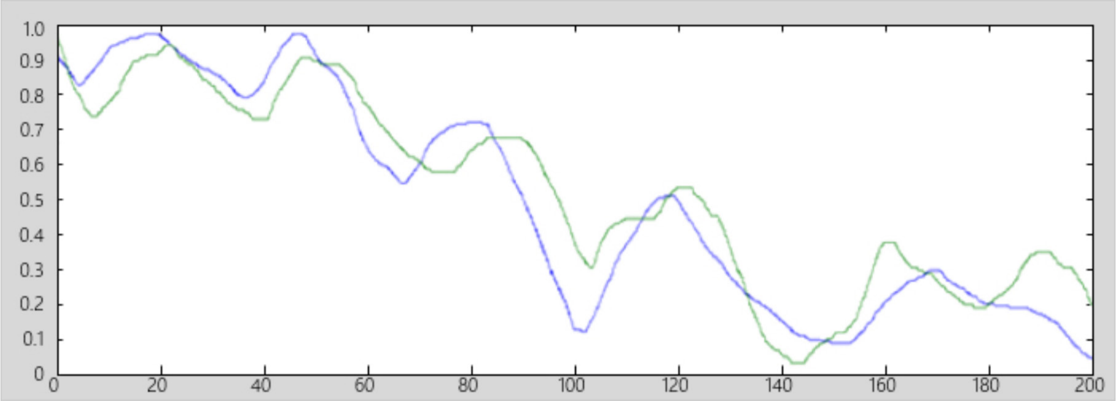

Fig. 4. Tracking stability curve - after normalization

Through calculating the area of the intersecting parts of the two normalized curves, the similarity between the curves can be determined. This enables a quantitative evaluation of tracking stability, as shown in Fig. 5.

$$S=\sum_{n=1}^{200}(V_n - \theta_n) . \tag{5}$$

As illustrated above, data analysis allows for the calculation of the tracking stability coefficient, the theoretical optimal stability coefficient, and the worst stability coefficient. These coefficients provide a quantitative measure of the operator's tracking stability. Quantitative evaluation can record each operator's training performance, thereby assessing improvement. The tracking stability curve for the 2 seconds before shooting is selected, with the aiming deviation calculated 10 times per second, resulting in 20 aiming deviation values. Summing the areas provides the operator's fluctuation curve over 2 seconds. By focusing on this short timeframe, we can theoretically exclude random factors affecting projectile hit rates, thus providing a more objective and accurate quantitative assessment of operator training performance. This approach ensures that the assessment is based on the operator's true skill level rather than irrelevant variables, thereby providing a reliable measure of their ability to effectively aim and track targets.

4 Experiment Verification

Based on the calculation methods proposed in this paper, a series of experiments were conducted to verify the feasibility of the methods for calculating tracking stability and aiming accuracy.

4.1 Image Recognition Method Verification

The verification of the image recognition method is carried out using the Yolo v7 and OpenCV image processing API interfaces. The verification process involves several key steps, demonstrated with the identification of a single target as an example:

(1) The detect module of Yolo v7 is employed to locate the target within the environment. The module identifies the target and provides the coordinates of the detection frame's upper left and lower right corners.

(2) Using the coordinates obtained from the detection frame, the recognized image is cropped to isolate the target area;

(3) The cropped image undergoes a series of processing steps using OpenCV:

- **Grayscale Processing**: The image is converted to grayscale to reduce complexity and enhance contrast, resulting in the output shown in Fig. 5

- **Binarization**: The grayscale image is then binarized, converting it into a binary image where pixels are either black or white, as depicted in Fig. 6
- **Noise Elimination**: An open operation is applied to the binarized image to eliminate noise and refine the target's outline, leading to the result shown in Fig. 7.

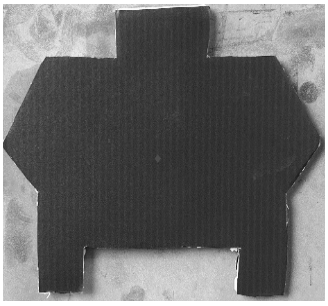

Fig. 5. Image after grayscaling process

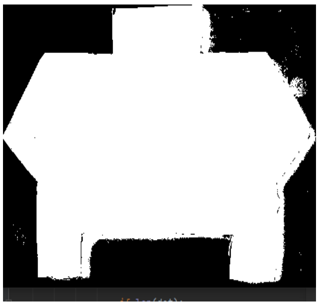

Fig. 6. Image after binarization process

Fig. 7. Image after open operation process

(4) Use the API interface of Opencv to find and determine all the contours in the processed image, compare all the contours, and take the largest as the outer contour of the target, as shown in Fig. 8.

(5) The points defining the target's outline are restored to the original image to visualize the identified target in its original context.

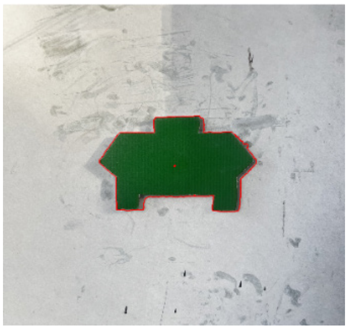

Fig. 8. Outline of the target

(6) Data enhancement operations on the training data: In order to strengthen the generalization ability of the image recognition model, we segmented and rotated (as shown in Fig. 10 and Fig. 11) the original image of the trained target image (as shown in Fig. 9), so that the model can be easily used in special scenarios [9-11].

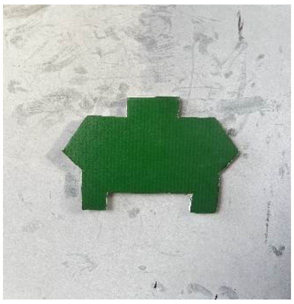

Fig. 9. Original image of training target image

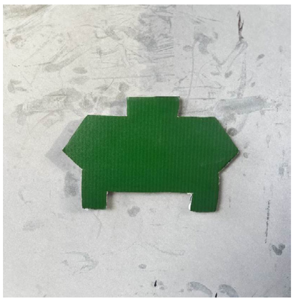

Fig. 10. Training target image after segmentation

Fig. 11. Training target image after rotation

(7) The enhanced target images are grouped and used for training the recognition model. The outcomes of the training process are depicted in Fig. 12, showcasing the effectiveness of the method. The performance indices of the model, including accuracy, precision, recall, and other relevant metrics, are summarized in Fig. 13.

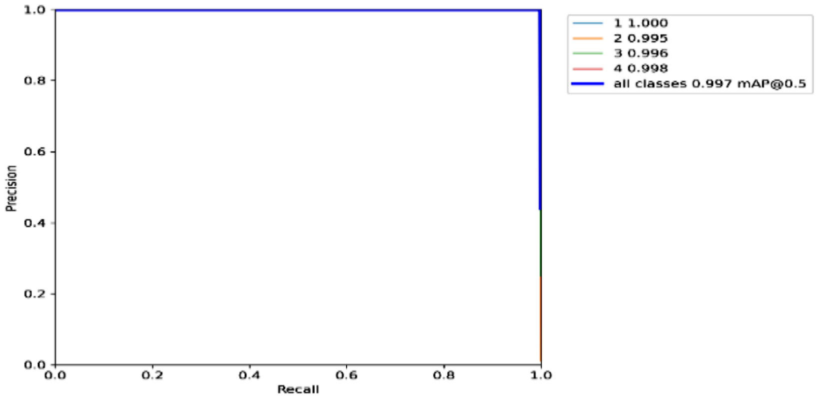

Fig. 12. Training results

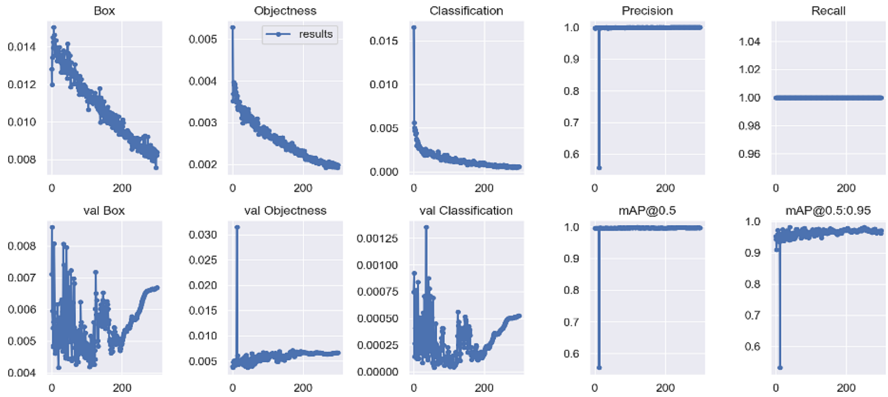

Fig. 13. Model indicators

In Fig. 13, Box represents the mean value of the Generalized Intersection over Union (GioU) loss function. The GioU loss measures the discrepancy between the predicted bounding boxes and the ground truth boxes. A smaller GioU loss indicates more accurate detection boxes, meaning the predicted boxes closely match the true target locations; Objectness refers to the mean value of the target image detection loss. This metric assesses the confidence score that a predicted bounding box contains an object. Lower objectness loss signifies higher accuracy in detecting target images; Classification represents the mean value of the classification loss, which measures how well the model distinguishes between different target classes. A smaller classification loss indicates higher accuracy in correctly classifying targets; Precison represents the accuracy of the model in finding the target image (also known as the accuracy and precision), that is, the proportion of all predictions that are true to the positive examples (positive classes that find the right ones/all positive classes). Higher precision means that a larger fraction of the predicted positive examples are correctly identified as targets; Recall represents the accuracy of the true positive (also known as the recall rate), that is, the proportion of the number of true positive examples in all predicted positive cases to the actual number of positive examples in the whole, that is, how many positive samples have been found out (how many are recalled). Higher recall means that the model successfully identifies a greater number of true targets; val box represents the loss of the verification bounding box. It assesses the model's performance in predicting bounding boxes during validation; val objectness represents the mean value of object detection loss in the validation set. It evaluates the confidence score of detected objects during validation. val Classification represents the mean value of the classification loss of the validation set. It evaluates the model's accuracy in classifying targets during validation. mAP represents the area enclosed by the graph after the user uses Precision and Recall as the two-axis plot, which can be used to observe the advantages and disadvantages of the model more intuitively and comprehensively. It is the area enclosed by Precision and Recall as two axes. m is the average, and the number after the "@" indicates the threshold at which the iou is determined to be a positive or negative sample. @0.5:0.95 indicates that the threshold value is 0.5:0.05:0.95 and then the average value is taken. "mAP@.5" indicates the average mAP with thresholds greater than 0.5, and "mAP@.5:.95" (also written mAP@ [.5:.95]) represents the average mAP at different IoU thresholds (from 0.5 to 0.95 in steps of 0.05) (0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.85, 0.9, 0.95) [12-14].

After completing the image recognition training, several groups of different targets were used for experimental verification, and the recognition effect is shown in Fig. 14. Notably, the system demonstrates its ability to accurately recognize all targets, including those that are incomplete or unclear. This highlights the robustness of the model in recognizing targets under challenging conditions. In addition, the model proved to be very effective in the presence of multiple targets in the same area. It successfully distinguished between different targets and accurately and automatically labeled the category of each target. This ability to simultaneously process multiple targets and provide accurate categorization highlights the efficiency and reliability of image recognition systems in diverse and complex environments.

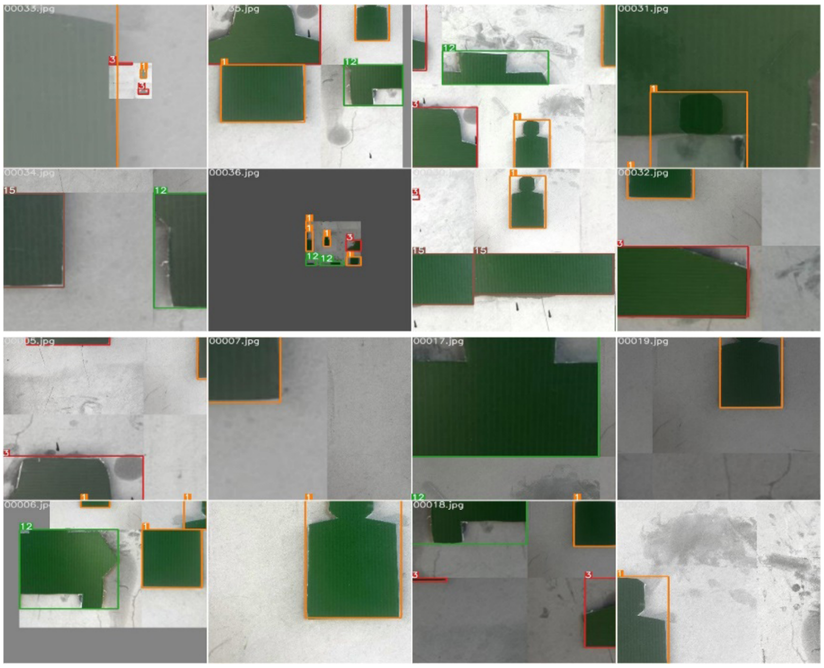

Fig. 14. Multi-group target test results

4.2 Verification of Aiming Accuracy Calculation Method

By collecting the CCD video signal of the fire control computer for image analysis, the system acquires vital visual data necessary for precise targeting and tracking. The field of view of the obtained video is 1.4×1.04 degrees, and the image resolution is 752×582 pixels. This high-resolution video signal is then analyzed to enhance the accuracy of target detection and aiming. To quantify the resolution of the image in terms of angular measurement, the resolution in mils per pixel can be calculated. The mil, a unit of angular measurement used in targeting, represents one-thousandth of a radian. The calculation of mils per pixel for both the horizontal and vertical dimensions is as follows:

$$\theta_{Horizontal}=\frac{1.4\times 6000}{752\times 360}=0.0310\approx 0.03\ mil/pixel. \quad (6)$$

$$\theta_{Vertical}=\frac{1.04\times 6000}{582\times 360}=0.0297\approx 0.03\ mil/pixel. \quad (7)$$

Usually, the minimum target size for image recognition is generally 8 pixels, and the minimum unit for image recognition is 1 pixel. As mentioned above, the video image resolution is 0.03 mil. This high resolution ensures that the collected images are sufficiently detailed to meet the stringent requirements of image recognition. Once the size of the image collected by the sighting and aiming device meets these requirements, the operator can identify the center of the collected target image as the target center position during training. The system then calculates the offset of the collected target image center within the field of view. This offset measurement is crucial for determining the aiming error at the time of firing. The calculated offset allows the system to assess the deviation of the operator's aim from the target center. This deviation, or aiming error, is quantified with an accuracy of 0.03 mils. This level of precision ensures that even the smallest aiming errors can be detected and corrected, enhancing the overall accuracy of the fire control system [15, 16].

Experimental verification takes the directional aiming deviation as an example, with the following steps:

(1) Before training, the operator operates the scope to aim at the center of the target, and the software identifies the target and records the center of the target in the image as the coordinates of the center of the image.

(2) During the training process, the image recognition system (programmed using the above model) calculates the coordinate position of the target in the image in real time, calculates the aiming deviation angle, and generates the directional aiming deviation angle θ curve.

Multiple groups of different targets were used for experimental testing. During the operator training process, the image acquisition module of the visual monitoring device captures the image outline as the target. The image resolution obtained by the CCD is 0.03 mil/pixel, and the target size is 5 meters × 2.2 meters. At a distance of 2400 meters, the image size of the target area is:

In the process of operator training, the image acquisition module of the view monitoring device of the sighting and aiming device of this system acquires the outer edge of the image as the target. The resolution of the image acquired by the CCD is 0.03 mil/pixel, and if the target size is 5 m x 2.2 m, the image size of the target area at 2400 m is:

$$\theta_w=5/2400=2.1\ \text{mil} \qquad \delta_w=2.1/0.03=70\ \text{pixels}$$
$$\theta_h=2.2/2400=0.92\text{mil} \qquad \delta_h=0.92/0.03=31\ \text{pixels}$$

Through experimental verification, the directional and vertical aiming deviation values, as well as the aiming deviation angle, can be accurately calculated. The generated aiming deviation angle curve can be used to assess tracking stability and aiming accuracy. The curves visualize the operator's performance over time, highlighting any deviations from the intended target and allowing for a thorough assessment of the operator's ability to maintain steady tracking and accurate aiming. By analyzing these curves, trainers can identify specific areas where an operator may need further practice or adjustment, thus improving the overall effectiveness of the training process.

4.3 Verification of Tracking Stability Calculation Method

For experimental verification, the aiming deviation angle curve for the 20 seconds preceding the shot is selected. During this period, the aiming deviation is calculated at a frequency of 10 times per second, resulting in a total of 200 aiming deviation values. In a specific experiment, illustrated in Fig. 15, the data analysis revealed that the tracking stability coefficient for the training process was determined to be 513.2. The theoretical optimal stability coefficient, which represents perfect tracking stability, is 0, while the worst possible stability coefficient, indicating significant instability, is 2000. This result clearly demonstrates the effectiveness of the calculation method in quantitatively evaluating each operator's training performance. It allows for a detailed assessment of their progress over time, highlighting improvements and areas that may need further attention.

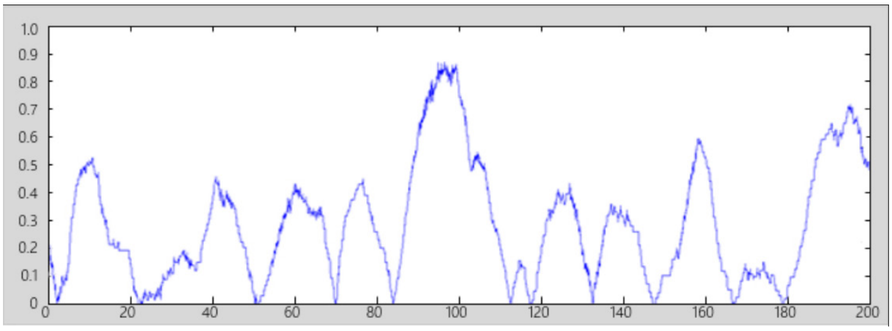

Fig. 15. Tracking stability curve

5 Engineering Application of This Principle

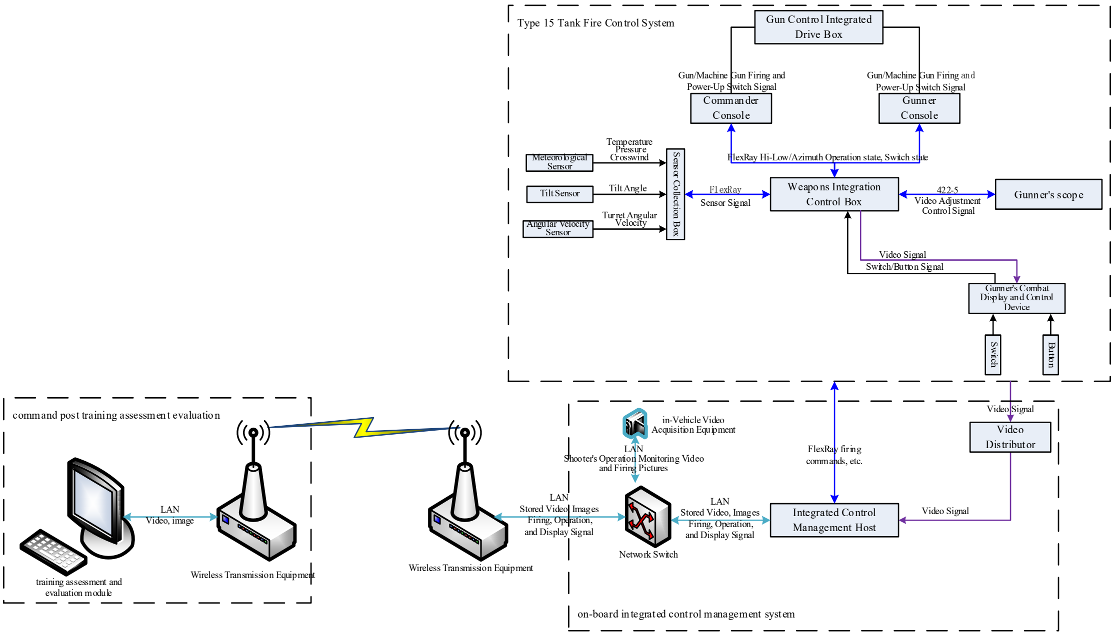

Fig. 16. Block diagram of system working principle

By using this method, a training evaluation system can be designed to automatically collect, upload, and analyze the training results of operators. This system completes the training analysis and evaluation of operators and is used for targeted guidance of the operators [17]. The basic principle of the calculation method of tracking steadiness curve and aiming accuracy curve proposed in this paper is as follows: through the real-time collection of the video image of the aiming field of view and the firing control command, ranging command, target distance and other information on the bus, the acquisition automatic tracker can output the video data, and distribute it as the CCD video of the fire control computer, and transmit it to the terminal interface at the same time. At the terminal interface, the video data is used to enter the aiming process image analysis phase. Here, the system identifies the target and generates the aiming deviation angle curve, which is crucial for calculating the tracking steadiness throughout the training process. This detailed analysis allows for precise measurement and assessment of the operator's performance. The system employs targets that have been recognized by the software during training, recording the image as the central coordinate. This central coordinate is then compared with the offset of the target within the scope's field of view. By analyzing this offset, the system accurately calculates the operator's real-time aiming accuracy [18]. This process ensures that the evaluation is comprehensive and provides a clear indication of the operator's proficiency.

The operational principle of this system is visually illustrated in Fig. 16, which provides a clear depiction of the data flow and various processing steps involved in evaluating the operator's training performance. This detailed representation underscores the system's capability to deliver a thorough and precise assessment, thereby facilitating effective and targeted training interventions.

The training and evaluation system is mainly composed of three parts: On-board integrated control management system, wireless transmission equipment, training assessment and evaluation module. The detailed composition of its system is shown in Fig. 17.

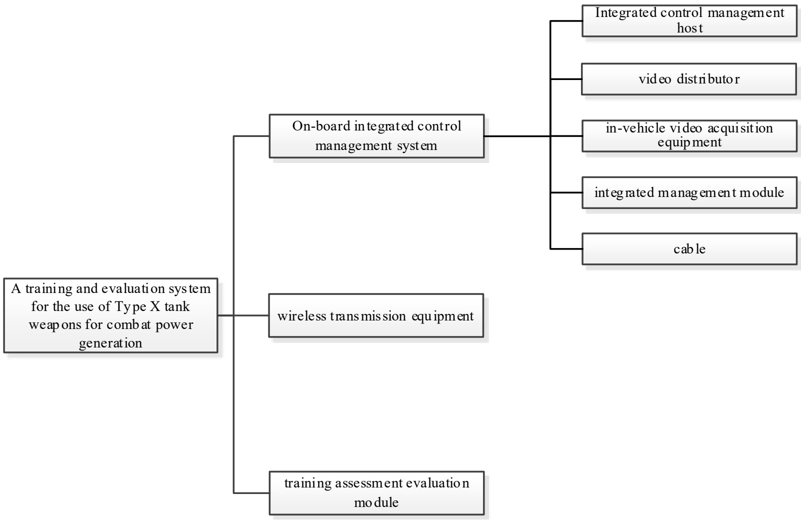

Fig. 17. Block diagram of system composition

5.1 On-board Integrated Control Management System

The on-board integrated control management system consists of several key components: the integrated control management host, video distributor, operation video acquisition equipment, operation video acquisition equipment, integrated management module and connecting cables, illustrated in Fig. 18. The on-board integrated control management system is mounted in a free position within the turret using magnetic suction, ensuring ease of installation and flexibility in positioning. The use of magnetic suction allows for quick adjustments and secure attachment, making the system adaptable to various operational scenarios. The relationship between this system and the other two modules is critical for the overall functionality and effectiveness of the training and evaluation setup. The integrated control management host is responsible for collecting data through the network interface and subsequently transmitting this data to the wireless transmission equipment. This data is indispensable, as it is the primary source for the training assessment and evaluation module. Additionally, it provides the control strike control relay signal, which is vital for the coordination of training exercises [19]. The information flow within this setup is meticulously structured to ensure efficient and reliable data transmission. Specifically, the integrated control management host sends data to the wireless transmission equipment, which acts as an intermediary, forwarding the data to the training assessment and evaluation module. This structured flow of information ensures accurate and timely delivery of data. It helps to facilitate real-time analysis and feedback, which is essential for effective training and evaluation.

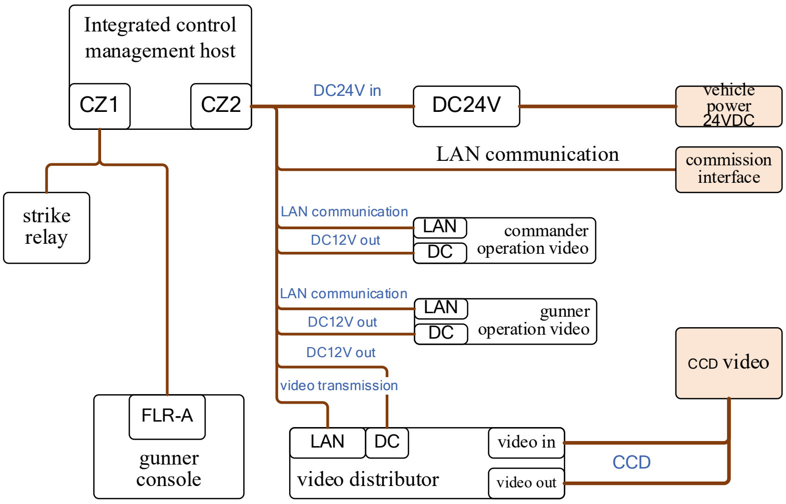

Fig. 18. Internal connection diagram of the on-board integrated control management system

Integrated Control Management Host. The integrated control management host is responsible for several key functions: power supply management, video data processing-forwarding, fire control data collection-analysis-forwarding, and fire control data acquisition (video distributor, operating video acquisition equipment). The mainframe ensures that all these functions are well integrated and efficiently managed. A primary role of the integrated control management host is to transmit the collected data to the wireless transmission equipment via the network interface. This transmission is crucial because the data serves as the primary source of information for the training assessment and evaluation module, enabling real-time analysis and feedback that are essential for effective operator training. The integrated control management host is strategically mounted on the left rear seat inside the turret, ensuring optimal performance and accessibility. Its composition includes several key components: a main control unit, which acts as the brain of the host; a bus communication unit, which facilitates data exchange between different subsystems; a video processing unit, which handles the video data; and an interface connector, which ensures proper connectivity with other system components. Each of these components plays a specific and vital role in the overall functionality of the host, contributing to its reliability and efficiency.

Video Distributor. The video distributor is a crucial component of the system, responsible for managing the output of the automatic tracker's CCD video. This component directs the video in two distinct paths: one path leads to the fire control computer and the operator display terminal, while the other path directs the video to the integrated control management host for sighting and aiming video acquisition. The relationship between the video distributor and the other three modules is integral to its operation. The integrated monitoring management host provides power supply for the video distributor. In turn, the video distributor distributes the output video data from the automatic tracker. This distributed video data serves as the CCD video feed for the fire control computer and is also transmitted to the terminal interface for the aiming process and image acquisition, as depicted in Fig. 19. The video distributor was mounted on the left rear seat inside the turret. This positioning facilitates the efficient management and distribution of video data, crucial for the accurate functioning of the system.

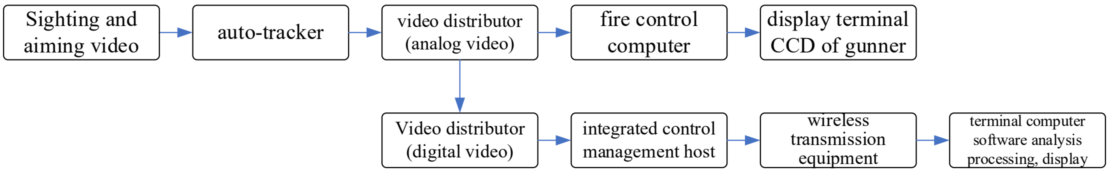

Fig. 19. Video distributor workflow diagram

In-vehicle Video Acquisition Equipment. The in-vehicle video acquisition equipment consists of two primary components: an image acquisition camera and a communication cable. Among them, the image acquisition camera is designed to be magnetic and bracket-mounted, making it easy to install and adjust within the vehicle. This camera is hemispherical visible/infrared POE power supply camera, which has the main function of video acquisition of the operation process in a low-brightness environment under the training scenario of closed windows. When in use, the camera is mounted on the inner wall of the turret. This strategic placement allows it to comprehensively capture the operational activities within the turret, providing a clear and detailed view of the training process. The communication cable connected to the camera ensures that the video data is reliably transmitted to the integrated management module for further analysis and evaluation.

Integrated Management Module. The integrated management module serves as the core processor of the system. It plays a pivotal role in ensuring the smooth and efficient operation of all components. This module provides the embedded software that governs the working sequence and the lower computer for the integrated control and management host. The integrated management module is equipped with various interfaces to facilitate its operations. These include a storage unit interface, which allows for the storage and retrieval of essential data, and a general resource interface, which coordinates the work of other modules within the system. By providing these interfaces, the integrated management module ensures that all components can communicate and function harmoniously. One of the primary functions of the integrated management module is to manage bus data communication. It handles the data exchange between different subsystems, ensuring that information flows seamlessly throughout the system. Additionally, the module is responsible for image processing, which is critical for analyzing video data captured during training sessions. The integrated management module also oversees surveillance video management, ensuring that video data is properly recorded, stored, and accessible for review. Furthermore, it handles wireless communication, enabling real-time data transmission and remote monitoring capabilities. Installed within the integrated control management host, the integrated management module coordinates the overall functionality of the system.

5.2 Wireless Transmission Equipment

The wireless transmission equipment is a critical component responsible for transmitting the data of the on-board integrated control management system to the training assessment and evaluation module by wireless transmission. This equipment is mounted in the external fence position of the turret, ensuring optimal signal transmission and reception. The wireless transmission equipment serves as the data exchange center and transmission carrier between the integrated control management host and the training assessment and evaluation module. The information flow relationship is structured as follows: the integrated control management host (wired network signals)(send)→(receive) wireless transmission equipment-transmitter (2.4G wireless signals)(send)→(receive) wireless transmission equipment-receiving end (2.4G wireless signals into wired network signals)(send)→(wired network signals) training assessment and evaluation module (receive) [20].

5.3 Training Assessment and Evaluation Module

The training assessment and evaluation module is used for the human-computer interaction of the training and evaluation system. It performs image recognition and automatically calculates the tracking steadiness and aiming accuracy of the operator. This module is installed on a computer specifically used for training and evaluation purposes. The relationship between the training assessment and evaluation module and the other two modules is based on the data collected by the integrated control management host. This module analyzes and displays the corresponding results, providing a comprehensive assessment of the operator's performance. The relationship between the information flow is: sending commands and receiving data information transmitted by the integrated control management host through the wireless transmission equipment, analyzing and processing them in combination with the training assessment module, and giving the results of training and assessment. By facilitating seamless data exchange and providing accurate performance metrics, the training assessment and evaluation module plays a crucial role in enhancing the overall effectiveness of the training system.

5.4 Steps for Use

System Installation. The installation process of the system involves setting up several key components to ensure smooth operation and communication. The wireless transmission equipment is installed in the command post, where it is connected to the command and control terminal. This setup allows for the commissioning of the training assessment and evaluation software, ensuring that all systems are properly configured and ready for use. On the vehicle, both the on-board integrated control management system and the wireless transmission equipment are installed. These components are crucial for data collection, processing, and transmission, enabling real-time assessment and evaluation during training exercises. In the target area, targets are strategically set up to provide realistic training scenarios for the operators. The accurate placement of these targets is essential for the effectiveness of the training, as it allows for the proper evaluation of tracking steadiness and aiming accuracy. The installation of each piece of equipment within the system is meticulously detailed and illustrated in Fig. 20.

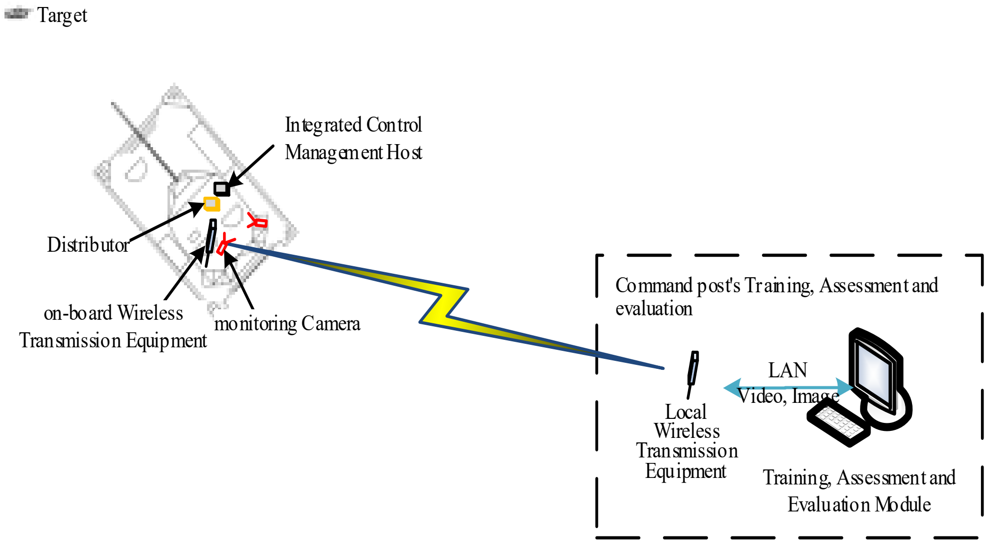

Fig. 20. Schematic diagram of system equipment installation and application

Pre-training Preparation. In the static room, the operator operates the maneuvering console to aim at the target, and through the training assessment and evaluation module, target training is performed and saved for all targets used in training.

Training Steps and Operator Operation. After the training starts, the terminal of the command center sends the training start instruction to the vehicle through the wireless transmission equipment, prompting the operator to initiate the training sequence. Upon receiving this instruction, the integrated control management host starts to collect the aiming image transmitted by the CCD in real time. These images are processed using a pre-trained image recognition model that accurately identifies targets. Recognition during aiming is done by the target image recognition unit. When it identifies the target, it dynamically annotates the target and collects data in real-time from the Flexray bus, including distance measurement commands, firing control commands, target distance, and control console voltage. This comprehensive data collection ensures that all relevant parameters are recorded for a thorough analysis of the training session. At the same time, the operating video acquisition device collects the operation process image of the operator in real time. This device records the entire operation process, providing a visual record of the operator's performance. The captured video is stored at a predetermined saving path, and the video information is also archived in a database for future reference and analysis.

The integrated management module plays a pivotal role in the system by synchronizing and categorizing various types of information. It handles the aiming process image, recognized image, operator operation image, firing control instruction, ranging instruction, target distance, control console voltage. This module stores all collected data in the integrated control management host and categorizes it by time and type, ensuring that the data is well-organized and easily accessible for analysis.

The categorized data is then packaged into different data streams. These data streams are transmitted through wireless communication equipment to the wireless receiving terminal at the command post. At the command post terminal, the data is displayed in real time, allowing command center personnel to monitor the training session as it unfolds. Additionally, the data is stored in real time, ensuring that a complete record of the training session is available for subsequent analysis. After the operator completes the tracking phase, they press the firing button to signal the firing event. This action marks the culmination of the tracking process. The training assessment and evaluation module then utilizes advanced image processing and analytical functions to automatically calculate the operator's tracking steadiness and aiming accuracy during the target tracking phase. This calculation involves generating detailed curves that represent the operator's performance metrics [21, 22].

Comprehensive Evaluation. By tracking the steadiness and aiming accuracy curves, combined with the video monitoring video of the operator's operation during the training process, the skill level of the operator is comprehensively evaluated.

6 Concluding Remarks

This paper proposes a comprehensive evaluation method for assessing the skills required for aiming and tracking target skills, using advanced image recognition technology. By generating tracking stability curves and aiming accuracy curves, which provide quantitative measures of the operator's performance. Additionally, it incorporates manual assessments of adherence to operational procedures during training sessions. This multi-faceted approach allows for a thorough evaluation of the operator's abilities in maintaining steady aim and accurately tracking targets over time. One of the key advantages of this method is its ability to significantly reduce the impact of random factors that often affect the accuracy of traditional training evaluations. By focusing on real-time data collection and precise image analysis, the method enhances the precision of skill assessments. This leads to more targeted and effective training guidance, tailored to the specific needs and performance levels of individual operators. The evaluation system designed using this method is particularly suited for training in stabilized modes, where maintaining steady tracking is crucial. It addresses several common issues associated with traditional training methods, such as low training quality, safety and economic concerns, and lack of specificity in training guidance to a certain extent.

References

[1] D.-J. Wang, S. Shang, H.-T. Liu, X.-W. Zhang, Analysis of image-stabilization-FCS live firing results' evaluated models, Journal of Ordnance Equipment Engineering 35(11)(2014) 12-13, 17.
[2] S. Calla, R. Mark, M.-D. Musicki, R.-J. Evans, Fundamentals of Object Tracking, National Defense Industry Press, Beijing, 2015 (Chapter 1).
[3] J.-F. Zhu, B.-J. Zhao, Q.-Z. Wang, Modern Tank Fire Control System, National Defense Industry Press, Beijing, 2003 (Chapter 1).
[4] J. Jiang, Z.-F. Zhang, Y.-C. Dai, X.-L. Hu, Design of turret angular velocity measurement device based on gyroscope, Measurement & Control Technology 34(10)(2015) 6-8, 18.
[5] B. Zhang, T.-Q. Chang, Q.-Z. Wang, Research of simulated training and evaluation system of tank firing in shooting

range, Microcomputer Information (11)(2008) 35-37.

[6] U.-K. Majumder, E.-P. Blasch, D.-A. Garren, Deep learning for radar and communications automatic target recognition, Microwave Journal 65(1)(2022) 126.

[7] H. Chen, M.-C. Schall, N.-B. Fethke, Gyroscope vector magnitude: a proposed method for measuring angular velocities, Applied Ergonomics 109(2023) 103981.

[8] Q.-S. Liu, B. Nie, Y. Cao, Evaluation system of steady tracking for image-stabilization-fcs based on picture operation, Computer Measurement & Control 17(4)(2009) 708-710.

[9] C.-Z. Wang, Discussion on computer intelligent image recognition algorithm, Computer engineering & Software 42(6) (2021) 136-138.

[10] X.-L. Huang, Research on algorithms and technologies for computer intelligent image recognition, Practical Electronics (22)(2020) 67-68.

[11] R. Udendhran, M. Balamurugan, A. Suresh, R. Varatharajan, Enhancing image processing architecture using deep learning for embedded vision systems, Microprocessors and Microsystems 76 (2020) 103094.

[12] J. Iacovacci, L. Lacasa, Visibility graphs for image processing, IEEE Transactions On Pattern Analysis And Machine Intelligence 42(4)(2020) 974-987.

[13] Y.-P. He, Q.-W. Sun, M. Matsunaga, A. Ota, Can feature structure improve model's precision? a novel prediction method using artificial image and image identification, JAMIA Open 7(1)(2024) 12-13.

[14] J.-X. Li, J. Wang, S. Han, Z.-F. Qi, Methods and applications of system effectiveness evaluation, National Defense Industry Press, Beijing 2022 (75-80).

[15] M.-H. Hu, Ship image recognition and classification based on support vector machine, Ship Science and Technology 44(11)(2022) 156-159.

[16] Z. Li, X.-X. Liu, B.-G. An, Development and application of image information processing system based on Open CV, Information Systems Engineering (4)(2023) 42-45.

[17] X.-J. Man, Simulation analysis of optical image information processing technology, Electronic Technology & Software Engineering (12)(2021) 128-129.

[18] H.-H. Wang, Research on ccd video signal processing method, Silicon Valley (1)(2011) 59, 69.

[19] S.-Q. Li, J. Wang, J. Chen, Y.-D. Chen, Wireless transmission technology for cognitive radio networks, National Defense Industry Press, Beijing 2014 (7-33).

[20] X.-L. Zhao, J.-L Xie, J. Wan, Design and key technology analysis of battlefield monitoring system based on wireless transmission, Electromagnetic Spectrum Management (1)(2022) 45-46.

[21] B.-J. Xing, Z. Yin, K.-W. Wang, X.-M. Peng, Flight training assessment and evaluation method based on video recognition, Ship Electronic Engineering 42(7)(2022) 88-90.

[22] G.-B. Zhang, Research on information warfare simulation training system for surface ships, Ordnance Industry Automation 41(5)(2022) 69-73.