# Research on Gunshot Impact Mark Identification Based on Deep Learning

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**Abstract:** Gunshot impact marks, as critical evidence in firearm-related investigations, are the focus of this study, which explores their automated identification and analysis through deep learning. Traditional methods rely on manual examination of marks left on targets, such as bullet hole morphology, texture, and gunshot residue distribution. The study proposes a integrated approach combining machine vision systems with deep neural networks to extract and enhance key features like shape, texture, and size. By building a curated database of impact marks and employing advanced algorithms for feature matching and retrieval, the system aims to improve accuracy in determining firearm types, reconstructing trajectories, and linking evidence to historical cases. This technology supports forensic investigations by providing efficient, data-driven tools for crime scene reconstruction and evidence analysis.

**Keywords:** Firearm Identification, Impact Mark Analysis, Deep Learning, Convolutional Neural Networks, Automated Ballistics Analysis

## 1. Introduction

In firearm-related cases, the projectile, as the tool that creates marks, exerts a penetrative effect on the target object and other obstacles related to the bullet's trajectory which the objects receiving the marks[1], thereby leaving impact marks[2]. In the investigation of shooting scenes, impact marks typically serve three purposes: firstly, to analyze and determine the nature of the case[3]; secondly, to analyze the types of firearms involved; and thirdly, to provide parameters of the bullet's flight trajectory and reconstruct the formation process of the ballistic path on site[4]. The identification and analysis of impact marks are highly significant for criminal investigation, evidence provision for litigation, and other aspects.

The identification and analysis of impact marks rely on the collection and analysis of both visible marks and trace materials near the impact point[5-6], such as: the diameter and shape of the bullet hole, the material and thickness of the target object, the distribution range and concentration of gunshot residue (GSR), and the distribution of physical evidence like blood spatter and glass fragments. In recent years, deep learning algorithms, capable of end-to-end self-learning from perception to decision-making control based on deep neural networks, have further propelled the revolution in artificial intelligence. The automated identification and analysis technology for impact marks based on deep learning is a comprehensive technique[7]. It is founded on researching firearm types and the quantitative characteristics of impact marks, integrates modern technologies and theories such as wavelet theory, artificial neural network technology, computer graphics theory, and fuzzy recognition technology[8]. It aims to determine image processing algorithms under different conditions, establish automatic identification models for impact marks under various conditions, and build an automatic identification and query platform for impact marks, among other related aspects. It will provide scientific and technological support for solving criminal cases, quickly determining the nature of the case based on scene impact marks, analyzing the types of firearms involved, and reconstructing the ballistic trajectory.

## 2. Key Problems to Be Solved

The identification of gunshot impact marks based on deep learning needs to focus on solving three main problems.

Firstly, constructing a high-precision machine vision inspection system to collect multi-dimensional feature data such as bullet hole morphology, crack distribution[9], and residue adhesion through technologies like multispectral imaging and 3D scanning, ensuring image resolution and detail integrity to provide reliable input for subsequent analysis.

Secondly, utilizing deep learning models like Convolutional Neural Networks (CNN) to process the data, focusing on key features such as the shape, texture structure, and size parameters of the impact point[10]. Feature enhancement algorithms are used to strengthen subtle marks and transfer learning is combined to address sample scarcity issues, enhancing the model's ability to recognize marks under complex backgrounds.

Finally, based on the extracted texture and morphological features, a feature vector database for impact marks is constructed[11]. Efficient retrieval and matching are achieved using methods like deep hashing and similarity measurement. By comparing real-time data with historical case databases, suspected firearm types or related cases can be quickly identified, providing intelligent support for trajectory reconstruction and closing the evidence chain.

## 3. Construction Objectives of the Gunshot Impact Mark Identification System

### 3.1 Establishment of a Mark Sample Database

Using the academy's domestic 7.62mm and 9mm caliber standard firearms, shotguns, and small-caliber sporting rifles as mark-making firearms. Using rubber and metal plates representing ductile objects, glass representing brittle objects, and textiles representing anisotropic objects as the target objects (mark-receiving objects) to create bullet hole samples. A machine vision recognition system will be used to extract samples and form the database.

### 3.2 Determination of Deep Neural Network Structure and Optimization of Network Parameters

Combining deep neural network models such as Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), Long Short-Term Memory networks (LSTM), and Restricted Boltzmann Machines (RBM), design neural network model algorithms suitable for object recognition and intelligent operation. Research parameter optimization, network structure layers, and parameter transfer methods.

### 3.3 Deep Reinforcement Learning Algorithms and Parameter Optimization

Based on the established deep neural network model, combine it with Temporal Difference learning, Q-learning, Monte Carlo reinforcement learning, etc., to establish multiple continuous space deep reinforcement learning algorithms. Analyze the advantages and disadvantages of the built models, find the optimal algorithm, and optimize the algorithm parameters.

### 3.4 Application of Deep Learning Methods in Gunshot Impact Mark Identification and Analysis

Target detection, feature extraction, and matching based on CNN networks are widely used in digital image processing, primarily for quantitative analysis of image characteristics and key feature extraction. Compared to manually designed feature extraction methods, CNN methods are more adaptable to complex environments and special tasks.

Therefore, using deep learning networks to extract sample feature descriptors and aggregate descriptors can achieve automatic analysis and retrieval of gunshot impact marks. Simultaneously, using actually collected gunshot impact mark samples to construct training sets, validation sets, and test sets can fine-tune network parameters and improve the network's generalization ability.

## 4. Implementation Path of the Gunshot Impact Mark Identification System

The establishment of continuous space deep learning mathematical models and parameter optimization enables precise and automated identification of bullet hole characteristics by enhancing feature extraction accuracy and improving algorithmic performance in complex forensic environments.

### 4.1 Research on Deep Neural Network Algorithms

The research analyze the practical advantages and disadvantages of various models, such as CNN, RNN, LSTM, and RBM, for intelligent recognition tasks. Utilize error update mechanisms like stochastic gradient descent for advancing research on novel neural network algorithms. Perform network parameter optimization through intelligent optimization algorithms.

### 4.2 Establishment of a Deep Reinforcement Learning Model

The proposed framework leverages a pre-existing network model to substitute the standard value function in reinforcement learning, thereby forming a deep reinforcement learning model with multiple layers. This architecture incorporates dedicated networks for both the current state value function prediction and the next state value function prediction. To ensure consistency and improve learning efficiency, a parameter sharing mechanism is adopted to synchronize weights between the networks. The action selection follows a greedy policy, and the model parameters are updated using stochastic gradient descent.

### 4.3 Optimization of Feature Localization and Analysis Strategies for Object Information Acquisition Based on Machine Vision

Select machine vision target recognition and localization methods based on deep learning, enabling the model to automatically identify and locate impact marks, completing automatic analysis of mark features.

In the deep learning algorithm model, CNN leverage its strong feature extraction advantages, and RNN can memorize sequences. Based on these advantages and the stochastic gradient descent strategy, construct a new deep learning architecture to address the issue where operations like subsampling and pooling in traditional deep learning architectures reduce image resolution and decrease algorithm accuracy.

### 4.4 Combining Traditional Impact Mark Examination with Digital Image Processing Algorithms

The characteristics of impact marks on different objects are key indicators for mark examination. Features such as characteristic cracks and white glass powder rings in glass bullet holes, depressions and "polygonal" holes in sheet metal edges, abrasion rings, fiber breakage, and GSR distribution around textile holes are all typical bullet hole characteristics. These features are crucial for analyzing firearm type and determining the direction of fire.

The research undertake a systematic examination of the aforementioned ballistic impact characteristics, including fracture morphology in brittle substrates and micro-deformation features in anisotropic materials. Subsequently, the investigation proceed through a standardized experimental protocol comprising quantitative analysis, comparative benchmarking, and computational modeling.

First, research the relationship between firearm type, target object properties, shooting direction, and impact mark morphology. For different target objects, collect image features of mark shape, depth, and size. Establish an automatic identification model for marks caused under conditions such as firearm model, firing angle, and distance. Complete the experimental platform setup. Based on the platform, establish an information database of impact mark patterns and quantitative features. Analyze the relationship between impact marks and firearm types, firing conditions, establishing a mathematical model. Complete the establishment of a multi-dimensional database based on multiple feature recognitions.

Then, use a feature analysis method based on mutual information entropy to optimize the texture feature parameters of the Gray Level Co-occurrence Matrix (GLCM). By calculating the maximum relevance and minimum redundancy between various GLCM texture feature parameters and the samples, select feature parameters that can describe the image texture. Based on experimental analysis of the impact of direction angle, window size, gray level, and step size on these texture parameters, determine their construction parameters. The texture of normal samples in the impact point surface image is relatively clear and orderly.

Finally, based on the analysis of the texture characteristics of impact marks on the target object surface and blank target object samples, combined with experiments, determine the values for the various construction parameters of the GLCM.

## 5. Conclusion

In firearm-related cases, firearms, ammunition, firing pin/breach face marks on cartridges, and impact marks are common evidence at crime scenes, often used to determine firearm performance, identify specific firearms, and estimate firing distance, among other things. Compared to other examination subjects, the identification and analysis of impact marks have always been a challenging topic. This project utilizes deep learning technology, combining artificial intelligence with traditional mark examination techniques, to efficiently use the characteristics of impact marks to infer the perpetrator's modus operandi and firing sequence, thereby enhancing the utilization effectiveness of firearm evidence. The project's outcomes can form a complete evidence chain through mutual corroboration with other physical evidence from the scene, thus reconstructing the shooting incident and proving the nature of the event. The research will significantly advance crime scene reconstruction in shooting cases, especially based on the identification of non-standard firearms. The research work is practice-demand oriented, meets the expectations of the people, and contributes to achieving the goal of solving major cases faster, solving more minor cases, handling cases more accurately, and better controlling the occurrence of cases.


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## References


[1] Gascho D. Virtual Bullet Examination: Forensic Insights from CT Imaging in Gunshot Victims. Forensic Sciences, 2025, 5(2): 23-23.

[2] Shrivastava P, Jain K V, Nagpal S. Gunshot residue detection technologies—a review. Egyptian Journal of Forensic Sciences, 2021, 11(1):11-11.

[3] Lily H, Diane B, Claude D. Effective Abatement of High Lead Level Contamination in a Forensic Firing Range via Inductively Coupled Plasma-Mass Spectrometry. SPECTROSCOPY, 2020, 35(11):47-53.

[4] Roberge D, Beauchamp A, Lévesque S. Objective Identification of Bullets Based on 3D Pattern Matching and Line Counting Scores. International Journal of Pattern Recognition and Artificial Intelligence, 2019, 33(11):34.

[5] Hesar D H, Bigdeli S, Moghaddam E M. A Bayesian approach based on Kalman filter frameworks for bullet identification. Science & Justice, 2019, 59(4):390-404.

[6] Saeed B, Mohsen M E. A Multimodal Fusion Approach for Bullet Identification Systems. Journal of forensic sciences, 2018, 64(3): 741-753.

[7] Bigdeli S, Danandeh H, Moghaddam E M. A correlation based bullet identification method using empirical mode decomposition. Forensic Science International, 2017, 278351-360.

[8] Lu J, Wu S, Yang K, et al. Automated bullet identification based on striation feature using 3D laser color scanner. Optik - International Journal for Light and Electron Optics,2014,125(10):2270-2273.

[9] Heleta S, Cochrane L, Mannai A S. The Impact of the SDGs on Donors’ Choices: Analysis of Trends and Types of Aid to Higher Education at the SDG Implementation Halfway Point. The Journal of Development Studies, 2025, 61 (8): 1201-1220.

[10] Reza K M, Sylvie D, Philippe G. Data Preparation Impact on Semantic Segmentation of 3D Mobile LiDAR Point Clouds Using Deep Neural Networks. Remote Sensing, 2023, 15 (4): 982-982.

[11] Shimazaki Y, Iwasaki Y, Takasugi A, et al. Retrospective Study of Trigger Point Injections for Myofascial Pain Syndrome in Cancer Patients: Impact on Pain Relief and Opioid Tapering.. Journal of pain & palliative care pharmacotherapy, 2025, 1-10.