An Image-based Digital Forensic Investigation Framework for Crime Analysis

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***Abstract*—Digital Forensic Investigation (DFI) is a big field in the technological era. Technology is constantly improving and being advanced. As technology advances, criminals are also changing their crime strategies. The real criminal is brutal to be caught. DFI is a process by which we can find out the criminal by making a detailed report based on the crime scene investigations. As a result, crime is increasing day by day. Several types of research have been conducted, and a lot of research is running on this topic. However, still have some confinements in this field. In this paper, we propose an image-based DFI model for crime analysis. The main goal of this paper is to analyze the crime scene images, detect suspicious objects efficiently and reduce crimes using the DFI process. Moreover, we use object detection algorithms (e.g., Faster R-CNN, R-CNN, and SSD), image enhancement techniques, and sharpening filters for low-quality images. Furthermore, the authors assess the performance of the framework using various metrics (e.g., Accuracy, Precision, Recall, and F1 Score).**

***Keywords*—Forensic, Investigation, Crime, Evidence, Objects, Image Processing, Faster R-CNN, Accuracy, and etc.**

I. Introduction

Crime is growing at a proportional rate as the population grows. But it needs to be judged fairly. DFI is a process [1] [2] by which we can find out the criminal by making an accurate report. Identifying crime in the past few years has been quite challenging. Also, the criminal was much harder to catch. The exact criminal has not been caught. Many innocent people have also been punished. But now mobiles, cameras, and Closed-Circuit Television (CCTV) are available. With these devices, pictures or videos can be easily captured, and crime and criminals can be detected. By CCTV, a specific distance range can be covered by the videos. But the video and image quality is inferior, especially for CCTV. That's why there's a lot of research going on. But even then, crime is not decreasing. Instead, it is increasing. We have analyzed a lot of research about DFI, but we have detected some limitations. For that reason, we have presented an architecture that investigates the crime scene based on the different types of images to reduce crime. In this research, we have used an image edge enhancement filter. Moreover, we have used different algorithms, such as Faster R-CNN, for object detection. Research keeps pace with the times through technology that has been used correctly. Applying this research to detect the exact criminals where there will be a crime. It can be on the street, office, bank, house, or anywhere.

However, object detection could be a common term for computer vision methods for finding and labelling objects. These methods can be applied to both static pictures and moving pictures. In the article, [3] TensorFlow-based object detection to perform waste object recognizable proof and classification. It was a little difficult to identify crime and the criminal before modern technology was invented. Very few CCTV cameras were on the street, at home, in the office, or in essential places. People had fewer smart devices or cameras. Due to this, the pictures of the crime could not be found. On the other hand, we often get pictures of crime scenes, but it is difficult to identify the crime because the image quality is not good. Another paper [4] has developed forensic video investigation strategies to assist in forensic investigations. To begin with, proposed video or picture improvement algorithms to convert low-quality videos or pictures into smart quality. In that case, image processing has to be done on the pictures. Image processing makes it easier to identify the crime. Moreover, in [5] proposes an inventive digital forensic architecture utilizing blockchain innovation for the fast-growing Software-D Networking.

In this article, we have used Faster R-CNN with TensorFlow on the crime images containing the data set. Faster R-CNN is a method that trains our model based on train data. We have taken 10 types of objects, with 4500 trains and 500 test data-set [6]. Considering the above premises, the contribution of this paper is as follows:

- We present a DFI model for detecting crime scenes based on images.
- Moreover, we analyze the crime images using various algorithms (e.g., Faster R-CNN, R-CNN, and SSD+MobileNetv1) for suspicious object detection.
- Finally, we evaluate the proposed model's performance using various performance metrics (e.g., Accuracy, Recall, Precision, and F1 Score).

Organization: We have discussed the related works in section II. After that, we proposed our DFI-based methodology in section III. Moreover, the result analysis and discussion have been analyzed in section IV. At last, the conclusion part has discussed in section V.

II. Related Works

In recent years, numerous research has been performed in this field. Most are intended for crime or accurate object detection to reduce crime and people's security. To solve various challenges in object detection, many researchers try to find optimal solutions for detecting the actual object. Some of them are listed below:

The author Sheng et al. [3] have proposed an intelligent waste management system. It is TensorFlow-based object detection to perform waste object identification and classification. The model detected and classified waste according to metal, plastic, and paper classes. Moreover, Xiao et al. [4]

have presented video-based evidence analysis and extraction in DFI. The main goal is to assist in forensic investigations through video analysis. Also, they have used video enhancement algorithms to convert low-quality videos or images into intelligent quality. Furthermore, Mehran et al. [5] have introduced an innovative digital forensic architecture using blockchain technology for the fast-growing Software-D Net networking and infrastructure-in-service cloud to resolve the collecting and storing of centralized evidence that reduces the reliability of digital evidence. Moreover, they have proposed a secure ring variation citation-based authentication scheme to protect the system from unauthorized persons.

In another article, Amin et al. [7] have suggested distance estimation using TensorFlow object detection. In this work, the author can detect any object up to a distance of 3.5 meters, but they cannot uniquely identify multiple objects at once. Moreover, Goel et al. [8] have proposed real-time object detection using TensorFlow, an application of ml. In this article, the author has used recent techniques in computer vision and deep learning. Furthermore, the Custom dataset was created using labelling, and the evaluation was consistent. Moreover, Hossain et al. [9] discuss the effectiveness of Faster R-CNN and SSD Mobile-Net methods for real-time object detection. Here, the algorithms of these two models are described. Also, performance evaluation is done using a training dataset of 400 images of four objects: persons, watches, cell phones, and books. In this article, [10], a Fast R-CNN algorithm with TensorFlow for underwater object detection is proposed. They have used a trained dataset to have smart accuracy. In another article [11] author has built a model by utilizing the Faster R-CNN algorithm, which recognizes the debilitating object of a picture. The author has constructed the model utilizing the object detection API. They have taken around 4500 steps to induce a misfortune underneath 0.1, which takes twelve hours. In another work, Kovacs et al. [12] have proposed that it is based on digital media evidence. In this study, they have shown how digital proof helps police in investigations. The reason for the paper is to focus on the tending of digital media investigators to help to investigate officers with the collection and clarification of digital proof.

III. Proposed Methodology for Image Based DFI

In this section, we have proposed a framework that analysis forensic images from crime scene-related digital sources. We have divided our proposed model into four individual processes shown in Fig. 1.

*1) **Forensics Process**:* In the first phase, we have shown the forensics process, where we have analyzed the crime scene and crime scene-related digital sources:

- **Crime Scene Analysis:** For normal crime, police or investigation teams first try to identify some suspicious objects from the crime scene, such as pistols, knives, blood samples etc.
- **Crime Scene Related Digital Sources:** Here, we have added some crime scene-related digital sources:
  - **Social Networks-** We can retrieve evidence from social platforms such as Facebook, WhatsApp, Instagram and etc. Where we can apply our further investigation processes.
  - **Image Recorder-** From image recording devices, we can retrieve crime scene-related images or evidence.
  - **Mobile or Smart Devices-** Also, we can collect evidence from mobile and smart devices.

  These all are crime scene-related digital sources where we can retrieve crime scene-related images.

*2) **Acquisition Process**:* In the second phase, we have shown the image acquisition process, where we have analyzed the image acquisition, quality enhancement, and image analysis processes:

- **Image Acquisition:** Image acquisition is a process that retrieves images from external sources for further processing. It's continuously the foundation step within the workflow since no process is available before getting an image.

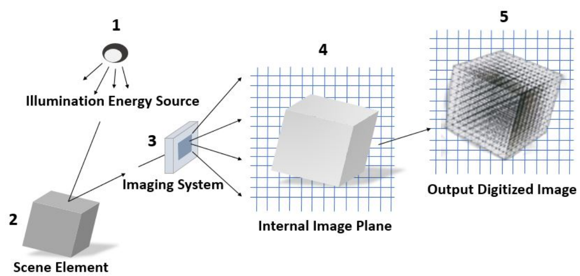

Figure 2. Digital Image Representation

  Furthermore, the author has shown a digital image representation using an array sensor in Fig. 2. Where the sensor array coincides with the central plane, it produces an output corresponding to the integral of light received at each sensor.

  For collecting the incoming energy, we use the imaging system that focuses on the image plane. The front end of the imaging system is a lens, that projects the viewed scene onto the lens focal plane. The sensor array coincident with the focal plane. It produces outputs that are proportional to the integral of the light received at each sensor. Another section of the imaging system that digitizes the focal plane signal and the process output is a digital image.
- **Image Quality Enhancement:** High-quality images are essential for our forensic investigation. The surrounding environment may damage an image during acquisition, transmission, and processing. For example- poor light conditions, device noise, and compression loss during transmission can cause serious damage to the image and reduce its quality. Image quality enhancement helps to recover the necessary contents and details from degraded images. We try to collect all potential data to maximize its information. The collected images from image capturing, mobile or smart devices are not suitable for forensic analysis. Because it can't maintain the original quality requirements that we require. So, our forensic images need quality enhancement to get maximum benefit and information through it.

  Here, we use the histogram equalization algorithm for quality enhancement that works the contrast level of an image. It improves the contrast in an image to extend the intensity range. First, it reads the input image from the input file and then computes the histogram. Then calculating, the normalized sum to transform the image and written into the output file.

  The histogram first computes input image pixel values. Histogram places each pixel values $f[x,y]$ into one of L uniformly-spaced buckets $h[i]$.

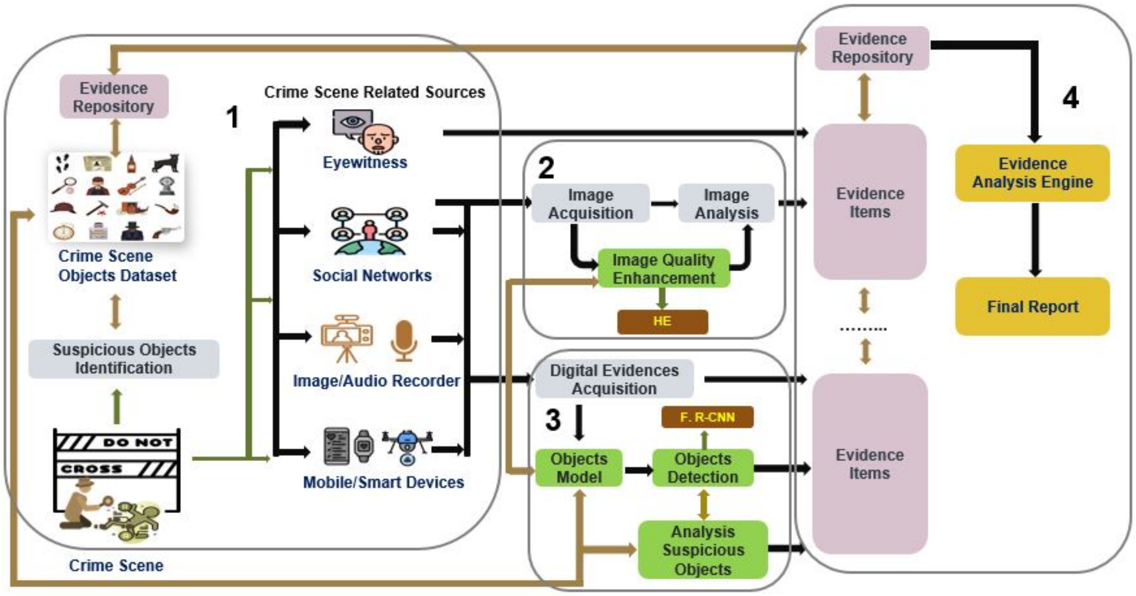

Figure 1. Proposed Image-based DFI model

$$h[i] = \sum_{x=1}^{N} \sum_{y=1}^{M} \begin{cases} 1, & if,\ f[x,y] = i \\ 0, & \end{cases} \quad (1)$$

Now, the cumulative distribution function,

$$CDF[j] = \sum_{i=1}^{j} h[i] \quad (2)$$

To produce the output image, we scale the input image using the cumulative distribution function. After applying it, we get

$$g[x,y] = \frac{CDF\Big[f\big[x,y\big]\Big] - CDF_{min}}{(N \times M) - CDF_{min}} \times (L-1) \quad (3)$$

Where CDF_{min} represents the smallest non-zero value of the cumulative distribution function. Moreover, $L = 2^8$ and image dimension = M*N.

- **Image Analysis:** Image analysis involves processing an image into fundamental components to extract meaningful information.
  - Image analysis helps to improve images for human interpretation.
  - Data can be prepared and extricated from images for machine interpretation using image analysis.
  - The pixels within the image can be controlled to any craved density and differentiate.

Algorithm 1: Algorithm for object detection and image quality enhancement

```
                              /* C_i = Crime image */
   /* β = Report generate with accuracy
 */
                            /* R_i = Resize image   */
Input : C_i
Output: β
1  for (i = 1; i ≤ C_i; i++) do
2      if (C_i == Low quality image) then
3          C_i= Image enhancement using edge enhance
             and sharpen filters;
4          for (j = 1; j ≤ C_i; j++) do
5              if (C_i ≠ R_i) then
6                  C_i= Image converted to (350*350)
                     pixels;
7              else
8                  go to step-12;
9              end
10         end
11     else
12         α = Object detection using faster R-CNN;
13     end
14 end
15 return (β)
```

*3) **Object Detection Process**:* In the third phase, we have shown the object detection process, where we have analyzed object detection and suspicious object analysis part:

- **Object Detection:** Object detection works on numerous applications in computer vision, such as object tracking, retrieval, image captioning, segmentation, etc. It recognizes the object with a bounding box, whereas in image classification, we can categorize that object in the image. We use the Faster R-CNN algorithm for object detection that works on extraction and region selection into a single machine-learning model [13]. It receives an image and calculates the Region of Interest (ROI). Then returns a list of bounding boxes and classes of the objects identified within the image.

- **Suspicious Objects Analysis:** Here, we analyze all suspicious objects in images. We also remove unnecessary data or elements and focus on crime-related raw data.

*4) **Investigation Process**:* In the fourth phase, we have shown the investigation process, where we have analyzed the evidence item, evidence repository, and evidence analysis engine part:

- **Evidence Item:** Crime scene-related all suspicious elements are evidence items such as knives, pistols, footprints, blood samples, etc. Suppose we identify a single knife from an image that is one evidence item. We analyze these evidence items for further investigation. Evidence repository stores all these evidence items.
- **Evidence Analysis Engine:** To analyze all the evidence we use an evidence analysis engine. It collects all crime scene-related evidence and analyzes it to generate a better and more useful framework. The evidence analysis engine provided evidence related to criminal justice and analyzed all the evidence. To explore evidence more deeply, we use it.
- **Final Report:** After organizing all analysis parts, we generated our final report, where we mentioned the final presentation of the total crime scene-related investigation.

Image Processing Procedures: In this procedure, Fig. 3 shows the procedures for advanced forensic image processing.

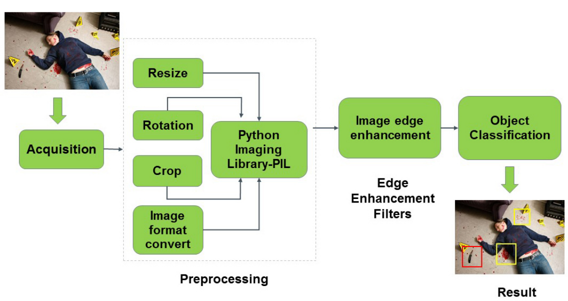

Figure 3. Procedures for Advanced Forensics Image Processing

Here, first, we take an image, and then we perform image acquisition. Where we convert an analogue image into digital form. Then we move on image processing part.
For image processing, we use the python imaging library pillow. To manipulate and process images, the pillow provides similar tools to other image processing software. Here, we perform various operations on images such as crop, resize, rotation, format convert, and so much more.
Then, we focus on the quality enhancement part, and after quality enhancement, we apply object detection algorithms to images and get our final result.

IV. Result Analysis and Discussions

A. Performance of the Faster R-CNN Algorithm

Table. I shows the Precision, Recall, and average time (sec) for faster R-CNN with respect to the various classes. We have used various classes (e.g., pistols, Hammers, Bullets, Knives

Table I
PERFORMANCE OF THE FASTER R-CNN

Class	Image	Labels	Precision	Recall	Avg Time(sec)
Pistols	1200	120	0.474	0.037	2.23
Hammers	900	70	0.538	0.237	2.35
Bullets	650	210	0.374	0.437	1.63
Knives	400	100	0.614	0.237	1.33
Scissors	450	110	0.514	0.337	1.35
Blood	150	50	1.00	0.00	1.45
Pens	350	20	0.470	0.037	2.13
Axe	500	50	0.454	0.137	2.24
Fire	150	80	1.00	0.470	1.00
Steel scale	250	140	0.150	0.437	1.21

Table II
PERFORMANCE RESULTS FOR HIGH-QUALITY IMAGES

Execution Metrics	Algorithms		
	SSD+MobileNet	***R-CNN***	***Faster R-CNN***
Accuracy (Pistol)	0.91	0.92	0.95
F1 Score (Pistol)	0.94	0.95	1.00
Accuracy (Bullet)	0.86	0.89	0.93
F1 Score (Bullet)	0.89	0.93	0.95
Accuracy (Knife)	0.89	0.90	0.94
F1 Score (Knife)	0.92	0.94	0.97
Accuracy (Wine)	0.89	0.90	0.94
F1 Score (Wine)	0.92	0.95	0.98
Accuracy (Hammer)	0.94	0.93	0.96
F1 Score (Hammer)	0.97	0.95	1.00
Accuracy (Blood)	0.90	0.92	0.95
F1 Score (Blood)	0.94	0.95	0.97

and etc.) for finding precision and Recall. Moreover, we have calculated the average time with respect to the Images and labels.

B. Object detection for high-quality images

The training data set comprises 4500 pictures and 500 pictures also the test data set was collected from camera devices, CCTV footage, google, social media and etc. The determination of the pictures is 350*350 (width*height). Fig. 4 represents a sample data set with various orientations. Table II shows the accuracy of hammers, bullets, pistols, knives, scissors, blood, pen, steel scale, axe, fire, and wines. But the accuracy of hammers and pistols is much better than other objects. Moreover, Table II shows the execution metrics for various algorithms such as SSD+MobileNetv2, Region-Based Fully Convolutional Network (R-FCN), and Faster R-CNN [14]. Furthermore, we have calculated accuracy and F1 score for different objects where Faster R-CNN performs better than SSD+MobileNet and R-FCN. A few detection scores cases are given in Fig. 5.

Table III
PERFORMANCE RESULTS FOR LOW-QUALITY IMAGES

Execution Metrics	Algorithms		
	SSD+MobileNet	***R-FCN***	***Faster R-CNN***
Accuracy (Pistol)	0.79	0.80	0.85
F1 Score (Pistol)	0.80	0.81	0.92
Accuracy (Knife)	0.80	0.80	0.85
F1 Score (Knife)	0.83	0.83	0.89

C. Object detection for low-quality images

In this part, we have conducted the process of object detection on low-quality images, such as dark pictures, blur

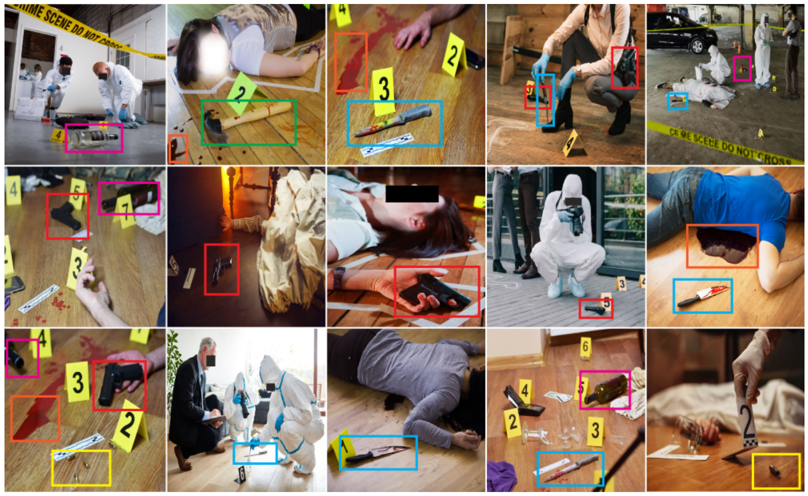

Figure 4. Sample of Crime Images Dataset

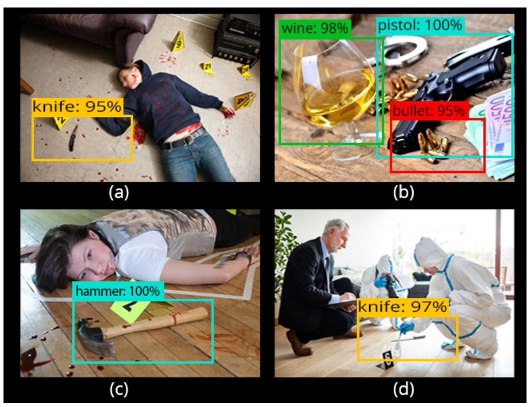

Figure 5. High-quality Object Detection's (a) Knife Detected (b) Wine, Bullet, and Pistol Detected (c) Hammer Detected and (d) Knife Detected

pictures and etc. It is very difficult to detect objects from those images. Fig. 6 shows the accuracy of the objects where accuracy for the pistol and knife is 92% and 89% respectively.

But before detecting objects for low-quality images, we need to enhance the quality of low-quality images by using edge enhancement and sharpened filters. Fig. 7 shows the enhancement technique for low-quality images.

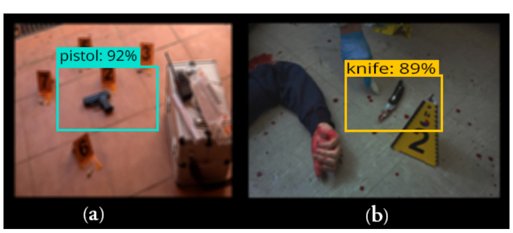

Figure 6. Low-quality Object Detection's (a) Detection of Pistol, (b) Detection of the Knife.

Table IV shows the average accuracy for existing works with various algorithms. We have analyzed our proposed work with recent existing works based on the various types of objects (e.g., metals, plastics, blood, knives, pistols, bullets, etc.). A lot of researchers have used algorithms such as R-CNN,

Table IV
PERFORMANCE COMPARISONS

References	Data Types	Algorithms	Acc(%)
Sheng et al. [3]	Metal, Plastic etc	MobileNetV2	88.43
Xiao et al. [4]	Person, Knife etc	YoloV3	90.98
Goel et al. [8]	Bird, Cat etc.	OpenCV	62.20
Hossain et al. [9]	Person, Book	MobileNet	85.00
Kushal et al. [15]	Bottle, Clock etc.	R-CNN	94.67
Luis et al. [16]	Bike, Car etc.	MobileNetV2	55.50
Srivastava et al. [17]	Sign Language	OpenCV	85.50
Peker et al. [18]	Car, L. Plate	MobileNetV2	88.90
Kanimozhi et al. [19]	Chair, Person	MobileNet	94.60
Proposed	Pistol, Bullet, etc.	Faster R-CNN	96.67

Contrast Limited Adaptive Histogram Equalization (CLAHE), MobileNetv2, K-Nearest Neighbor (KNN) and etc. for object detection but we have applied the Faster R-CNN algorithm and also some edge enhancement and sharpen filters in our object detection method, comparatively, our average accuracy is better than the average accuracy of other object detection processes, it is almost 97%.

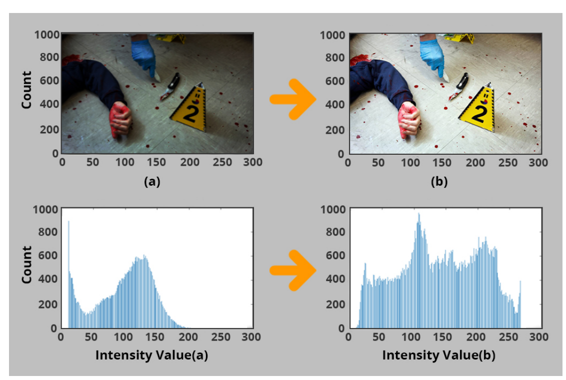

Figure 7. Image Quality Enhancement

Moreover, Fig. 8 depicts the accuracy of various objects (e.g., pistols, knives, bullets, hammers, scissors, wines, and blood) based on the test and training dataset. For knives and pistols, we have found the highest accuracy(%). On the

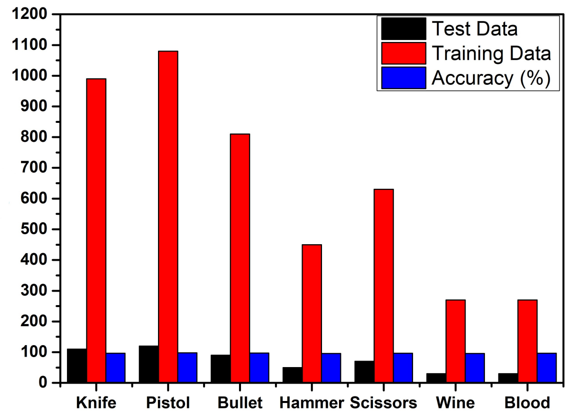

Figure 8. Data Accuracy (%) with Respect to the Test and Training Data

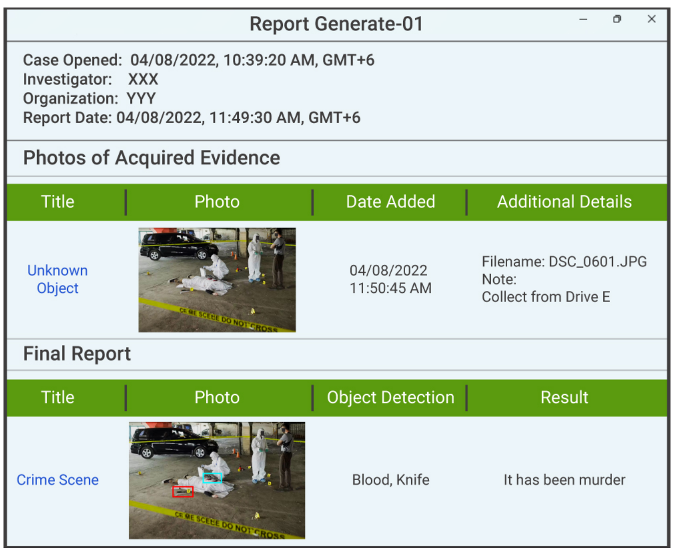

Figure 9. Sample Report-01

contrary, we have found lower accuracy for the liquid types of objects such as wines and blood (%). Here, we have used 4500 data for training and 500 data for testing purposes.

Finally, Fig. 9 shows the final reports which are provided by the system. It displays that it will be possibly murdered depending on the crime scene.

V. Conclusion

In recent years, several kinds of research have been done in this field. But a lot of challenges and limitations remain. To overcome these issues, we have proposed an image-based DFI model to detect crime accurately. The authors have used various object detection algorithms and image enhancement techniques for low-quality images in the article. Moreover, we have evaluated our outcomes based on the performance metrics. Furthermore, we prepare a crime report based on the results to reduce crimes. However, we also still have some limitations. We will overcome these limitations in the future by developing a new object detection algorithm and sharpening the filter. New algorithms will be developed for detecting crime-related objects accurately.

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