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DEVELOPMENT OF AN AI-ENABLED VIDEO CAPTURING DEVICE FOR BULLET TRAJECTORY ANALYSIS AND BALLISTIC RESEARCH

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ABSTRACT

A ballistic experts' discipline is the ability to compare the characteristic marks found on the surface of different fired bullets to determine whether they were fired from the same gun. These tool marks become a "ballistic fingerprint" that examiners can use to identify specific characteristics of the firearm that discharged the bullet. One such tool mark is the striation marks left on the bullet, identical to scratch marks. Manually done, a comparison microscope is used in this process, where the testing bullet is rotated until a well-defined land or groove comes into view. The sample bullet is then rotated in search of a matching region. But in this process opinions are given through only the manual experimental process and not through an automated system. The proposed solution was to develop a cost-effective automated system that captures the video of the bullet in one go. Also, the focus was to develop a lighting arrangement independent of the environment, so that the device can be efficiently used in any environment.

I. INTRODUCTION

The increasing rate of crime is a matter of concern for the country. According to a statistic by National Crime Records Bureau, a total of 51,56,172 crime incidence have been reported in 2019, and out of 44,823 cases of murder by firearms 44,513 are cases of unlicensed firearms [1].

The illegal manufacturing and smuggling of firearms have become a topic of concern for the country breaching any citizen's security. To encounter this challenge, the country's criminal investigation department plays a major role to gather evidence against a criminal using forensic science.

Forensic ballistics, a branch of forensic science, is about the examination and identification of firearm evidence from a crime scene. In our country India there are seven Central Forensic Science Laboratories (CFSL) and 30 State Forensic Laboratories that were established as a scientific department to provide scientific support and services to the investigation of crime [2].

The experts of CFSL examine the exhibits forwarded by the Investigating Agencies and render an expert opinion and substantiate their opinions in the Court of Law through court testimony and evidence.

Bullets are intentionally designed to be wider than the barrel of the firearm. When a bullet is fired, it travels through the barrel of the firearm. As the bullet passes through the barrel, the barrel compresses, thereby leaving tool marks on the bullet. These tool marks become a "ballistic fingerprint" that examiners can use to identify specific characteristics of the firearm that discharged the bullet.

These striation marks on the bullet are the target of examination because of their specific identity as depicted in **Figure 1**.

Figure 1: Striation mark captured in confocal microscope in CFSL Laboratory, Kamrup, Assam.
Source: Authors, (2024).

A ballistic expert's discipline is their ability to compare the striations found on the surface of different bullets, and to determine whether these striations indicate the different bullets were fired by the same gun. Making such determination is not an easy task as it depends on the quality of striations marks. Generally, it takes a few days for the examination, but complications arise due to segregation or overlapping of multiple marks which makes the process tedious, which further delays the service.

In forensic science laboratories, microscopes are used to study the striation marks of a bullet. An expert must be equipped with a microscope to check and compare two different bullets. The modern technology of microscopes allows us to capture pictures easily from the microscope. But there is no automated process of taking pictures of the whole bullet. At present, to do that, precision hand movements are required so that there is neither any overlapping part nor any part left out. A typical AI-based system would follow the steps as depicted below (Figure 2). But it is not possible to capture complete images of the striations of the bullet, as depicted in Figure 3, and hence only parts are taken and either analysed independently or after stitching them [3] [4] [5]. If the striations can be captured in totality, and in the desired magnification (for clear view of the marks) then the analysis of the features would be much improved and easier.
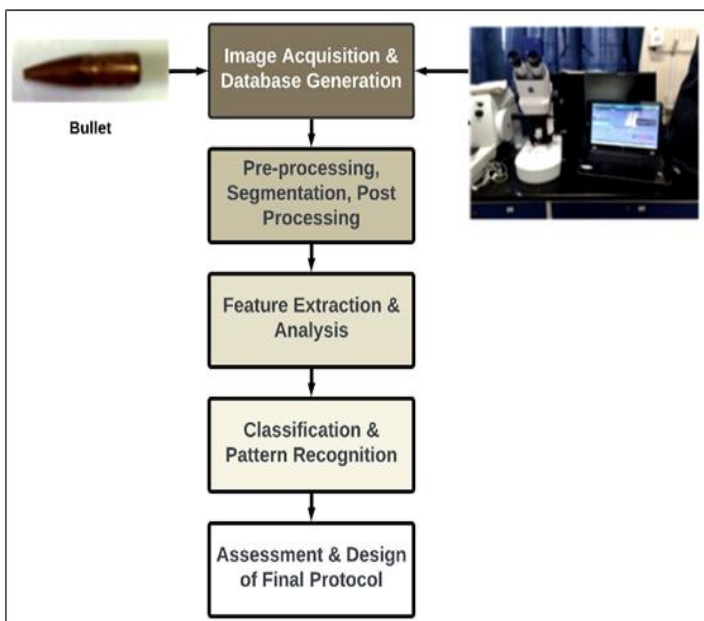

Figure 2: Usual methodology of AI-based image analysis of a bullet.
Source: Authors, (2024).

With this motivation, the idea of the device proposed in this work by us is to capture the video of a bullet in a very easy and comfortable way and eliminate the difficulties that are present in the above-mentioned item. So that all the details of any bullet can be recorded precisely in just one click without any overlapping part. The recorded footage can be successively studied, transported/distributed with the corresponding authority very conveniently. A person, who doesn't have a microscope is now able to study the bullet from the video sent to him. One can develop a computer application to study the bullet by importing the video to it. So, this method can be used as a standard procedure in near future for ballistic science studies.
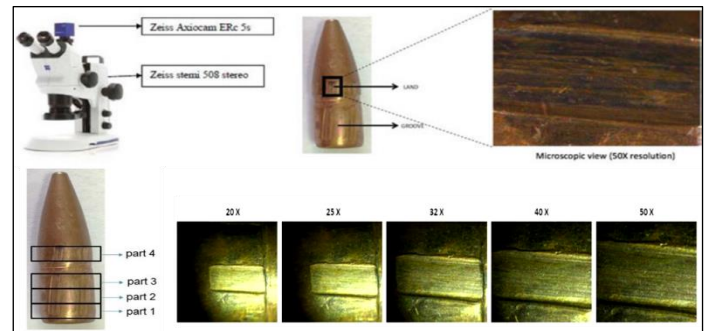

Figure 3: Depicting how images are catured in parts and different magnification views of striations marks.
Source: Authors, (2024).

II. RELATED WORKS

The prior art reveals that an imaging system, known as Fireball [6], was developed for the Police Services which can store, analyze, retrieve, and match high-resolution digital images of cartridge cases. But the system was not equipped for fired bullets. In India, there is no such device available until now which aims to solve the particular problem we intend to. However, in Thailand, there has been a system [7] developed which carries out a similar process. They have implemented a system where a 9 mm bullet is placed into a mechanism. It is rotated using a motor with the help of a micro-controller and the details of the bullet are captured using an iPhone camera. The drawbacks of the system are as follows:

i. The system is designed to take only 9 mm bullets. One can't use any other sizes of bullets.
ii. There is no synchronization/communication between the rotation and recording. One has to manually start the rotation and start the recording, which is not an ideal condition. If there is any kind of delay, the results will be improper
iii. There is no mechanism to prevent the recording after a certain revolution so that no overlapping part occurs. One has to process the video in a machine learning model to get rid of the overlapping part.
iv. The recording system is not universal. It depends on a particular app platform.

III. PROPOSED SOLUTION

The object of the proposed device is to develop a cost-effective and efficient system that can capture/record the unique/feature details of a bullet. The main contributions of the work presented in this paper are enumerated as follows.

i. Since different bullets have different diameters, so there is a requirement of a base where any bullet can be placed. Hence, an adhesive mechanism base has been prepared where a bullet of any diameter can be placed.

ii. Using a digital Vernier calliper will help to measure the diameter of the bullet which is to be used in the system. This diameter is used to calculate the required rotational speed so that all bullets have one steady translational speed.

iii. Usage of motor feedback mechanism. From the motor's feedback of rotation, the micro-controller can send signals to the recording device to start/stop recording. Hence the recording process has been automated.

iv. Lighting system independent of the environment light, which will make sure that the bullets are lit exactly at the required intensity with minimal reflection and ambient light can't disturb the system.

IV. STATEMENT OF THE PROPOSED DEVICE

A prototype has been built that can be used to capture all the details of a bullet in a single video. This video can then be used for several purposes. It will be easier to distribute to different experts and trainees for carrying out related forensic analysis using a computer and a common video application. It will eliminate the need for carrying an actual bullet to a laboratory with a sophisticated microscope, which is being conventionally done now. Further, the classification and identification of the bullet can also be done using machine learning and deep learning algorithm implementations from the acquired video. The use of artificial intelligence (AI) will reduce the analysis time and also increase accuracy. The USP of the prototype are:

- The bullets can be compared by studying the video footage.
- Doesn't need a costly microscope just to declare the class.
- Anyone can use the system. It is as easy as plug and play.

V. DESCRIPTION OF THE PROPOSED DEVICE

He portable device can be equipped with any type of camera, providing it has an external trigger, with any existing microscopic lens system. The bullet is placed on a 360-degree rotating base. The camera is connected to the system and placed properly in front of the microscopic lens system. As the rotating starts it starts the recording automatically and it stops before overlapping parts occur in a full rotation. Besides, there is a calliper attached to the system so that the diameter of the bullet can be measured in the beginning and the rotational speed can be determined from it to maintain a steady translational motion throughout different bullets of different diameters, this would help in reducing the blurriness and rolling shutter effect that arises in a moving object in a video by minimizing the speed of rotation

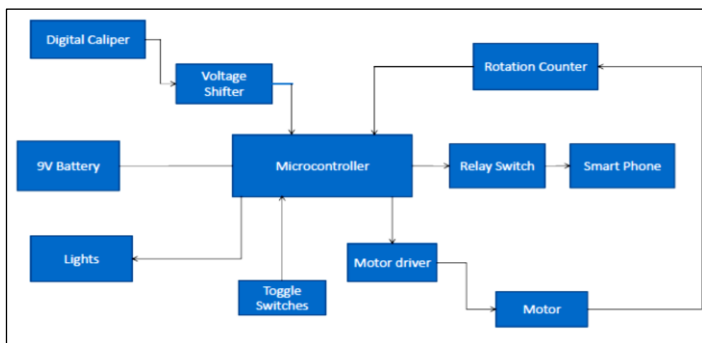The working is described with a Block Diagram (Figure 4) and in details below:

Figure 4: Block Diagram of proposed device.
Source: Authors, (2024).

V.1 DETAILED DESCRIPTION

One digital calliper has been implemented in the system to measure the diameter of the bullet. This measurement directly affects the rotational speed. The calliper has a resolution of .01" and 0.01mm. At first, the camera is connected and placed properly in the system. After the bullet diameter is measured using the calliper attached to the system it is placed on a base and it is checked whether the lens is focused or not. The lighting is set up by observing how the bullet is reflecting/reacting to the lights and how well the detailed marks are visible. After that, the speed level is set from three predetermined sets of speeds. The final rotational speed is determined by the speed level which is set by the user and the calculated speed due to the diameter of the bullet.
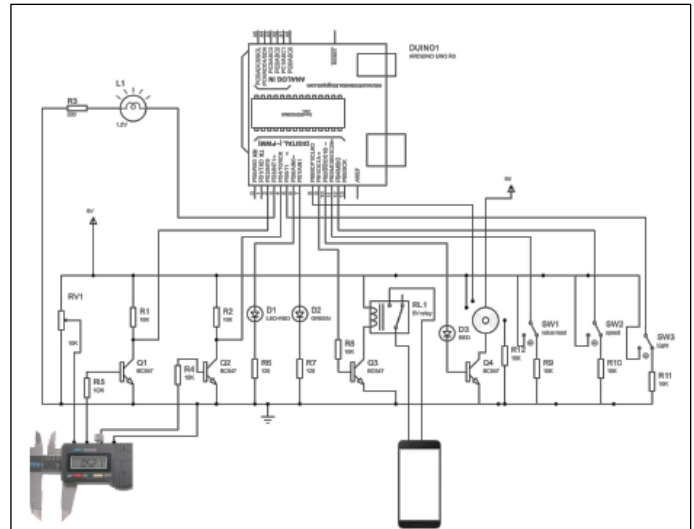

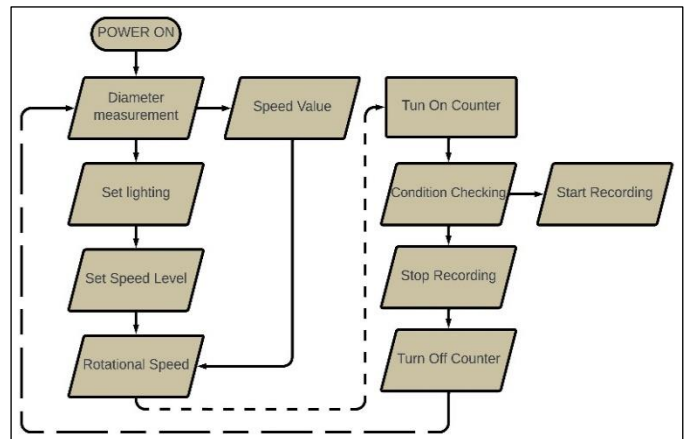Figure 5: Flowchart of working.
Source: Authors, (2024).

Figure 6: Circuit Diagram.
Source: Authors, (2024).

A rotational counter is attached to the rotor of the motor which is turned on after the lighting and speed are set appropriately. As for now, there are 12 divisions (which can be increased also), 30 degrees (can be decreased) each, in the counter. The value of the counter increments after crossing each division. It counts from 0 to 11. After 11 it is again set to 0 by the program. When the counter counts 1, the microcontroller triggers a relay, which toggles the recording in the smartphone via an earphone jack. When the counter Counts 11, again the

relay is triggered which stops the recording. The video is obtained that way. It is known that the focal plans are flat and the lens introduces chromatic aberrations at the edges. Here it is assumed that 60 degrees are properly covered by the camera without any chromatic aberration, focal error, as the bullet surface is not flat. If we use some advanced optical system, then this measurement can be changed. The flowchart of working is depicted the Figure 5.

VI. CIRCUIT EXPLANATION

Figure 6 depicts the proposed circuit diagram. The micro-controller board has been powered using a 9V DC battery. The micro-controller board has been powered using a 9V DC battery.

The board gives an output of 5V from its internal voltage regulator. The digital calliper operates on 1.5V, which is not enough for the Arduino board (ATmega328P) to distinguish high (1) and low (0) states, as the threshold voltage to distinguish between high and low is 2.8V for Arduino. Therefore, to power the calliper a 10K ohm potentiometer is attached to the 5V supply to provide 1.5V and also two BC547 transistor amplifiers has been used to amplify 1.5V signals to 5V signals which are being sent by the calliper from data and clock port to the Arduino board. 10K ohm resistors have been used on the base and the collector of the transistors, otherwise, the transistors may get damaged or some fault in amplification may arise.
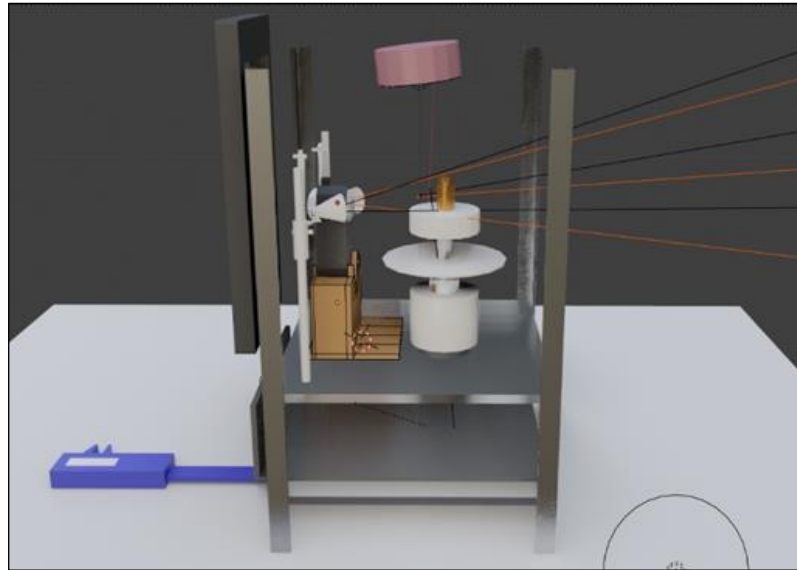

Figure 7: A 3D representation of the prototype.
Source: Authors, (2024).

The counter is a simple design that increments the value when it reads a logic 1. A HIGH voltage is applied to the counter divisions and a low voltage is applied to the reader pin. When the reader touches the divisions, it sends HIGH logic to the board and the board increments the counter value. The LOW voltage is kept applied the rest of the time to the reader pin so that it turns back to the LOW state immediately after touching the divisions. A resistance of 10K ohm is connected so that no short circuit takes place. Green LED is an indication of the counter. Whenever the value increments, it lights up for a few milliseconds. A current-limiting resistor (100 ohms) is connected in series to protect the LED from getting burned by excessive current.

The relay works on 5V voltage. It doesn't work below that voltage. The output pins of the Arduino board provide 4.8Vwhich is not enough for the relay to work properly. Again, one transistor with appropriate resistors has been used to amplify the output pin signal to 5V. The collector of the transistor is connected to one pin of the relay. Another pin of the relay is connected to a 5V supply. In this case, the transistor is acting as a switch. When the base is HIGH, the relay circuit closes and the relay is switched on. When the base is LOW, the transistor goes to cut off state, the relay circuit becomes open and hence the relay is turned off.

The relay has a total of 5 pins. Two pins are used to control the relay. Rest three are used to switch the external circuit. The pins are- NC (normally connected), NO (normally open) and common. When the relay is not active, the common and NC remains in short. When the relay is active, the common and NO are connected in short. The triggering pin of the earphone jack is connected to common and NO. So, when the relay is active, the common and NO are shorted, so the triggering pin sends that signal to the smartphone (or any other device which supports external triggering) and the phone starts recording. Red LED is an indicator that stays ON while the recording is taking place. The motor speed control is done by the Arduino board itself. As a motor driver, another transistor (BC547) is used, which takes the signal from the microcontroller and amplifies it to motor operable 9V.

There are three digital switches, their functions are to act as speed controller, brightness controller, read calliper measurement. The lights are connected in parallel connections, i.e. the ring light, sidelights get the same voltage from the micro-controller. The brightness is adjusted by a digital switch. If we want, we may control it differently by introducing some regulators. Figure 7 showcases a 3D representation of the prototype.

VII. RESULTS AND ANALYSIS

The prototype was built with simple components to confirm the working of the device. It was found to work in smooth condition and the following were ensured:

a) Fired bullets of small arms calibre such as 0.22 in., 5.56 mm, 6.35 mm, 7.62 mm, 7.65 mm, 8 mm, 9 mm, 0.303 in., 0.32 in., 0.380 in., etc. generally used in handguns (pistols/revolvers), carbine, rifles can be mounted with the device.

b) Can measure the diameter of a mounted bullet with 0.01 mm resolution.

c) One fired bullet (of calibre as stated in 9. a) can be mounted.

d) Characteristic marks such as rifling marks and/or barrel marks and/or striated /scratch marks imprinted on the bullet can be visualized.

e) Characteristic marks present on the fired bullet can be captured using a suitable digital recording device.

f) A mounted bullet can be rotated and video capturing can be performed to a full rotation of the bullet or part of the bullet to acquire the characteristic marks present on a fired bullet.

Comparison of the proposed device with devices or processes of prior studies can be summarized in Table I.

Table 1: Comparison With Prior Art.

	Prior Art Process	Improvement of the Process
Efficiency	• Holds only one type of bullet • Fixed diameter, fixed speed • Rotation is not precise, no control over overlapping parts • A specific mobile application is developed	• Developing a system that can hold any bullet of any diameter • Bullets of different diameters can maintain a fixed translational speed • Precise and programmable rotation with no overlapping part • Doesn't need a different mobile application to run.
Cost	• Use of stepper motor which is costlier than DC motor and draws high current • 3D printed mechanism to hold a bullet • Usage of a commercially available motor driver	• Use of DC motor which is cheaper than a stepper motor and draws very little current compared to a stepper motor • A simple adhesive mechanism that is much cheaper • A self-developed, simplest motor driver which is 80% cheaper
Ease	• The developed app supports iOS for recording purposes; hence the system is not compatible with all recording devices.	• Doesn't depend on any app/OS as long as the recording device responds to an external trigger switch, which smartphones and cameras have already. • Works on the existing camera application
Environment Protection	Doesn't arise	Does not arise

Source: Authors, (2024).

VIII. CONCLUSIONS

We can draw the following conclusions from our study:

a) There is no such device available in any of the Central or State Forensic Science Laboratory (FSL) in India. Such a device is highly felt necessary to conduct necessary scientific examination on the samples to be tested in the ballistics division of Central or State FSLs. Hence, the thus developed device can help forensic scientists to perform necessary scientific examination and testing of fired bullets. Therefore, the demand for such a device could be very high for the Central or State FSLs in India and neighbouring countries or other interest countries.

b) Ballistic research organizations in civil and military establishments, Central or State Police Organizations, Academic institutes /Universities/ Colleges where Ballistic science is taught as one of the scientific subjects to impart knowledge including laboratory experimentations can be potential users of such device.

c) Law enforcement agencies, police training centres, judicial academies, central detective training institutes, crime investigating establishments can also be potential users.

IX. AUTHOR'S CONTRIBUTION

Conceptualization: Shashanka Handique, Sweta Saha, R Suresh, Lipi B Mahanta,
Methodology: Shashanka Handique, Sweta Saha.
Investigation: Shashanka Handique, Sweta Saha.
Discussion of results: Shashanka Handique, Sweta Saha, R Suresh3, Lipi B Mahanta.

Writing – Original Draft: Shashanka Handique, R Suresh.
Writing – Review and Editing: Shashanka Handique, Sweta Saha, R Suresh, Lipi B Mahanta.
Resources: R Suresh.
Supervision: R Suresh, Lipi B Mahanta.
Approval of the final text: Shashanka Handique, R Suresh.

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