COMPARISON OF BULLET STRATION PATTERN USING IBIS BULLETTRAX-3D AND ALICONA-INFINITE FOCUS MICROSCOPE

by

MARIA MAGDALINA ANAK DENNIS JANTING

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ABSTRAK

Pengenalan senjata api merupakan proses penentuan sama ada butir peluru atau kelongsong telah ditembak oleh senjata api tertentu berdasarkan ciri-ciri individu yang dihasilkan. Corak penggoresan yang unik pada butir peluru atau kelongsong memberi ciri-ciri individu untuk pengenalan senjata api. Empat pucuk pistol dari model yang sama digunakan dan enam butir peluru diperolehi menggunakan setiap pucuk pistol. Objektif kajian ini adalah untuk membandingkan secara objektif corak penggoresan peluru daripada model pistol separa automatik yang sama, *Walter P99* melalui kaedah perbandingan automatik iaitu *Integrated Bullet Identification System (IBIS) BULLLETRAX-3D* dan *Mikroskop Fokus Alicona-Infinite. IBIS BULLETTRAX-3D* menghasilkan imej 3D permukaan peluru manakala Mikroskop Fokus *Alicona-Infinite* menghasilkan imej dan juga ukuran topografi peluru. Analisis menggunakan *IBIS BULLETTRAX-3D* menunjukkan imej yang memerlukan keputusan akhir juru analisis. Manakala, Mikroskop Fokus *Alicona-Infinite* juga memberikan imej visual permukaan peluru beserta profil permukaan topografi dan set data bagi setiap sampel. Perbandingan secara berpasangan melalui kaedah *Pearson Product Moment Correlation* (PPMC) menggunakan data set ringkas menunjukkan hubung kaitan yang positif antara peluru yang ditembak (r = 0.99 dan keatas) daripada pistol yang sama. Kedua-dua kaedah ini berpotensi untuk saling melengkapi dan diyakini dapat membantu dalam pengenalan senjata api.

ABSTRACT

Firearm identification is a process to determine whether a bullet or cartridge was fired by a particular weapon based on individual characteristic. The unique patterns created on the surfaces of the bullet or cartridge carry an individual characteristic which is useful for firearm identification. Four different pistols of same model were used in this study and six bullets were obtained per pistol. The objective of this study is to exercise objective comparison of bullet striation patterns within the same model of semi-automated pistols, Walther P99 by automated comparison performed using Integrated Bullet Identification System (IBIS) BULLLETRAX-3D and Alicona-Infinite Focus Microscope. IBIS BULLETTRAX-3D gives 3D images of the bullet's surfaces while Alicona-Infinite Focus Microscope also gives images and surface topography measurement for identification. Analysis using IBIS BULLETTRAX-3D showed striation images which required the final decision by the examiner for bullet identification. Meanwhile, Alicona-Infinite Focus Microscope also captured visual images of the bullet surface as well as surface topography profile with dataset for each sample. Pairwise comparison with Pearson Product Moment Correlation (PPMC) from summarised datasets showed positive correlation among the bullet fired from the gun (r = 0.99 and above). Both methods potentially may complement each other and will be beneficial for forensic firearm identification.

CHAPTER ONE

Introduction

In January 2016, Royal Malaysia Police discovered seven rusty guns and several ammunitions kept in a gunny sack that was buried in the ground by militants who slipped into Lahad Datu, Sabah in 2013 (Sokial, 2016). The weapons and ammunitions were seized by police for further action (Sokial, 2016). Such finding would require firearm examination in order to identify the type of firearms and ammunitions used by the militants. Firearm examination or sometimes referred to as firearm identification is a process to determine whether a bullet or cartridge was fired by a particular weapon. The science behind the Firearm and Tool Mark Examiners Identification relies on the theory of unintentional random tooling marks generated during the manufacture of a firearm onto its interior surfaces which are unique to each individual firearm (Lizotte and Ohar, 2008). As a result, the unique patterns on the surfaces of the bullet or cartridge may carry an individual characteristic of that single particular firearm.

1.1 Study Background

Firearm identification field is more than 100 years old (Vorburger *et al.*, 2015) and the first firearm identification in 1925 by Philip Gravelle (Castro *et al.*, 2014) method is by side-by-side image comparison using optical microscopes before an automated ballistics identification occurred 1980 (Song *et al.*, 2014). Most of the comparison of these system is based on comparisons of optical images acquired by microscopes under different lighting conditions in which the accuracy of the identification solely depending on image quality (Song *et al.*, 2014). The examiner will be using an optical comparison microscope to evaluate the fine scratches which known as striae found on the bearing surfaces of the fired bullet (Castro *et al.*, 2014). One of the new method competing with optical image methods in firearm identification is surface topography method. Surface topography measurement has been used for about 80 years and now newly applied in firearm and tool mark analysis (Vorburger *et al.*, 2015). According to Vorburger and his colleagues (2015), the combination of surface topography measurement and the analysis in the study of fired cartridge cases and bullets has been around for about 15 years.

In general, identification of firearms involves microscopic examination of impression marking on cartridge or bullets obtained from the scene or victim and then comparison to cartridge or bullets from suspected firearm. Theoretically, each model of firearm will give the same gross features known as class characteristics meanwhile individual characteristics are markings (impressions or striations) that are randomly generated due to natural wear of the manufacturing tool surfaces (Bolton-King, 2015). Firearm identification starts with the use of photomicrograph, a device to capture and enlarge image of an item before comparison microscope is introduce. The genius invention of "optical bridge" of two compound microscopes were joined together allow the firearm analyst to observe and compare two objects at same time and same magnification developed by Philip O. Gravelle (Thompson, 2010). Later, around early 1900, the use of comparison microscope to examine such evidence was practised ever since. Modern comparison microscope has evolved and improvements in term of design and functions have made it a vital instrument for firearm identification. Its use however, is not without limitations. The subjectivity issue evolving around manual comparison and demand for faster turnaround time in conducting analysis requires forensic firearm analyst to consider a more up-to date approach.

Daubert standard relies on the "scientific knowledge" approach to determine whether expert testimony are relevant and reliable as evidence in court which "applies not only to testimony based on scientific knowledge, but also to testimony based on technical and other specialised knowledge" (Roberts *et al.*, 2013). In the wake of Daubert standards and the advancements in computer technology, forensic firearm examination has adopted a more automatic approach such as the use of Integrated Ballistic Identification System (IBIS) BULLETTRAX-3D in conducting ballistic sample comparison as complimentary to the existing practise, however this still does not address the subjectivity such comparison. In order to support the comparison result from IBIS, surface topography measurement is suggested to be applied in order to give more conclusive results.

In this study, the striation patterns of fired bullet using semi-automated handguns within same model were be compared. All of the bullets were be analysed using two different microscopic methods namely are Integrated Ballistic Identification System (IBIS) BULLETTRAX-3D examination and Infinite Focus Microscope (IFM). Four handguns from same Walther P99 model were used to fire 9mm bullets. Six bullets were fired from each handgun because when there were consecutive test-fires produced, the firearm-ammunition combination should demonstrate reproducible tool marks pattern provided with a consistent possible variables (Bolton-King, 2015). Variation within and between handguns of the same model was studied.

1.2 Problem Statement

Manual comparison using comparison microscope lacks of assisting tools that can help to confirm the result as the examination depends entirely on the ability of the examiner to identify, recognise and match marks displayed on questioned bullets and known bullet samples. This procedure requires highly skilled operators and could be daunting for novice scientist. This also means that the person needs to undergo lengthy training and exposure before becoming competent. A forensic scientist trained in firearms and tool mark identification is often capable to specifically identify or specifically exclude the recovered evidence components (Castro *et al.*, 2014). The examination depends on the ability of the firearm examiner to identify, recognize and match marks found on the bullet to a test-fired standards via visual examination which depends on the subjectivity, experience of examiner and illumination setup (O'Keeffee *et al.*, 2015). Limitations exist with variations in angle of lighting to the sample. Under different lighting orientation, images could show significant variation in striation details even though the image is taken from the same spot (sample area) that could lead to false conclusion (Song *et al.*, 2012).

Automated ballistic identification system (IBIS) BULLETTRAX-3D is a rapid acquisition of 3D/2D digital image of fired ballistic samples. It works based on the principle of confocal microscope. Two dimensional and three dimensional (black and white) images of questioned samples are compared to items of potential hits, given in ranks. This system is able to firearm examiner to draw the final conclusion. The positive identification for fired cartridge cases is frequently generated however can be problematic for fired bullet samples (Brinck, 2008). Similar limitations also exist in angle of lighting to the sample that can complicate comparison and possibly lead to large variation in hit list scores from the system.

Surface topography measurement is one of the attempted approach to overcome the limitation in digital imaginary system by providing surface measurement thus gives more reproducible and reliable results (Xie *et al.*, 2009). Automated ballistics identification does not give a conclusive result, as the final decision will be verified by firearm examiners (Xie *et al.*, 2009) so by having surface topography measurement in firearm identification, it can help to increase the confidence level in the final decision. Since ballistic signatures are geometrical micro-topographies by nature, as a result direct measurement and correlation of the surface topography can be used for ballistic identification (Song *et al.*, 2012).

1.3 Scope of Study

The study focuses on the bullet striation patterns for identification of one type of semiautomatic pistols using ammunition carrying copper-lead bullets. Although impression marks on cartridge cases can also be used for firearm identification, it is not considered in this study. Fired bullet comparison was made using two advance microscope systems. First, fired bullet samples were analysed using commercial microscope system which is the Integrated Ballistics Identification System (IBIS) BULLETTRAX-3D. Secondly, the same set of samples will undergo surface measurement using Infinite Focus Microscope (IFM). Both systems can positively help in firearm identification because both can give visualisation on bullet striation patterns either class or individual characteristics. However IFM is able to measure and generate useful data for objective comparison. A simple statistical approach namely Pearson Product Moment Correlation (PPMC) was attempted for firearm identification.

1.4 Objective

The general objective for this research is to compare bullet striation patterns of the same model Walther P99, of semi-automated pistol using Integrated Ballistics

Identification System (IBIS) BULLETTRAX-3D examination and Alicona-Infinite Focus Microscope (IFM). The results were will be analysed using statistical method to process the data from topography measurements and striation patterns using Pearson Product Moment Correlation (PPMC).

The specific objectives for this research are:

- To demonstrate comparison of striation patterns of the spent bullets using Integrated Ballistic Identification System (IBIS) BULLETTRAX-3D.
- To perform surface topography measurement of spent bullets using Infinite Focus Microscope (IFM).
- To evaluate the feasibility of surface topography measurement for objective firearm identification.

1.5 Research Question

Theoretically, every pistol is unique. Two weapons of the same manufacture and model cannot be differentiated solely on the class characteristics alone thus individual characteristics for identification is required (Bolton-King, 2015). This study is conducted to answer;

- whether surface topography measurement of bullet striation pattern can facilitate bullet identification
- can surface topography measurement help in making a more objective comparison for firearm identification (using fired bullet samples)

1.6 Significant of Study

This study could contribute to the knowledge of firearm identification. There is limited research concerning to support the validity and reliability of scientific certification of pattern recognition based discipline such as firearm (Bolton-King, 2015). Furthermore, by knowing the class characteristics imparted to a bullet which represents in a family group, it can help to eliminate the bullet search by narrowing down the large database of the other handguns into more manageable level (Xie *et al.*, 2009).

The findings of the study can demonstrate the useful application of surface measurement for a more objective comparison in forensic firearm identification. Measurement of striation marks on fired bullets and making comparison based on its topography is an alternative to problems related to image quality. The use of surface topography measurement can be regarded as a complementary technique to the existing technique that could assist analyst interpretation and decision making. Data generated with statistical methods may facilitate firearms identification analysis and contribute positively to forensic investigation.

CHAPTER TWO

Literature Review

Chapter two presents brief theories regarding forensic firearm investigation. The current practices and researches on firearm identification are also included as well for further information. Specific terminologies in firearm identification, firearm technology, violent crime trend and characterization of firearms are explained for a clearer understanding about forensic firearm investigation.

2.1 Gun Crime

Crime and weapon are inseparable. Firearm is known as a deadly weapon because it can be used to kill the target at a great distance as well as in a short distance. One of the main reasons to own a gun is for protection purposes. Despite of that, there are some people misuse gun and even owned them illegally. Under Malaysia Firearm (Increased Penalties) Act 1971, a person will be charged *"...for the use of firearms in the commission of certain offences and for certain offences relating to firearms..."*. According to International Police Organization (INTERPOL) (2016), each year there are more than 245,000 homicide cases worldwide (exclude war-torn countries) in which firearm are widely used to threaten and support other criminal acts. In Malaysia, 314,675 violent crime cases were reported from 2004 to 2013 where robbery with firearm and gang robbery with firearm were the least types of violent crime recorded (Amin *et al.*, 2014). According to trend of violent crimes 2007-2013 (Amin *et al.*, 2014), in 2012 to 2013, robbery with firearm increased from 17 cases to 21 cases while gang robbery with firearm decreased from 110 cases to 98 cases.

From a research done by Wright and Rossi (1980), most criminals prefer guns that are easily concealable, large caliber and well made (Zawitz, 1995). The use of firearm in public area has threatened the safety of the community, especially when a shooting incident happened in a public area. For example, on 13th January 2016 a shooting case in a market located in Selayang, Kuala Lumpur lead to a major concern to public (Goh, 2016). Particularly the innocent people might become the victim in the shooting incident. Malaysia has enacted Firearm (Increased Penalties) Act 1971 to provide penalties for unlawful possession carrying, trafficking and unlawful discharge of firearms with intent to cause death or hurt to any person include imprisonment, whipping and death sentence.

2.2 Firearm

The history of firearm is begin with the invention of gunpowder, followed with the invention of cannon where the basic principle of firearm is applied until now. Cannon is a large thick metal tube with one closed (the breech) end and an open end (the muzzle), which was loaded with gunpowder and with projectile. The powder was ignited with the smoldering ember in a small hole of the rear. The heat from the ember causing a rapid expanding gases from the gunpowder explosion which caused the projectile thrown out from the barrel (Supica, 2013). Our modern firearm is an evolution from this simple cannon mechanism, in 1350 A.D. the first firearm hand-cannon which applied same principle used for individual hand-held weapon.

The evolution of firearm progressed to meet the demand in efficiency and accuracy. For example, during early age of hand gun, the firing of projectile was not efficient. Slow match was used where by a length of cord that had been treated chemically need to be ignited and allowed to continue burning before dipping the cord into the hole in order to ignite the gunpowder (Supica, 2013). On the contrary, nowadays the action of pulling the trigger can ignite the gunpowder in the cartridge which is a very fast action compared to the conventional method. The gun improve projectile stability and accuracy. The idea of riffle barrel was belief to have come from the concept of archers where if the fletching feathers on their arrow were at a slight angle, the ability to hit the target is improved due to the rotation during the flight (Supica, 2013). Based on this concept, gun barrel was carefully cut in twisting direction (Figure 2.1) forming groove down the interior length of the barrel thus the bullet will spin as it left the muzzle (Supica, 2013) to increase the accuracy hitting the target.

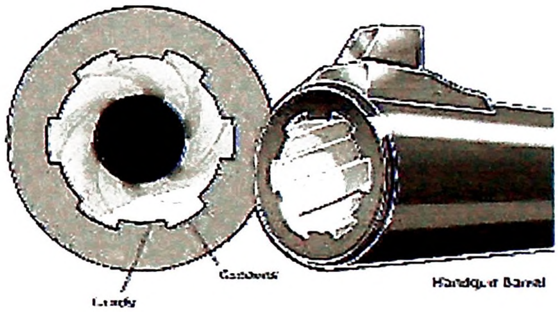

Figure 2.1: Twisting direction in the barrel forming lands and grooves

2.2.1 Types of Firearms

Firearms can be divided into three different types which are rifle, shotgun and handgun or pistols. The general components of a rifle, a shotgun and a semi-automated pistol are depicted in Figure 2.2, Figure 2.3, and Figure 2.4 respectively. These type of firearms again can be sub-divided into automatic and semi-automatic firearms as shown in Table 2.1.

The three basic parts of a modern firearm are action, barrel and stock. Action is which loads, fires and ejects the ammunition meanwhile barrel is a metal tube that allow the projectile passes through and stock helps to support the action during the firing (Richardson, 2013). The action of modern firearms depend on the design of the firearm where a "firing cycle" is composed of the actions performed by the shooter and the firearm mechanism to fire a cartridge with the subsequent readying of the firearm for a discharge of the next cartridge (Thompson, 2010). Semiautomatic firearm actions is a firearm that requires a separate pull of a trigger for each shot while automatic firearm actions is a firearm that feeds cartridges, fires, extracts and ejects cartridge cases continuously for as long as the trigger is fully depressed (Thompson, 2010). A firearm can be breakdown into few basic components which are bore, breech, cylinder, grip, hammer, magazine, muzzle, trigger and trigger guard (Richardson, 2013). These components are explained in Table 2.2.

The main differences of these firearms are their barrels and the type of ammunition used. The rifle's barrel is long which has thick spiraling grooves wall that cut the bore. On the other hand, the shotgun's barrel is long and inside the barrel is very smooth. Meanwhile for handgun, their barrel is grooved pattern similar to rifle but much shorter than rifle and shotgun's barrel. Next, the ammunition for rifle and handgun has a spiral spin due to the rifling action in the barrel which later produce pattern on the bullet known as lands and grooves. In addition, ammunition for shotgun is known as shell where they were classified by gauge in which a measure related to the diameter of the smooth shotgun bore and the size of the shells.

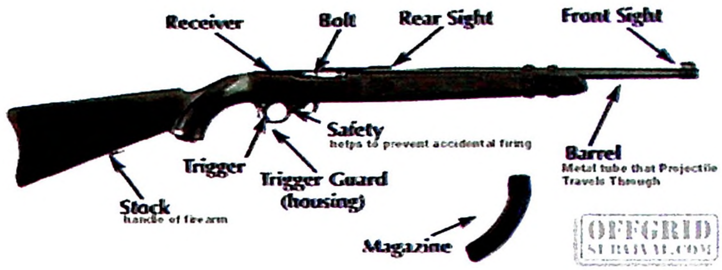

Figure 2.2: Components of rifle, adapted from Offgrid Survival (2016)

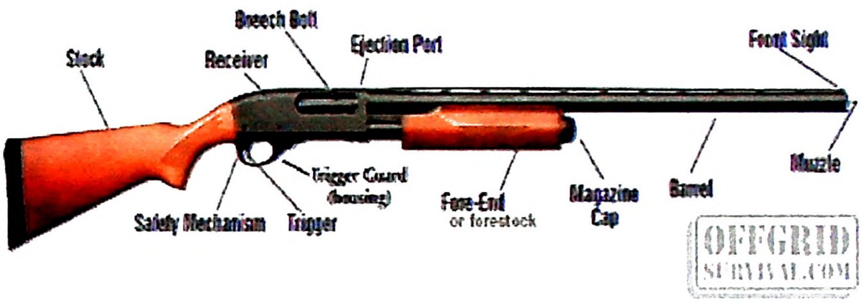

Figure 2.3: Components of shotgun, adapted from Offgrid Survival (2016)

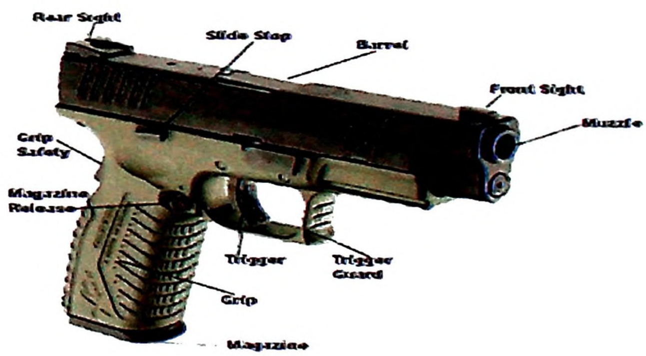

Figure 2.4: Components of semi-automated pistol, adapted from Offgrid Survival (2016)

Table 2.1: Different categories of firearms

Categories	Types
Rifle	o Automatic o Semi-automatic o Bolt action o Lever action
Shotgun	o Pump-action o Semi-automatic
Handgun/Pistols	o Revolver o Semi-automatic o Automatic

Table 2.2: Basic components of a firearm

Component	Explanation
Bore	Bore is in the inside of the barrel through which the projectile travels when fired.
Breech	Breech is the area that contains the rear of the barrel where the cartridge is inserted.
Cylinder	Cylinder is the part in a revolver that hold cartridge in a separate chambers which can rotate as gun is cocked.
Grip	The Grip is used to hold the firearm.
Hammer	Hammer is on a revolver which strikes the firing pin.
Magazine	Magazine is a spring-operated container which holds cartridges for a repeating firearm.
Muzzle	The muzzle is where the projectile exits the firearm.

Trigger	Trigger is the lever that will be pulled or squeezed to initiate the firing process.
Trigger Guard	Trigger guard is the part of the firearm that wraps around the trigger to provide protection and safety.

2.2.2 Barrel

The rifling pattern on the barrel imprints an individual characteristic to the bullet due to the imperfections in the manufacturing procedures (O'Keeffee *et al.*, 2015). According to Cork et al. (2008) stated rapid firing of different types of ammunition through a barrel lead to a modification of the barrel. This is due to the development of the hot gases and bullet movement which might give sufficient wear characteristic (O'Keeffee *et al.*, 2015). In addition, if presence of any rough finishing due to modification on the barrel may cause impressions and striation marks, leading to an easy identification (O'Keeffee *et al.*, 2015).

There are three common methods for rifling of barrel which are cut, button and hammer forging (Turpin, 2012). Firstly, cut rifling is a method where a cutter is inserted into the barrel either the steel barrel or the cutter is slowly rotated to form the twist in the rifling during the cutting or scraping the grooves in the steel to form the lands and grooves (Turpin, 2012). Normally the number grooves cut in a barrel is three, four or six (Turpin, 2012) which depends on to the manufactures. Secondly, button rifling method. The button is a hardened steel or titanium carbide which has a negative image of the barrel. This button is either pushed or pulled through the bore inner side (Turpin, 2012) where by the button tool is attached to a rotating rifling head as the button is being pulled or pushed through the barrel. Thirdly is hammer-forging rifling method, a method where by the barrel is pounded into shape from the outside (Turpin, 2012) in order to forming groove. Hammer-forging rifling method is the opposite method to the button rifling method.

2.2.3 Ammunition

Ammunition is any projectile such as bullets that can be discharged from a weapon (Collins English Dictionary, 2014). A unit of ammunition is properly termed a cartridge (Thompson, 2010). Ammunition for rifle and handgun is called cartridges while ammunition for shotgun is known as shells. A cartridge consists casing, primer, propellant (powder) and projectile or known as bullet which shown in Figure 2.5. The projectile is the true bullet or also termed as pellet (Thompson, 2010). Shotgun ammunition contain shotshell which refers to a round pellet, another type of shotshell for shotgun is slug which shown in Figure 2.5.

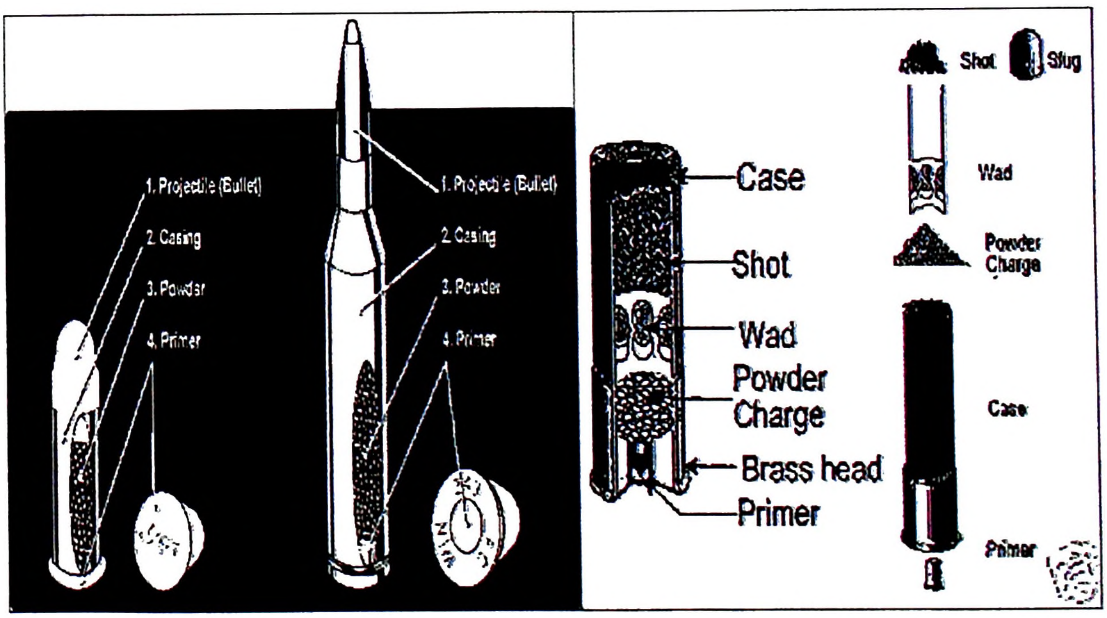

Figure 2.5: Component of ammunitions from handgun, rifle and shotshell (Rimfire, 2004)

2.3 Firearm Examination

Forensic firearm identification is more than 100 years old (Thompson, 2010; Vorburger *et al.*, 2015). In the beginning of the firearm identification, there was no specifically instrument available thus the examiners depend on photomicrograph comparisons to determine the identity of the fired bullets or cartridge cases (Thompson, 2010). Next, with the advancement in engineering filed of the "optical bridge", two compound of microscopes were combined together thus giving the examiner the ability to observe and compare two objects at the same time under magnification (Thompson, 2010).

Through the invention of comparison microscope, the firearm identification become less time consuming. Later for about 80 years, the examiner using the same basic design of comparison microscope as their primary tools to make firearm identification (Thompson, 2010). The modern comparison microscope was added with microscope stages that were designed for the mounting of fired bullet, cases, and other items bearing tool marks (Thompson, 2010). The recent firearm identification using computer technology for searching image database (Thompson, 2010) as well as using automated identification system.

2.3.1 Test Firing

Test firing is a process to obtain the fired bullet from suspected weapon or recovered weapon to be compared with bullet or cartridge from the crime scene by trapping the bullet in a chamber. The common bullet trap are water tank and a large box stuffed with cotton. The bullet trap will make the fired bullet to stop without making any damage or additional marking on the fired bullet and cartridge (Bell, 2008). The water tank can be divided into two categories, horizontal water tank and vertical water tank which depends on the size of the test firing room. The main purpose for test firing is to get the bullet from known suspected weapon which later used to compare with the unknown bullet from crime scene for identification purposes.

2.3.2 Bullet and Cartridge Examination

Bullet fired from rifle and shotgun will give striation pattern on it surfaces as due to the rifling barrel. The features are determined by the manufacturer which include the size of cartridge chambered by the firearm, the orientation of the extractor and ejector, the width and twist direction of the land and grooves and the total number of land and grooves (Thompson, 2010). Ammunition from the test firing must be examined to identify family characteristic on the fired bullet and fired casing. The rifling of each weapon will have a series of class characteristic of same weapon model and maker of the bullet, which are number of lands and grooves, direction of twist, inclination of twist, and width of lands and grooves. Meanwhile, characteristic can be found in fired casing are firing pin impression, breech face marks, ejector marks, and extractor marks.

Family characteristic are only useful to identify the caliber and model of the weapon but they cannot be used to individualize the weapon. Individual characteristic in fired bullet are caused by the small defects in the rifling produced during the manufacturing process and random in nature. In addition, the individual characteristic caused by the defects in the barrel on the bullet will be in the form of "fine lines" known as striation. The ability to determine all of fired bullet's class characteristics is limited due to the condition of the bullet when it was recovered (Thompson, 2010).

2.4 Automated comparison

Traditional method of firearm identification by using manual comparison microscope has been a tedious work and time-consuming. This comparison microscope made up from two microscopes arranged together for the images passing through both are in one-eye piece midway between them, then two images were merged together as one (Carpenter, 2004). After sometimes during the examination, the examiners tend to experience severe stress and eye strain therefore automated comparison firearm identification was introduced. An automated comparison is a computer-based comparison system which would speed up and ease the work of firearm examiners (Leon, 2006). There are two major component in automated system, which are the acquisition of the data for encoding and the correlation of encoded data components (Carpenter, 2004).

Firstly, automated comparison comprise an automated imaging system that provide high quality of images and thorough data acquisition under reproducible condition (Leon, 2006). Secondly, this system can extract certain features which necessary for database search and produce a hit list of possible striae correspondences (Leon, 2006). Finally, the firearm examiner can perform visual comparison on the hit list (Leon, 2006) such as Integrated Ballistic Identification and DRUGFIRE. Both Integrated Ballistic Identification System (IBIS) and BULLETTRAX-3D Technology can identify bullet fired by the same weapon but BULLETTRAX 3D is more effective than IBIS due to higher quality of images produced (Brinck, 2008) to observe the individualistic of bullet striations.

The current automated ballistic identification systems are mostly based on image comparison using optical microscopy (Song *et al.*, 2012). Automated ballistic identification systems accompanied with digital camera, computers, huge databases, and image analysis techniques (Xie *et al.*, 2008) have created a foundation in forensic firearm identification such approaches based on 3D digital representations of evidence surface topography. The 3D surface topography measurement can overcome the limitations of digital imaging by making the bullet surface measurement reproducible and reliable (Xie *et al.*, 2008). Surface topography techniques for bullet marks characteristic extraction gives a variety of 2D and 3D visualization of graphics for firearm examiners to make a final decision (Xie *et al.*, 2008).

A study by Bonfanti and Chauharali (2000) on the usefulness of confocal scanning laser microscopy in firearms identification visualize a microscopic objects in 3D structure was reported. The general attractive features of confocal microscopy are i) its multipurpose applicability, ii) the availability of versatile 3D image processing software, iii) the combination of high quality optical microscope, and iv) short speed in image acquisition (Bonfanti and Ghauharali, 2000). In addition, confocal microscopy provide specific complications such as high resolution overview images, gives quantitative 3D information of the imaged object in forensic firearm examination, as well as 3D topography visualization techniques with software (Bonfanti and Ghauharali, 2000).

However, most of the automated system has an insufficient quality of raw image data thus bullet comparisons based on 3D data must be accomplished (Leon, 2006) in which recently using BULLETTRAX-3D. The 3D geometric data of the tool marks is obtained by a confocal microscope and then reconstructed virtual impressions on a computer screen (Banno *et al.*, 2004). Optical image is influenced the lighting condition, surface slope, shadowing effects, multiple reflections, changes in optical properties, and color and reflection of the ballistic sample (Song, 2012).

According to a study proposed by Song (2012) for ballistic identifications, current ballistic identifications need surface topography measurement, and need to increase correlation speed and minimise manual operation. Topography gives ballistic signature rather than just optical image because topography can provide 2D profile and 3D topography (Song, 2012).

2.4.1 Integrated Ballistics Identification System (IBIS)

Forensic Technology Incorporated (FTI) developed an automated computer search technology called Integrated Ballistics Identification System (IBIS) in which the images acquired were converted into the form of mathematical algorithm for comparison (Thompson, 2010). IBIS BULLETTRAX-3D (Figure 2.6) is a system to automatically image and compare 3D images of fired bullets. This system is capable to produce automated imaging, comparison, enhanced visualization and analysis of fired bullets (IBIS BULLETTRAX-3D MANUAL, 2009). This IBIS BULLETTRAX-3D is an integrated hardware and software system that automates the task of collecting 2D digital images and topographical 3D data of bullet exhibits for law enforcement agencies (TRAINING FOR IBIS BULLETTRAX-3D MANUAL, 2012).

The approach of imaging and comparison of BULLETTRAX-3D depend on two important factors which are the sufficient depth and lateral resolution, and sufficient rotational and lateral control of the bullet (IBIS BULLETTRAX-3D MANUAL, 2009). The system is shown in Figure 2.6. The striation marks on the bullet's surface are less than one micron deep and fifteen microns wide thus the details and accurate data must in order for the system to automatically compare the markings in an accurate away (IBIS BULLETTRAX-3D MANUAL, 2009). The bullet with correct orientation is must be placed perpendicularly to the sensor in order to obtain interest topographical area to produce an accurate and non-distorted image to be captured especially for damaged bullets and fragments (IBIS BULLETTRAX-3D MANUAL, 2009).

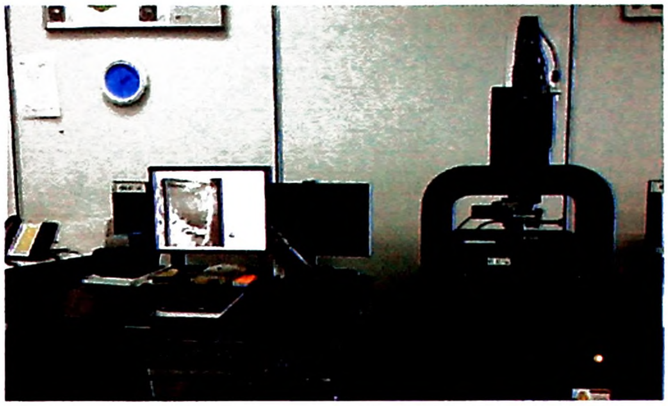

Figure 2.6: IBIS BULLETTRAX-3D system

BULLETTRAX-3D works by reconstruct 2D images into 3D images by using confocal microscope. A 3D automated acquisition of the bullet's surface is the key of success in BULLETTRAX-3D. During the acquisition of bullet, rotation mode alone is not sufficient for acquiring all the pristine bullet thus topography must be perpendicular to the optical axis to make sure all the surface details are captured and prevent occlusion. Figure 2.7, illustrated occlusion of some parts on the bullet surface. Occlusion can be minimized with the aid of motorized repositioning involving the combination of rotation and signal transition (Beauchamp, 2012). During image acquisition, BULLETTRAX-3D will captured 2D and 3D data simultaneously, where 2D is like a photograph of the bullet's surface whereas 3D data captures depth measurements of the surface (TRAINING FOR IBIS BULLETTRAX-3D MANUAL, 2012).

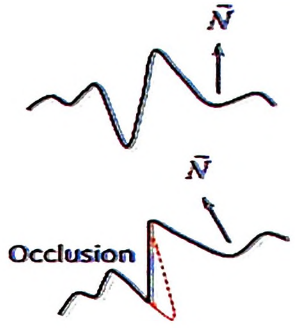

Figure 2.7: Occlusion missing of surface area scanning during the acquisition of the bullet

An algorithm has been implemented in BULLETTRAX-3D for deformed bullet acquisition and the topography visualisation (Figure 2.8) from the splitting topography resolution of the waviness cloning and roughness enhancement from the bullet's surface (Beauchamp, 2012). IBIS Correlation Server will accept the submitted bullet images from the BULLETTRAX-3D for comparison and analysis (*IBIS BULLETTRAX-3D Mannual*, 2012). The workflow of IBIS BULLETTRAX-3D divided into imaging of firearm examiner, storage and data processing of the IBIS administrator, and result analysis using IBIS Match point of the firearm examiner (*IBIS BULLETTRAX-3D Mannual*, 2012) shown in Figure 2.9. Despite all the sophistication of the system, these features were not fully utilised since current practice still rely on the comparison of 2D images for firearm identification.

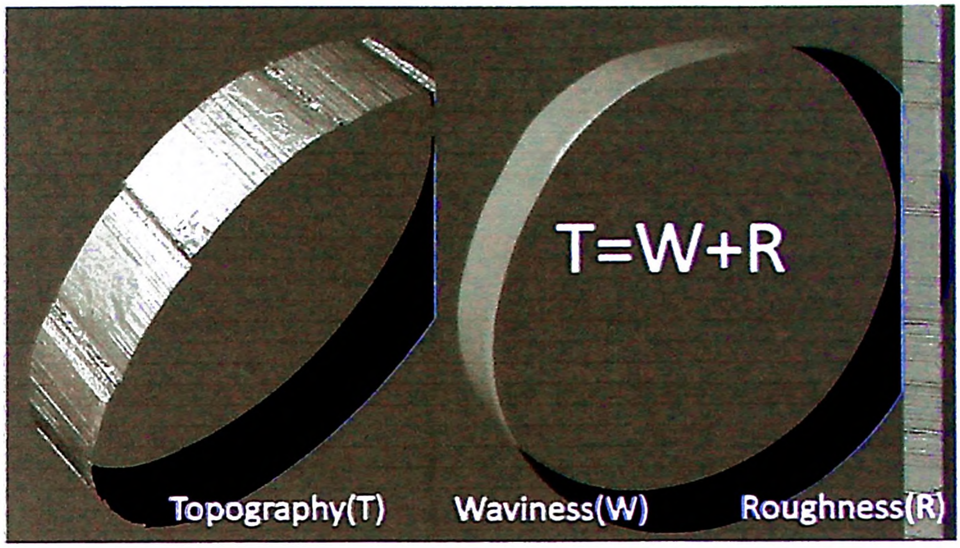

Figure 2.8: Topography, waviness, roughness on the bullet's surface

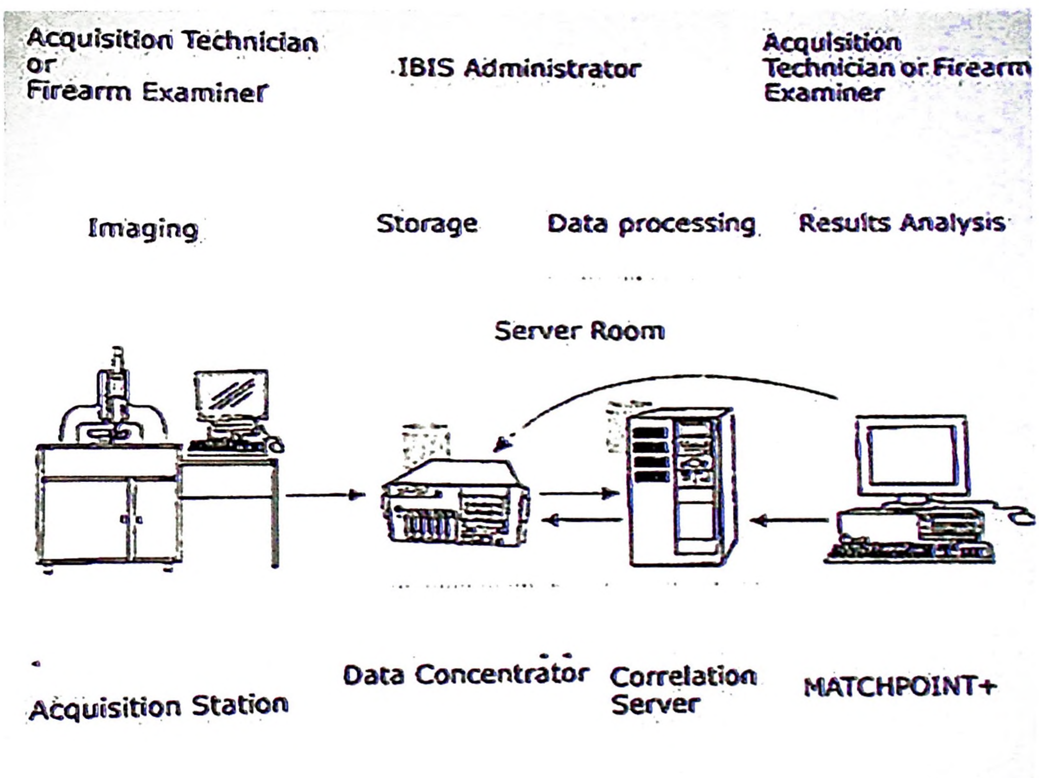

Figure 2.9: Workflow of IBIS BULLETTRAX-3D

2.4.2 Alicona-Infinite Focus Microscope

Alicona-Infinite Focus Microscope (Figure 2.10) is a quality assurance tools with a high resolution of optical 3D surface measurement. The measurement is done using Focus-Variation Measurement Technique (Etter, 2012). Through Focus-Variation technique, an object can be observed in details at different adjustable distance (Figure 2.11). This is due to the combination of the small depth of focus of an optical system with vertical scanning to give topographical and color information from the variation of focus (Optical 3D Surface Metrology-Infinite Focus, 2009).

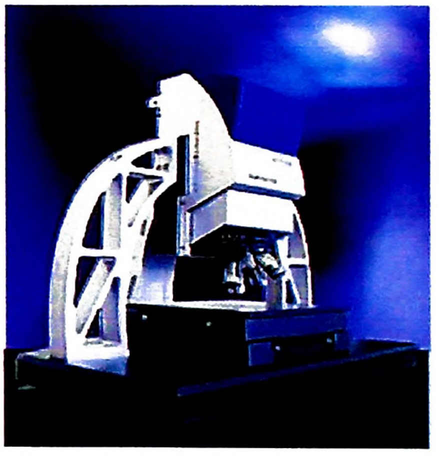

Figure 2.10: Alicona-Infinite Focus Microscope

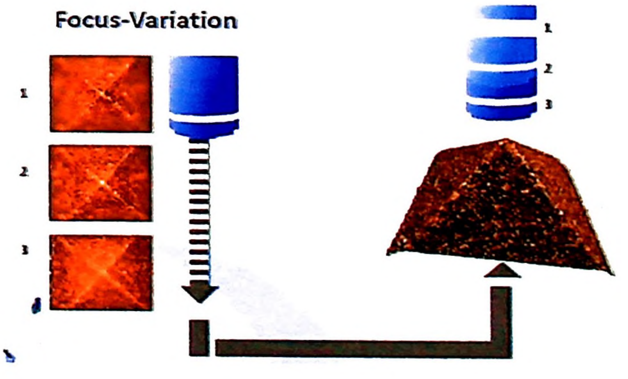

Figure 2.11: Focus-Variation Measurement Technique