BULLET IDENTIFICATION BASED ON STRIATION FEATURES USING FAST FOURIER TRANSFORM AND ARTIFICIAL NEURAL NETWORK

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Abstract

Firearms identification from bullet specimens is important and useful in crime and forensic investigation. When a bullet is fired, characteristic markings are created due to contact between the bullet and the barrel of the gun. Every firearm has its own unique characteristic markings, also called ‘fingerprint’ regardless of its size, type and model. These unique characteristics are the important features in identifying firearms. However, traditional bullet identification is a labor intensive activity with several weeks of time being devoted to a single analysis and comparison. This paper investigates the firearm identification method based on fast Fourier transform (FFT) and Artificial Neural Network (ANN). This project presents an approach to examine and analyze the bullet specimens using FFT technique for 9 mm handgun identification. There are 5 types of bullets classes and 6 specimens per class. A total of 30 specimens bullet were used in the identification method and they were scanned by using Alicona Infinite Focus measurement machine. Fundamental frequency and harmonics were extracted by the FFT technique and act as input parameter for neural network training. ANN was applied in this project to identify the bullet classes. Experimental result show that the proposed system can achieve 66.7% accuracy through analyzing the fundamental frequency and harmonics of the fired bullet specimens. Although the amplitude of the fundamental frequency and harmonics have limited impact to justify the bullet type but there is still room for improvement of the classification accuracy.

***Index Terms* - Fast Fourier Transformation, Artificial Neural Network, Ballistics, Bullet Identification, Firearm Identification, Forensics**

Abstrak

Klasifikasi senjata api daripada spesimen peluru adalah penting dan berguna dalam penyiasatan forensik. Penghubungan antara permukaan peluru dan barrel senjata akan menyebabkan tanda-tanda pengoresan semasa peluru ditembak. Setiap senjata api mempunyai tanda pengoresan yang unik, juga dikenali sebagai 'cap jari' tanpa mengira saiz, jenis dan model. Tanda-tanda unik tersebut adalah penting dalam klasifikasi senjata api. Cara-cara tradisional yang digunakan untuk mengelaskan peluru merupakan aktiviti yang memerlukan tenaga pekerja pakar selama beberapa minggu untuk analisis dan perbandingan. Kaedah klasifikasi senjata api berdasarkan Fourier transform cepat (fast Fourier transform, FFT) dan rangkaian neural tiruan (Artificial Neural Network, ANN) telah dikajikan dalam projek ini. Sampel peluru diperiksakan dengan menggunakan teknik FFT dalam klasifikasi handgun 9 mm. 5 jenis peluru dan 6 sampel setiap jenis handgun telah diperiksa. Sebanyak 30 sampel peluru diperiksakan dalam projek ini dengan menggunakan ukuran mesin Alicona Infinite Focus. Frekuensi asas dan harmonik telah diekstrak dengan teknik FFT sebagai parameter input untuk ANN. Eksperimen tentang sistem tersebut boleh mencapai 66.7% ketepatan dengan menggunakan cara analisis frekuensi asas dan harmonik daripada spesimen. Hal ini menunjukkan bahawa frekuensi asas dan harmonik berfungsi secare terhad untuk mengelaskan jenis peluru tetapi masih ada ruang untuk peningkatan ketepatannya.

Declaration

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree

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Statement 1

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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Date ………………………………………………………….

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1.0 Introduction

Firearm and tool mark identification in criminal investigation has more than a century of history [1]. The need for firearm identification systems by police services continues to increase with greater accessibility to weapons in the international contexts. The analysis on marks of a fired bullet is very useful to identify the firearm from which bullet is discharged. However, its subjectivity and its difficulty to articulate how identification is made has been challenged over the years.

Characteristic markings on the bullet are produced when a gun is fired. The forensic identification of bullet specimens relies on the detection, recognition and ultimate matching of markings on the surfaces of cartridges and projectiles by the firearms [2]. Different features within these marks can be distinguished as "fingerprints" for identification of a firearm. Extremely fine striation markings will be exhibited when a bullet is fired through the barrel of a gun. Some of these are derived from minute irregularities in barrel produced during the manufacturing process.

Traditional ballistic identification is a labor intensive activity with several weeks of time being devoted to a single analysis and comparison. Comparison microscope detecting method [3], continuous shooting method [4], and roughness measuring instrument of stylus [5] have their disadvantages of low sampling precision, lacking of 3D information, damaging the physical integrity of evidence and non-automated detecting. Therefore, optical methods, the non-contact methods with high precision, are widely used for bullet inspection [6,7]. The comparison of these marks is based on incident light microscopy. By using optical microscope, the image formed from the oblique illumination of the mark gives a representation of the surface of the specimen [8]. However, the representation is critically dependent on the surface intensity of the material in the illumination system. Digital imaging techniques have the potential to detect the presence of striation on bullet specimens for identification within several hours.

Several countries and researcher organization have developed computer systems for firearm identification. The two major international ballistics imaging systems are manufactured by the Integrated Ballistics Identification System (IBIS) [9] Company in Montreal, AC, Canada and the FBI, DRUGFIRE [10] in the USA. IBIS is an international ballistics imaging systems which has been widely used in many countries while the American DRUGFIRE system is the most extensive of the overseas database systems but the system does not deliver fully automated pattern recognition technology. A Canadian company, Walsh Automation has developed a commercial system called “Bulletproof” which can acquire and store image of projectiles and cartridge cases and automatically search the image database for particular striations on projectiles [11]. However, it is required to match the impressed markings or striations on the projectiles and cartridge cases end-user. This kind of limitation makes the system very difficult to use. The firearm identification system called Fireball [12] was developed by Edith Cowan University in 1995 and it has been used by Australian Police Services for identifying, storing and retrieving the images of projectiles and cartridge cases. The major limitation of Fireball is that the shape and position are tuned manually and thus the precision of comparisons relies on the expertise and experience of the end-user. The efficiency and accuracy of the FireBall system must be improved and increased.

Li [13] proposed an analytic system based on the fast Fourier transform for identifying projectile specimens by the line-scan imaging technique. His work focused on mapping the topography of the surfaces of forensic projectiles for the purpose identification. However, mapping between the crime scene and test specimens were not given in this paper. Huang and Leng [14] proposed an Online Ballistics Imaging System for Firearm Identification by combining the traditional functions with new features such as the line-scan image module, the characteristics extraction module, and the intelligent image processing module. However, the function of intelligent analysis and criterion for extracting individual characteristics for firearm identification are limited in the paper.

Automated bullet identification based on consecutive matching striation (CMS) criteria [15] was studied by Chu, Robert, Song and Theodore. A model for automatic and objective counting of CMS is proposed based on signal processing and extraction. The position and shape information of the striation on the bullet land is represented by a feature profile, which is used for determining the CMS number automatically. It increases the objectivity of firearm identification. However, this method is not identical as CMS criteria that were proposed for manual operations with optical microscopy whereas the model employs 3D topography data. The thresholds for height and width parameters in the model are determined empirically. Further theoretical and experimental study are required to obtain optimized parameters.

This paper introduces a new analytic system based on the fundamental frequency and harmonics of the striation features using fast Fourier transform (FFT) for identifying the bullet specimens with Artificial Neural Network (ANN). This system can store and automatically analyze the amplitude of the harmonics for the identification of bullet using ANN as the automatic pattern recognition technology. The manual tuning of the bullet shape and position does not rely on the expertise and experience user in this system, making the scanning process easier and faster. An experiment was carried out using this new analytic method to test the accuracy of this system.

2.0 Methodology

Figure 1 shows the overall flow of the bullet identification process based on striation features using fast Fourier transform and Artificial Neural Network. The specimens in this project are fired 9 mm bullets. There are total of 30 specimens and all specimens are from different firearms. The 30 specimens were shot by using 5 different firearms respectively. Therefore, there are 5 types of bullets classes (based on individual characteristics) and 6 specimens per class. All the bullet specimens were scanned using Alicona Infinite Focus measurement machine to generate the 3D surface topography.

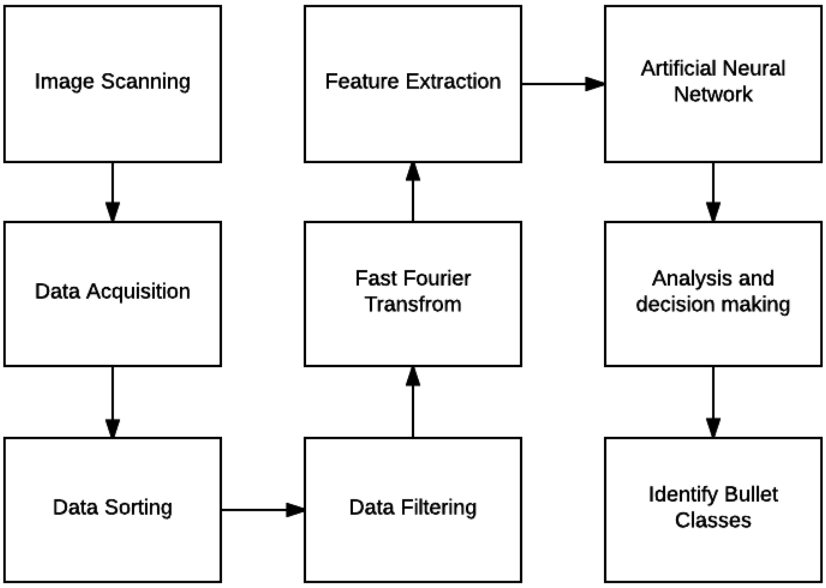

Figure 1: Flowchart of Bullet Identification

The surface topography of the specimen was used to determine the coordinate information for data analysis. After going through several data preprocessing method such as sorting and filtering, the data obtained was subjected to fast Fourier transform (FFT) to generate frequency spectrum graph. The ANN system was built to analyze the data from the extracted parameters which were the fundamental frequency and harmonics obtained from the frequency spectrum. The individual features signatures were stored in the weightage of ANN system and were ready to be used for further testing.

2.1 Image Scanning

Alicona Infinite Focus is a non-contact, three-dimensional profiler. The maximum objective magnification is up to 100x and the maximum resolution is 10 nm. The specimens were scanned using focus-variation technique to generate the 3D surface profile of the specimens from the cylindrical shaped surface. Focus variation technique combines the small depth of focus of an optical system with vertical scanning to provide topographical and color information from the variation of focus.

The scanned surface topography was about 1.44 mm, which was located about 3mm from the flat end of the bullet specimen. The unique striation marks, also called individual characteristic used to identify a bullet to a particular barrel are usually located in the land impression areas [16]. Figure 2 shows the location of the scanned surface of the bullet.

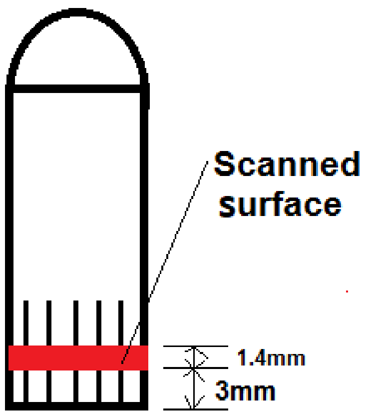

Figure 2: Location of the scanned surface

Focus variation technique was used by scanning consecutive columns of picture information with various focusing and storing the data in a database so that a three-dimensional (3-D) profile image of the surface of the cylindrical specimen is produced shown as Figure 3.

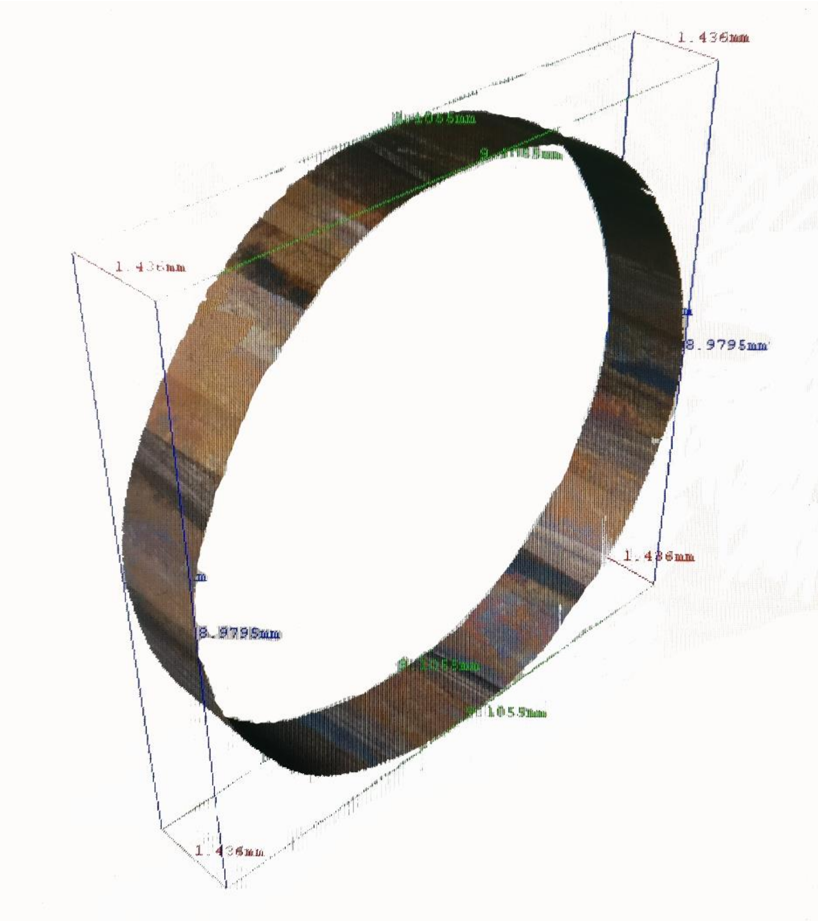

Figure 3: 3-D surface topography of specimen

Bullet marks consisting of class and individual characteristics where class characteristics represent a family of firearms and usually are limited to a group manufacturer. The lands, grooves and diameter of the barrel impart the class characteristics. Individual characteristics are striations and other imperfections making a particular fired bullet unique and serve as the basis for a conclusive identification to a particular firearm. Figure 4 shows the land impression on bullet surface: 1, land impressions; 2, striations in land impressions; 3, forcing cone marks.

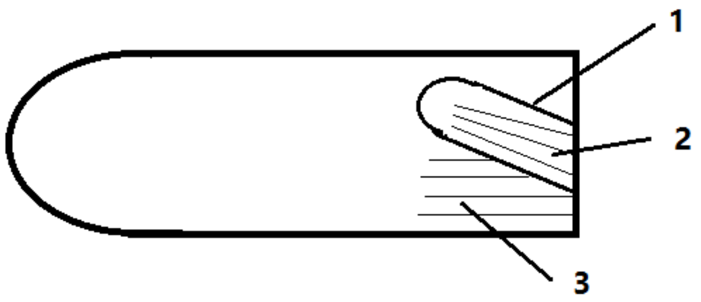

Figure 4: Single land impression on bullet surface

The cylindrical bullet specimen was rotated about an axis of rotation relative to a stationary camera. All the points on the rotating surface were captured by using focus-variation technique during one full rotation of the cylindrical bullet specimen. The image scanning setup is shown as Figure 5 and Figure 6.

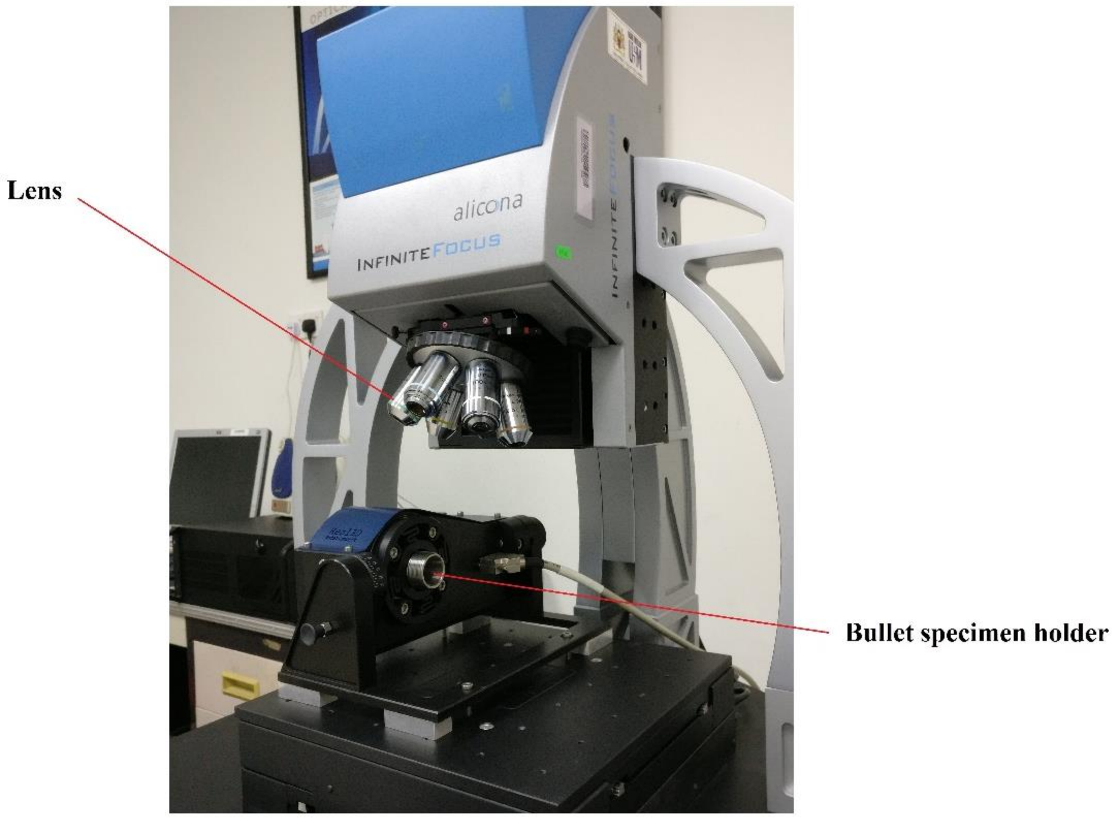

Figure 5: Bullet Specimen Scanning Setup

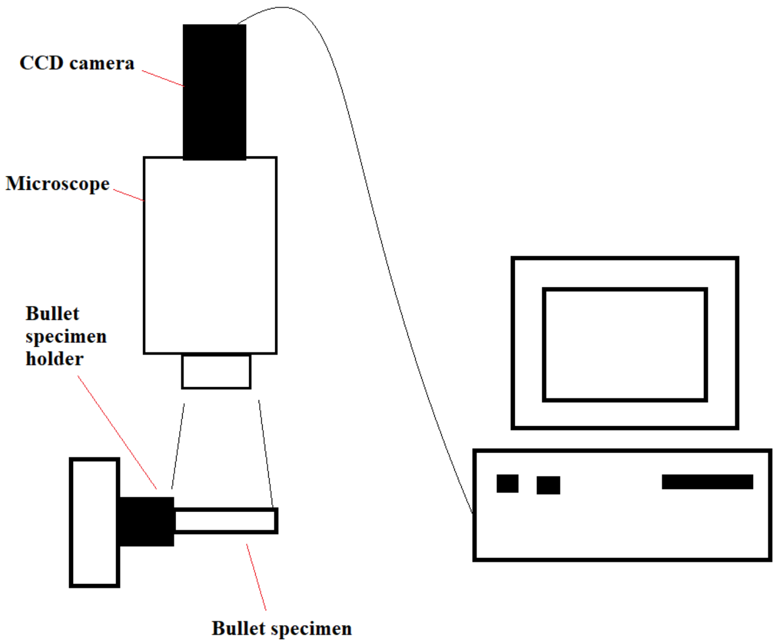

Figure 6: Schematic diagrams of Scanning Setup

All the bullet specimens were scanned under the same conditions (eg. light conditions, stepping angle of the stepper motor, etc.). The landmarks and groove marks of bullet specimen were captured through adjusting the stepping angle of the stepper motor by one full rotation. The coordinate information of the surface topography at the middle of the scanned surface were extracted from the database and analyzed. The data extracted from the surface topography were in terms of Cartesian coordinate. Besides, there are many different features (visible or hidden) in the 3-D surface topography forming a unique combination for every weapon as a set of unique marking for the particular firearm.

2.2 Data Preprocessing

The coordinate information extracted from the Alicona Infinite Focus measurement machine were subjected to several preprocessing techniques before classification. In a practical application, the quality of the coordinate information can be affected and noised by many factors such as lighting conditions, the materials of specimen, the original texture on the surface of specimen, and the deformed shapes. Strong noise and damage may cause difficulties in extracting and verifying the important features used for identifying the individual specimen. To minimize the effects mentioned above, data preprocessing was applied to the raw coordinate information.

The system generates 13479 points of the raw coordinate information from one point to another point through a full rotation of 360 degree. Firstly, the raw coordinate information was plotted as in a Figure 7, showing the data information in Cartesian coordinate system. Figure 7 shows a set of unreadable raw data. Therefore, data sorting was applied to the raw coordinate information because the data obtained was not in sequence. The sorted data was plotted in Figure 8.

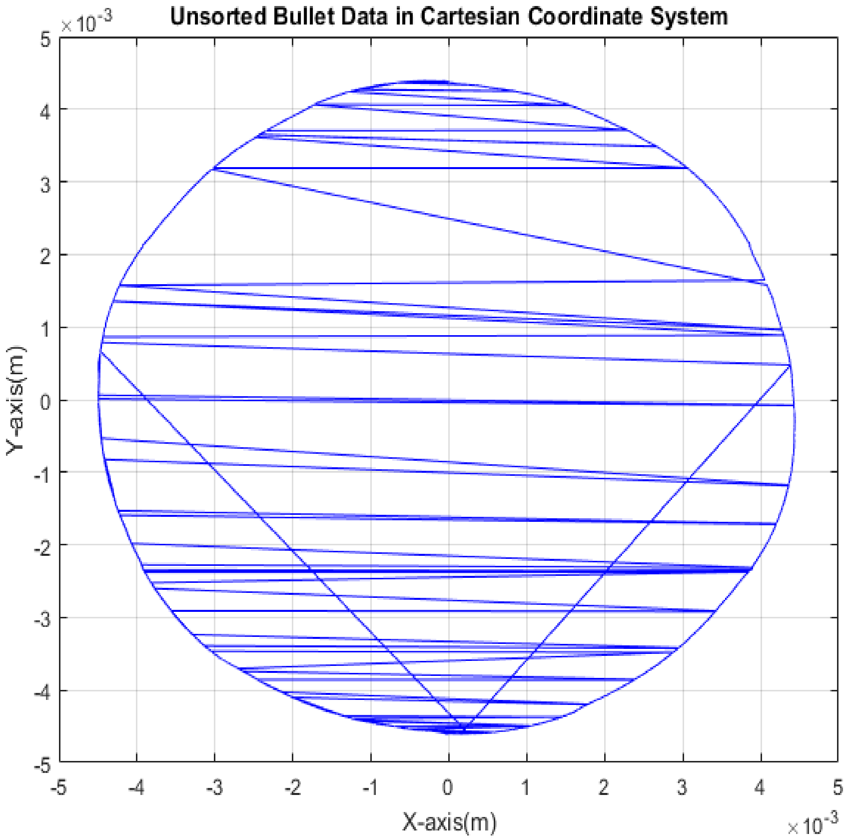

Figure 7: Unsorted bullet data in Cartesian coordinate system

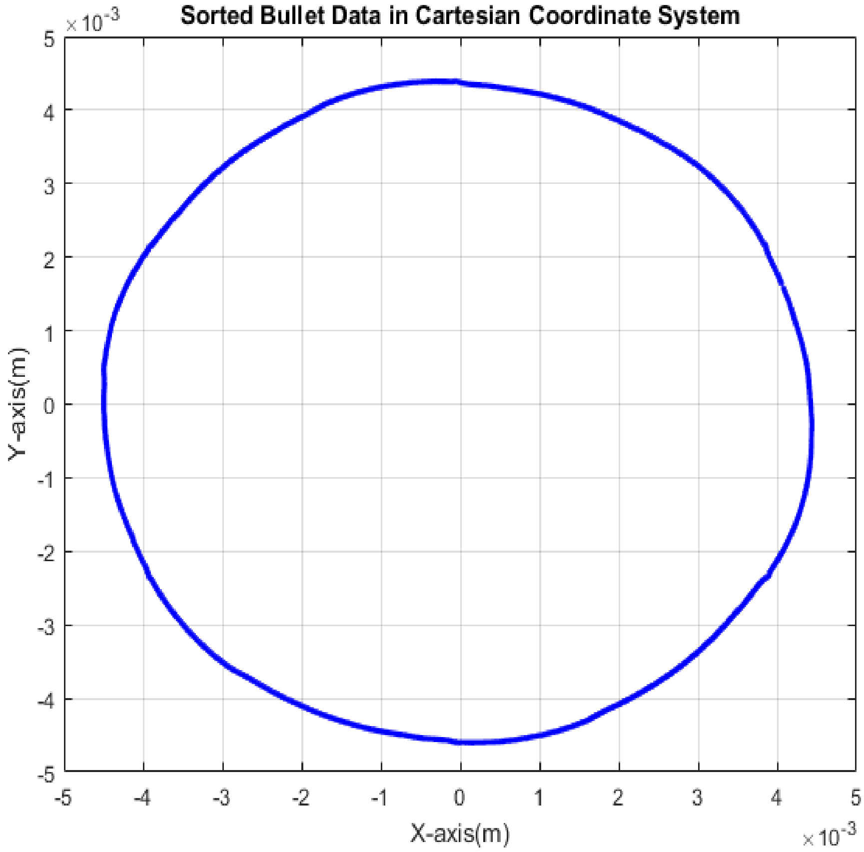

Figure 8: Sorted bullet data in Cartesian coordinate system

From Figure 8, all the peaks, grooves and other unique characteristics markings of the fired bullet were unobservable. Polar coordinate system was used to replace Cartesian coordinate to observe the significant change of the surface topography. Figure 9 shows the unsorted bullet data in polar coordinate system. Figure 10 shows the sorted bullet data according the degree in polar coordinate system.

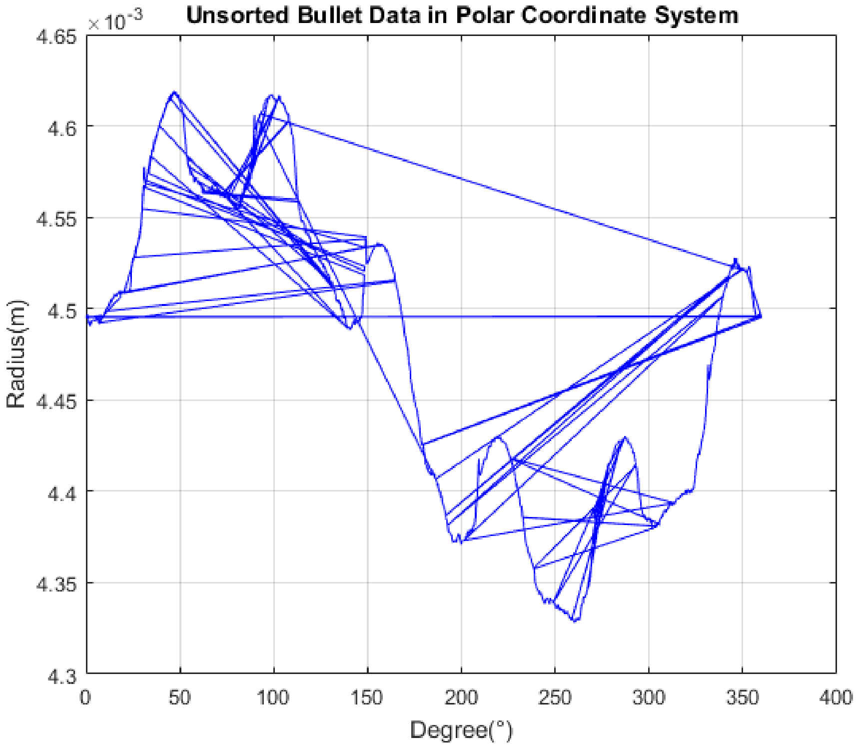

Figure 9: Unsorted bullet data in polar coordinate system

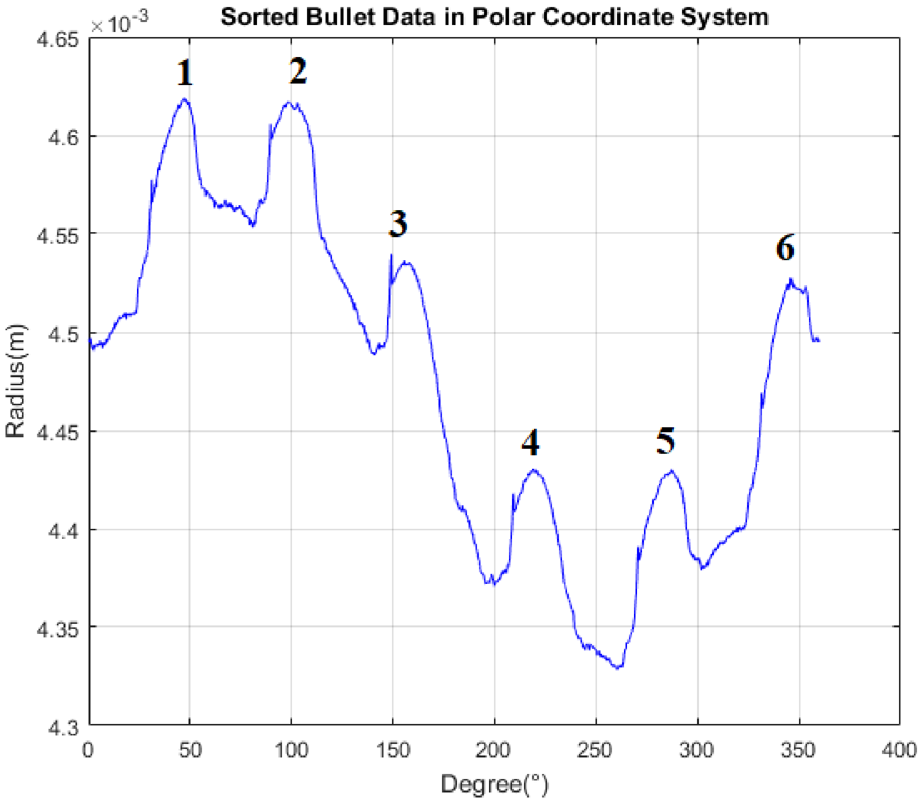

Figure 10: Sorted bullet data in polar coordinate system

There are about 13 thousand (in this case, 13479) points in the sorted bullet data in the polar coordinate system. The *y*-axis represents the radial distance of the points of the bullet from the origin while the *x*-axis is the angle of rotation in degree. From Figure 10, there are six significant peaks, in which the individual characteristic might be present.

The sorted bullet data in the polar coordinate system was duplicated over five cycles to determine the fundamental frequency and frequency resolution. The angular distance for a full cycle was converted into fundamental frequency using Equation (1). Equation (2) showed the calculation to get the frequency resolution.

$$f_m = \frac{1}{T_1} \tag{1}$$

where T_1 = angular distance for a cycle

f_m = fundamental frequency

$$\Delta f = \frac{1}{T_{all}} \tag{2}$$

where T_{all} = Total angular distance

Δf = fundamental resolution

Figures 11 shows the five cycle bullet data in polar coordinate system. A FFT graph was plotted by using the bullet data from Figure 11. More details about fast Fourier transform is discussed in Section 2.3. Figure 12 shows the Single-Sided Amplitude of *S(f)* of the five cycles. From Figure 12, the fundamental frequency and harmonics are represented by the peaks of the data. The amplitude of the fundamental frequency and harmonics are recorded for further analysis.

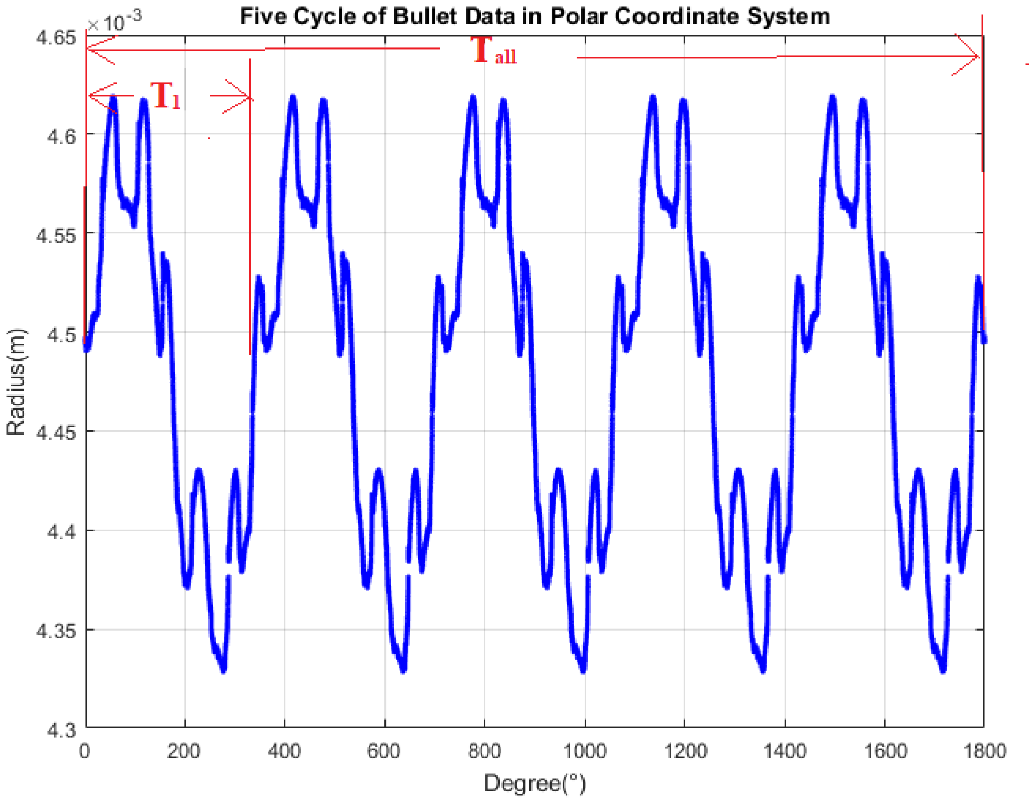

Figure 11: Five cycle of bullet data in polar coordinate system

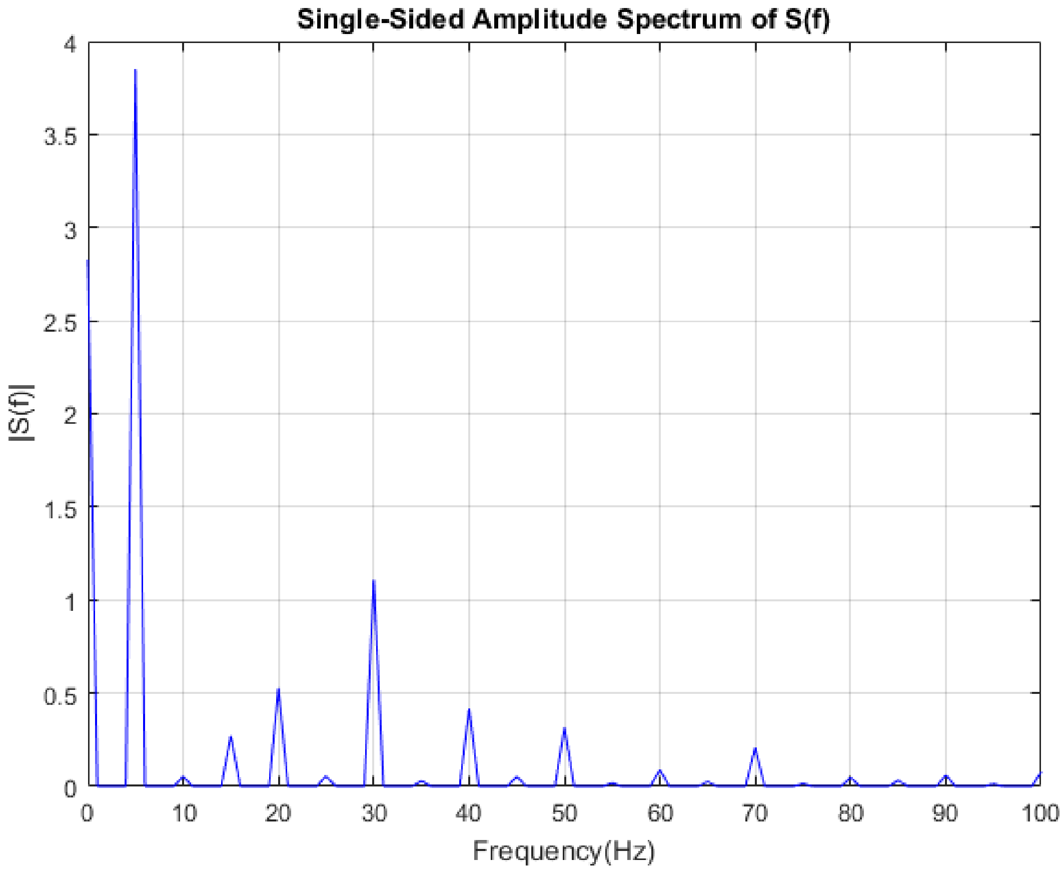

Figure 12: Single-Sided Amplitude of S(f) of five cycle

Figure 13 to Figure 16 show the scatter diagram of spectrum amplitude S(f) against bullet classes from 1st harmonic to 4th harmonics. The results obtained show that the bullet classification was hard to achieve as the distinction between the bullet classes was not clear. This would increase the difficulty to identify bullet class by using ANN. One of the reason caused situation above was due to noisy data. Therefore, data filtering was applied to remove the unwanted noise.

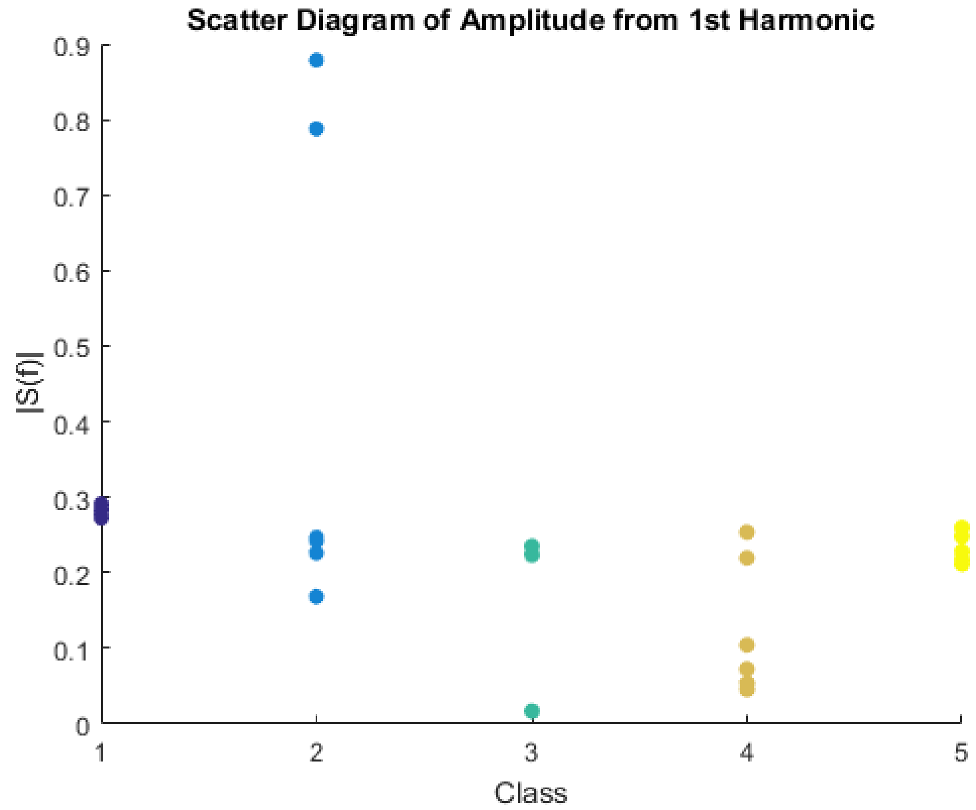

Figure 13: Scatter diagram of amplitude from 1st harmonic

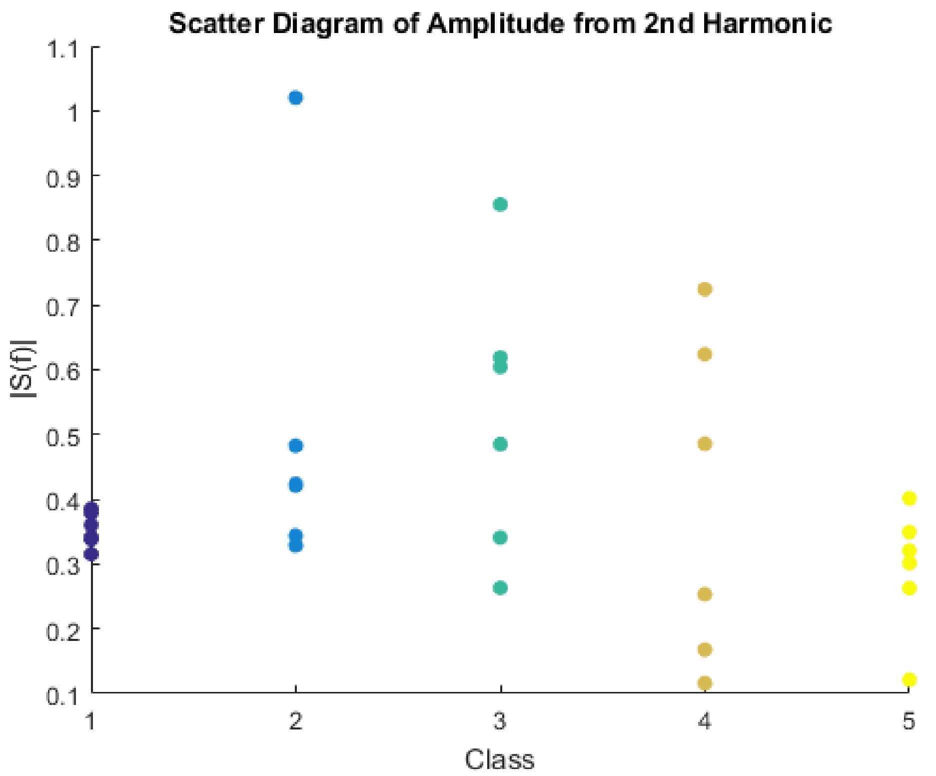

Figure 14: Scatter diagram of amplitude from 2nd harmonic

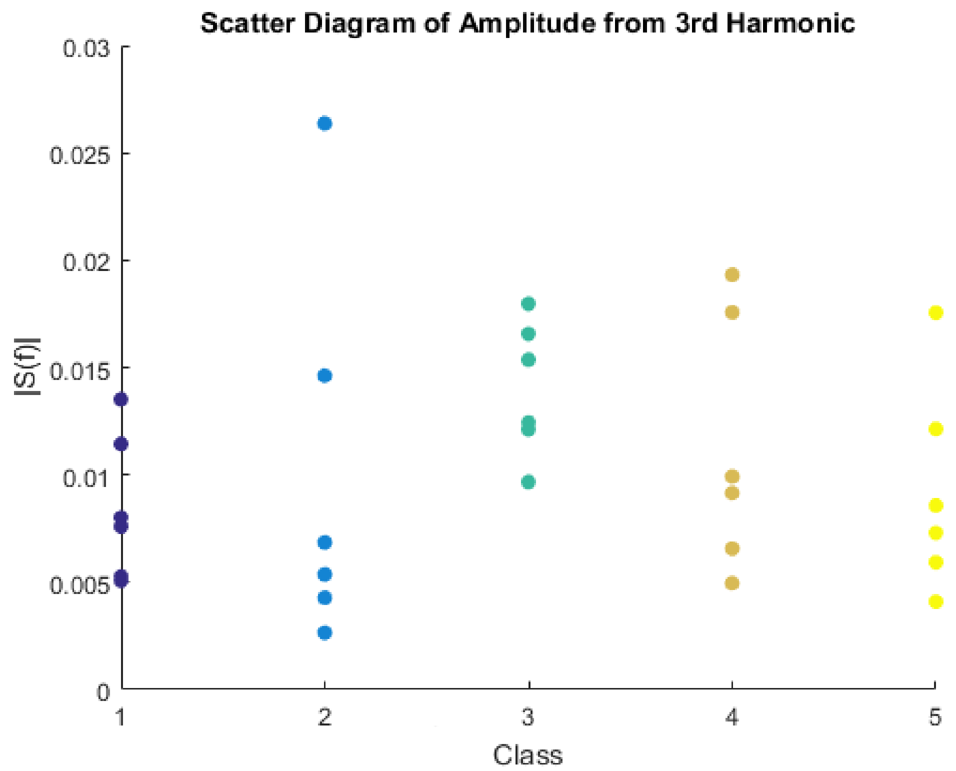

Figure 15: Scatter diagram of amplitude from 3rd harmonic

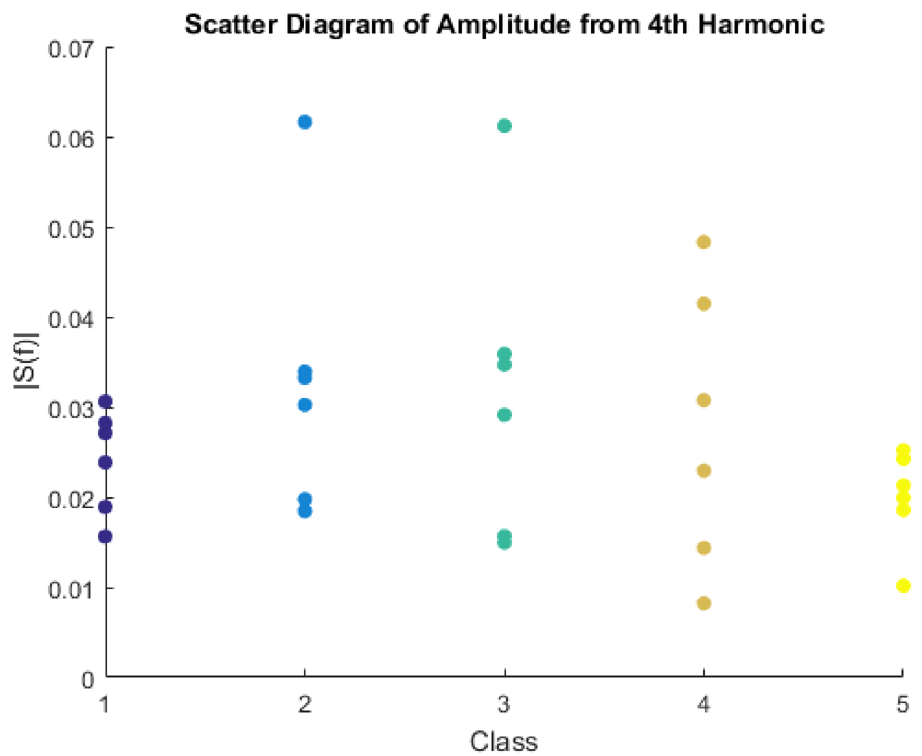

Figure 16: Scatter diagram of amplitude from 4th harmonic

The bullet data in Figure 17 were the combination of the roughness and waviness. Thus, filtering process was applied to remove the waviness from the bullet data. In this project, average filter was applied to calculate the average radial distance value throughout certain number of points. Average mask was generated in this project to calculate the average radius value throughout 2000 points. The filtering of 2000 points in the average mask can provide optimum average radius value and remove the waviness after several trials. Figure 17 showed the average filter line in the polar coordinate graph. Figure 18 showed the filtered bullet data graph.

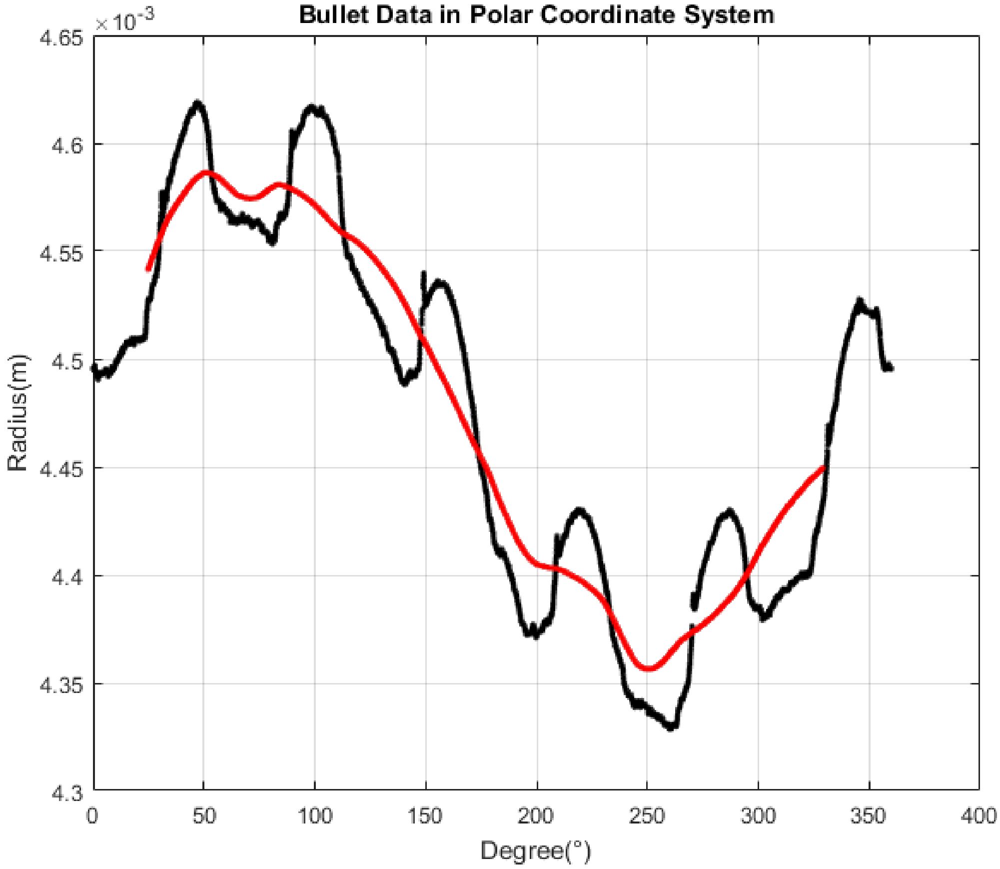

Figure 17: Sorted Polar Coordinate with Average Filter Line