DEVELOPMENT OF SUPPORT SYSTEM FOR IDENTIFICATION OF BULLET-INDUCED GLASS FRACTURES

by

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LIST OF ABBREVIATION

API	Application program interface
D	Fractal dimension
D_B	Box counting method
DFD	Data flow diagram
Dom0	Privileged domain
DomU	Unprivileged domain
dpi	Dots per inch
FMJ	Fully metal jacketed
ForeSS	Forensic support system
FORZA	Digital forensic investigation framework
gr	Grain
HarFA	Harmonic and fractal image analysis
hollpt	Hollow point
IC	Image Comparer
JPEG	Joint photographic expert group
LAS	Leica Application Suite
Na_2CO_3	Sodium Carbonate
NBW	Number of black and white
PAE	Physical address extension
pis	Pistol
rev	Revolver
rif	Rifle

SEM	Scanning electron microscope
SiO_2	Silicon dioxide
SMG	Sub machine gun
sRGB	Standard red green blue
VIX	Virtual introspection techniques

PEMBANGUNAN SISTEM SOKONGAN BAGI MENGENALPASTI KERETAKAN KACA YANG TERARUH OLEH PELURU

ABSTRAK

Ahli Sains Forensik dalam bidang analisis kaca mendapati bahawa gabungan senjata api dan peluru menghasilkan corak unik pada retakan kaca. Penyiasat forensik yang berpengalaman boleh mengenal pasti ciri-ciri senjata api dan peluru berdasarkan keretakan. Biasanya, analisis retakan kaca perlu mengikuti prosedur yang panjang dan membosankan serta melibatkan kos yang tinggi. Teknik tradisional yang telah digunakan dalam menjaga data telah menyebabkan kesukaran untuk mendapatkan semula data kerana data boleh menjadi rosak atau hilang. Skop kajian ini adalah untuk membangunkan Sistem Sokongan Forensik (ForeSS) untuk membantu Penyiasat forensik mempercepatkan proses mengenal pasti peluru yang menyebabkan keretakan kaca berdasarkan data yang telah dikumpul oleh ahli sains forensik. Metodologi kitaran hayat pembangunan sistem telah digunakan untuk pembangunan sistem. Data telah dibahagikan kepada sepuluh kumpulan: 1) Peluru, 2) Chronograph , 3) Perubahan bentuk, 4) Senjata api , 5) Kaca , 6) Harfa , 7) Image Comparer , 8) Leica Application Suite, 9) Jadual pengguna, dan 10) Ketebalan. ForeSS telah dibangunkan menggunakan aplikasi sumber terbuka yang melibatkan MySQL dan phpMyAdmin. Macromedia Dreamweaver MX telah digunakan sebagai sistem pengkodan. Hasil daripada kajian ini adalah satu sistem sokongan keputusan yang boleh memberi manfaat kepada siasatan yang melibatkan kes-kes keretakan kaca yang teraruh oleh peluru. Di dalam kajian ini ahli sains forensik boleh menggunakan sistem ini untuk menguruskan semua data yang berkaitan seperti memuat naik dan memasukkan maklumat data manakala Penyiasat forensik boleh menggunakan system ini untuk mendapatkan profil senjata api dan peluru berdasarkan ciri-ciri keretakan kaca. Pada masa hadapan, ForeSS boleh ditambah baik supaya boleh digunakan untuk mengenal pasti senjata api dan peluru yang menembak tubuh manusia.

DEVELOPMENT OF SUPPORT SYSTEM FOR IDENTIFICATION OF BULLET-INDUCED GLASS FRACTURES

ABSTRACT

Forensic Scientist in the field of glass analyses observed that combination of firearms and ammunitions produced unique pattern on glass fractures. Experienced forensic investigator could identify the characteristics of the firearms and ammunitions based on the fractures. Normally, analysis of the glass fracture has to follow lengthy and tedious procedures that were costly. The traditional technique that was used in keeping the data has caused difficulty to retrieve the data because the data could be damaged or loss. The scope of the study was to develop the Forensic Support System (ForeSS) to help forensic investigators expedite the identification of bullet induced glass fractures based on the data that was collected by forensic scientist. System Development Life Cycle methodology was used for the system development. Data were divided into ten groups: 1) Bullet, 2) Chronograph, 3) Deformation, 4) Firearm, 5) Glass, 6) HarFA, 7) Image Comparer, 8) Leica Application Suite, 9) Table pengguna and 10) Thickness. ForeSS was developed using open source applications involving MySQL and phpMyAdmin. Macromedia Dreamweaver MX was used as a coding system. The result from this study is a support system that can benefit the investigations involving cases of bullet-induced glass fractures. In this study, forensic scientist also can be a system administrator where they can use the system to manage all related data such as upload and key-in data info meanwhile forensic investigator can use this system to find the result profile of firearms and ammunitions based on the characteristics of the glass fractures. Overall, ForeSS could reduce the use of resources in terms of manpower and investigation time.

CHAPTER 1

INTRODUCTION

1.0 Introduction

A forensic scientist in the field of glass analyses observed that combination of weapons and ammunitions produced unique pattern on the characteristics of the fracture marks. The pattern characteristics provide evidences such as type of bullets and weapons.

All the data collected from the glass analyses should be stored in an appropriate place and safely to ensure the legitimacy and security of the data, this analyses practice using the traditional method where all the data documentation were kept in a proper filing system or in a offline hard disk. The traditional technique that was applied by forensic scientist to store data such as offline hard disk acquisition and analysis are not effective (Hay & Nance, 2008). In 2012, Syed-MohdDaud’s study of the fracture phenomena in soda lime silica glass caused by bullet impacts suggested to develop a database as a support system to store the data of the glass fracture (Syed-MohdDaud, 2012).

This encourages us to conduct this study a forensic support system should be developed to support forensic scientist for identification of bullet-induced glass fractures in order to reduce investigation time, manpower, cost and simplify the investigation of the crime scene.

ForeSS is a computerized support system to help forensic scientist finding the glass fracture characteristics of the pattern on the glass panes that caused by the bullet and it also can support forensic investigator to produce the result of the glass fracture and solving the crime case.

1.1 Problem Statement

Information gathered from research conducted by Syed-MohdDaud (2012) is very important because the study documented that combination of firearm and ammunition has produced distinctive characteristics of the fracture marks where the fracture patterns should be stored in a database. The data collected from the shooting range and all the information is only available in the Syed-MohdDaud's thesis. The data can be further analysed and use by forensic scientist for future cases involving glass fractures induced by bullet if they are kept in digital forms and shared through Information Communication Technology (ICT) (Vacca, 2005). Based on findings and observations that have been made, there is no proper system developed to analyse the glass fracture that was collected by forensic scientists.

The traditional technique in keeping the data properly such as filing system or in a offline hard disk has caused difficulty to retrieve the glass fracture data each time it is required and could be damaging and loss of data (Bui, Enyeart, & Luong, 2003). Previously, analysis of the glass fracture has to follow a lengthly and tedious procedure that were costly. Certain parts of the process performed can be negligible due to the very limited access and not efficient (Carrier & Spafford, 2004).

Agarwal *et al*., (2011) propose a systematic model of the digital forensic procedure that can assist the forensic scientist to decrease the cost of time, manpower and money in digital forensic investigation. Based on findings and observations that have been made, there is no proper system developed to analyse the glass fracture that was collected by forensic scientists.

This system could be helpful to expedite the identification process and reduce the use of resources in terms of manpower and investigation time because the support system (SS) for bullet-induced glass fractures might help forensic scientists to identify the profile of the bullet that caused the fractures to the glass panel.

1.2 Scope and Objectives of Research

The scope of the study was to develop the Forensic Support System (ForeSS) based on bullet-induce glass fracture, the data that was collected earlier and the data of glass fracture analysis acquired from HarFA, LAS and IC. ForeSS can be used by forensic scientists to expedite the identification process of bullet identification in new cases involving glasses. The system can also reduce the use of resources in terms of manpower and investigation time.

The specific objectives of this study are:

(i) To develop a Forensic Support System (ForeSS) and Micro Topographic Database System which may assist forensic scientists and forensic investigators to analyse bullet induced glass fracture.

(i) To store the data of glass fracture characteristics, fractal dimensions and ballistic data in the Micro Topographic Database System that was done by Syed-MohdDaud (2012).

(iii) To calculate the fractal dimension of glass fracture using Harmonic and Fractal Image Analysis (HarFA)

(iv) To evaluate performance of Image Comparer (IC) software in analysing or creating similar images.

1.3 Methodology

The micro topographic database was designed to store all the data of the ammunations, ballistic and glass fracture marking pattern induced by bullet impact that was analysed by Syed-MohdDaud (2012). The data and images of glass were further analysed in this study in three stages using the Leica Application Suite (LAS) version V2.7 developed by Leica Microsystems in Wetzlar, Germany, Harmonic Fractal Analysis (HarFA) version 5.5 developed by Institute of Physical and Applied Chemistry Faculty of Chemistry Brno University of Technology Brno Czech Republic and Image Comparer (IC) version 3.7 developed by Bolide Software in Seattle, USA

Leica Application Suite (LAS) was used to measure the basic micro topographic data of the glass fractures where the analysis was done by Syed-MohdDaud (2012). Harmonic Fractal Analysis (HarFA) was used to calculate fracture dimension (Zmeškal, 2001) and Image Comparer (IC) was used to compare the similarity of the new glass fracture image and existing images in the database (Raduan, 2012).

All the data were divided into ten groups to be stored in the micro topographic database; 1) Bullet, 2) Chronograph, 3) Deformation, 4) Firearm, 5) Glass, 6) HarFA, 7) Image Comparer, 8) Leica Application Suite, 9) Table User and 10) Thickness.

The Macromedia Dreamweaver MX version 6.0 developed by Macromedia, Inc. in the United States, was used for coding system in developing Forensic Support System (ForeSS), Micro Topographic Database was developed by using MySQL web server version 5.6.17 where the administrator of the MySQL web server is phpMyAdmin.

1.4 Research Outline

The study of the literature review was described in Chapter 2. There are four phases of methodologies in developing the Forensic Support System, which are described in Chapter 3. Chapter 4 describes the process of acquiring the result of analysis by using the applications (LAS, HarFA and IC) and Forensic Support System (ForeSS) to identify which firearms and ammunitions caused the fractured glass. Chapter 5 discusses the results of the glass fracture produced by ForeSS in terms of fracture phenomena, and fractal dimension of fracture patterns. Finally, the conclusion of the research will be explained in Chapter 6 with the recommendations for future study.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Forensic scientists are often being asked to examine broken glass to reconstruct events surrounding a crime (Almirall *et al.*, 2000). The examination and interpretation of glass fractures provide a wealth of interpretable information in criminal investigations. The fracture patterns generally provide information regarding the point and angle of impact, direction of force, sequence of firing and the type of bullet that causes the fractures (Ahearn *et al.*, 2006; Syed-MohdDaud, 2012).

Syed-MohdDaud (2012) has carried out a study to identify the fracture pattern of the glass surface when a projectile such as a bullet hit glass panes, the impact causes changes in the form of fractures within the glass. Fracture patterns caused by a bullet are unique. Fracture patterns in a piece of glass reflect the nature of the glass and the travelling direction and velocity of the breaking object (Mecholsky *et al*., 1992).

Mecholsky *et al*., (1992) noted that the fractures have a certain symmetric pattern in terms of cracks, craters, wallner lines and hackle marks (Mecholsky *et al*., 1992). Glass fracture examination can provide information the breaking force of the direction and the type of bullet that cause the fracture (Mecholsky *et al*., 1992).

Forensic scientists used the traditional procedures to obtain a result with experiments on the samples and then make decisions through the analysis as static analysis techniques (Hay and Nance, 2008). In addition, this procedure should be enhanced by the latest support system such as digital Forensics analysis (Hay and Nance, 2008).

Forensic scientists have conducted numerous studies of the glass fracture and they have published various aspects broken glass (Syed-MohdDaud, 2012). Unfortunately all the relationships data between the projectile impact factors and fracture patterns such as shape and velocity, its bullet type and calibre are not well stored (Syed-MohdDaud, 2012).

The ballistic data that were obtained from forensic studies scientist should be stored securely and systematically, to ensure the data can be easily retrived in solving crime scene cases (Leong, 2006). To solve this problem, it requires an information communication technology (ICT) in order to resolve the crime scene investigation. Computer forensics is a method that can be used to securely store all the forensics data digitally and electronically (Turner, 2007).

2.1 The identification process of the bullet induced glass fractures components

The forensic ballistic data could be stored electronically when an identification process is been done as to allow system administrator to further classify the data (Turner, 2007). The data collection used three material components, namely the firearms, ammunitions and window glass panes. This materials components were used by forensic scientist to acquired data for their computer forensic investigation (Bui, Enyeart, & Luong 2003).

These materials; i) firearms, ii) ammunitions and iii) window glass panes was used in all experiments involved to find the characteristics of the glass panes such as type and size which are related to impact resistance, fracture pattern and surface markings (Syed-MohdDaud, 2012). The glass panels were analysed by Leica MZ16 Stereomicroscope Research Grade with Leica Application Suite (LAS) software to measure basic micro topographic data in forms of line length, width, diameter and radius of the glass fractures (Syed-MohdDaud, 2012).

Fractal dimension was measured using HarFA (Zmeskal *et al*., 2001) and Image Comparer was used to make comparison between the new glass fracture image and images of glass fracture in the database (Raduan *et al.*, 2012).

2.2 The firearms

Figure 2.1 exhibits seven types of firearms used in the study by Syed-MohdDaud (2012). There are provided by Logistic (Firearm) Department, Bukit Aman, Kuala Lumpur and also by Firearms Unit, Police Headquarters, Kelantan. The firearms was used in the glass shooting experiments to produce glass fracture patterns on soda lime window glass. These experiment results illustrate the fracture pattern characteristics of the glass panes involving high velocity impacts.

(a) 0.38 Smith & Wesson Heavy Barrel revolver (left) and G-Lock 9 × 19 mm pistol (right)

(b) .7.65 mm Walther Semi-auto pistol (left) and Bushmaster (SMG) Carbon-15. Cal 9 mm (right)

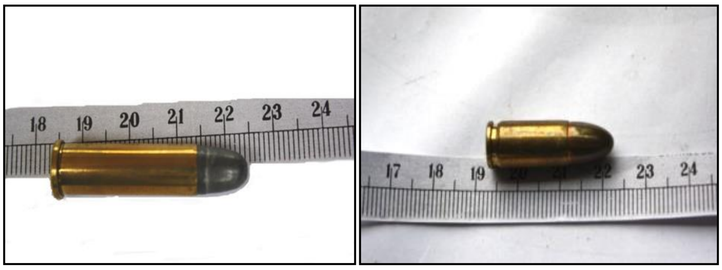
(c) M16A rifle (left) and Carbine 15-Cal.223 (right)

(d) M70 rifle Winchester (right)

Figure 2.1: (a) (b) (c) (d) Firearms used in the previous research study by Syed-MohdDaud (2012).

2.3 The ammunitions

Eight types of ammunition that were tested in the study by Syed-MohdDaud (2012). The ammunitions were also provided by Logistic (Firearm) Department, Bukit Aman, Kuala Lumpur and Firearms Unit Police Headquarters, Kelantan. The image details of the ammunition are presented in Figures 2.2 as conducted by Syed-MohdDaud (2012).



(a) SME 0.38 in. Special calibre (left) and 7.65 mm FMJ calibre (right)

(b) 9 mm SME FMJ (left) and 9 mm Luger Flat nose (right)

(c) 9 mm Luger Hollow point (left) and 5.56 mm FMJ calibre (right)

(d) 7.62 mm FMJ M70 rifle Winchester

Figure 2.2: (a) (b) (c) (d) Ammunitions used in the previous research study by Syed-MohdDaud (2012)

The detailed description of the firearms and ammunitions are reproduced from previous study and presented in Table 2.1. The table describes the firearm serial number, type of bullet, bullet weight, diameter of the bullet and velocity range as the firearms ammunitions data collected and used in study by Syed-MohdDaud (2012).

Table 2.1: Description of firearms and ammunitions used in the study by Syed-MohdDaud (2012)

Firearm, Serial number	Ammunition description	Type of bullet	Bullet weight		Diameter of bullet (mm)	Bullet length (mm)	Velocity range (m/s)
			*gr	*g			
0.38 Smith & Wesson Heavy Barrel revolver J 477682	SME 0.38 in. Special	Lead round nose	158	10.2	9.1	18.5	200 - 250
7.65 mm Walther Semi- auto pistol 315314	7.65 mm FMJ	FMJ**	75	4.892	7.65	12.5	300 - 350
G-Lock 9 X 19 mm pistol EAH 523 and Bushmaster SMG Carbon-15.Cal 9 mm HO 3404	9 mm SME	FMJ**	115	7.5	9	15	350 - 400
	9 mm Luger	FMJ**	115	7.5	9	15	350 - 400
	9 mm Luger	Flat nose	123	7.97	9	15	350 - 450
	9 mm Luger	Hollow point	147	9.525	9	16.5	250 - 400
M16A rifle 9287710	5.56 mm	FMJ**	55.23	3.5789	5.56	19	1000 -1030
Carbine 15-Cal.223 00267	5.56 mm	FMJ**	55.23	3.5789	5.56	19	700 - 770
M70 rifle Winchester G1618087	7.62 mm	FMJ**	146	9.46	7.62	28.43	800 - 850

[*] 15.432 gr (grain) = 1 g

** FMJ = Fully Metal Jacketed

Table 2.2 shows the bullet deformation data and velocity of nine type of bullet striking into two different glass panes. Bullet deformations of all calibers were similar, except G-Lock 9 x 19 mm Pistol 9 mm hollow point pistol (9mm_hollpt_pis) firearm id EAH 523 and M16A 5.56 rifle firearm id 9287710 (5.56_rif) had a huge deformation which shows a deformation of the former 15.82% and the latter had a deformation of 34.84% respectively.

Table 2.2: Bullets deformation data and the striking and remaining velocity, which were shot on two type of glasses (Syed-MohdDaud, 2012)

bullet	glass	striking velocity (m/s)	remaining velocity (m/s)	Original bullet length (mm)	bullet length after penetration (mm)	deformation (%)
0.38_rev	G1	220	177	18.59	12.55	32.49
0.38_rev	G2	237	198	18.59	12.57	32.38
7.65_fmj	G1	257	189	12.66	10.13	19.98
7.65_fmj	G2	259	189	12.66	9.87	22.04
9mm_pis	G1	361	280	15.06	11.75	21.98
9mm_pis	G2	362	286	15.06	11.87	21.18
9mm_flatnose_pis	G1	355	290	15.14	8.87	41.41
9mm_flatnose_pis	G2	351	286	15.14	8.81	41.81
9mm_hollpt_pis	G1	280	277	15.14	13.94	15.82
9mm_hollpt_pis	G2	277	224	15.14	10.79	34.84
9mm_hollpt_smg	G1	323	269	15.14	10.65	29.66
9mm_hollpt_smg	G2	318	265	15.14	10.61	29.92
5.56_rif	G1	1023	945	18.73	6.61	64.71
5.56_rif	G2	1016	938	18.73	9.26	50.56
5.56_car	G1	715	641	18.73	9.84	47.46
5.56_car	G2	714	640	18.73	9.63	48.59
7.62_M70	G1	821	768	28.43	20.71	27.15
7.62_M70	G2	826	769	28.43	20.88	26.56

1. rev: revolver
2. fmj: fully metal jacketed
3. pis: pistol
4. flatnose_pis: flatnose pistol
5. hollpt_pis: hollow point pistol
6. hollpt_smg: hollow point submachine gun
7. rif: rifle
8. car: carbine
9. G1: glass 1
10. G2: glass 2

Table 2.3 illustrates the ballistic data of broken glass panes caused by two types of firearms and bullets, Carbine 15-Cal.223 5.56 mm calibre (5.56_car) and 0.38 Smith & Wesson Heavy Barrel revolver SME 0.38 in. special calibre fired on the 2 mm, 3 mm, 5 mm and 10 mm glass.

Table 2.3: Striking, remaining and loss of velocity, momentum and kinetic energy loss for all glass thickness (Syed-MohdDaud, 2012)

bullet	**glass thickness (mm)**	**striking velocity (m/s)**	**striking MV (m/s)**	**striking energy (J)**	**remaining velocity (m/s)**	**remaining MV (m/s)**	**remaining energy (J)**	**loss of velocity (m/s)**	**Loss of MV (m/s)**	**loss of energy (J)**	**original bullet length (mm)**	**bullet after penetration (mm)**	**deformation (%)**
5.56_car	2 mm	737	2.638	971.97	710	2.541	902.06	27	0.097	69.91	18.73	16.11	14
5.56_car	3 mm	751	2.688	1009..25	703	2.516	884.36	48	0.097	69.91	18.73	13.15	29.8
5.56_car	5 mm	706	2.527	891.93	632	2.262	714.75	74	0.265	177.18	18.73	9.63	48.6
5.56_car	8 mm	745	2.666	993.19	594	2.126	631.38	151	0.54	361.81	18.73	Bullet fragments	Bullet fragments
5.56_car	10 mm	772	2.763	1066.48	601	2.151	646.35	171	0.612	420.13	18.73	Bullet fragments	Bullet fragments
0.38_rev	2 mm	239	2.438	291.32	226	2.305	260.49	13	0.133	30.83	18.59	16.97	8.71
0.38_rev	3 mm	230	2.346	269.79	209	2.132	222.77	21	0.214	47.02	18.59	15.22	18.13
0.38_rev	5 mm	237	2.417	286.46	194	1.979	191.94	43	0.438	94.52	18.59	12.62	32.11
0.38_rev	8 mm	233	2.377	276.87	130	1.326	86.19	103	1.051	190.68	18.59	5.74	69.12
0.38_rev	10 mm	235	2.397	281.65	88	0.898	39.49	147	1.499	242.16	18.59	Bullet fragments	Bullet fragments

1. MV: momentum

Several components; i) impact test stand, ii) firearm rest, iii) bullet velocity measurement, iv) target glass stand and v) bullet catch were used in order to have the best results that are addressed in this study and they were firearms and ammunitions. Table 2.4 describes the types of firearms and ammunitions, as well as the bullet type, weight, diameter and length. This table shows nine types of firearms and nine types of ammunition that were used in the glass shooting experiments.

Table 2.4: Description of firearms and ammunitions used in the study done by Syed-MohdDaud (2012)

firearm serial number	**J 477682**	**315314**	**EAH 523**	**EAH 523**	**EAH 523**	**HO 3404**	**9287710**	**00267**	**G1618087**
bullet	0.38_rev	7.65 fmj	9mm pis	9mm flatnose pis	9mm hollpt pis	9mm hollpt smg	5.56 rif	5.56 car	7.62 M70
firearm types	0.38 Smith & Wesson Heavy Barrel revolver	7.65 mm Walther Semi-auto pistol	G-Lock 9 X 19 mm pistol	G-Lock 9 X 19 mm pistol	G-Lock 9 X 19 mm pistol	Bushmaster SMG Carbon-15.Cal 9 mm	M16A rifle	Carbine 15-Cal.223	M70 rifle Winchester
ammunitions	SME 0.38 in. Special	7.65 mm FMJ	9 mm SME	9 mm Luger	9 mm Luger	9 mm Luger	5.56 mm	5.56 mm	7.62 mm
bullet types	Lead round nose	Fully metal jacketed (FMJ)	Fully metal jacketed (FMJ)	Fully metal jacketed (FMJ)	Flat nose	Hollow point	Fully metal jacketed (FMJ)	Fully metal jacketed (FMJ)	Fully metal jacketed (FMJ)
bullet weight (g)	10.2	4.892	7.5	7.5	7.97	9.525	3.5789	3.5789	9.46
bullet diameter (mm)	9.1	7.65	9	9	9	9	5.56	5.56	7.62
bullet length (mm)	18.5	12.5	15	15	15	16.5	19	19	28.43

Table 2.5 exhibits the summary of ballistic data with 7 samples of shots on the glass panes. The ballistic data consists of the striking velocity, remaining velocity, striking and remaining momentum, initial energy and remaining energy for broken glass panes caused by the bullets fired from several types of firearms.

Table 2.5: Summary of ballistic data for samples of shots on glass panes done by Syed-MohdDaud (2012)

Ballistic data	velocity range	shot	striking velocity (m/s)	striking MV (m/s)	striking energy (J)	remaining velocity (m/s)	remaining MV (m/s)	remaining energy (J)	loss of velocity (m/s)	Loss of MV (m/s)	loss of energy (J)
9 mm hollpt pis	350-450	S4	282	2.686	378.73	230	2.162	251.94	52	0.495	126.79
9 mm hollpt pis	350-450	S5	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
9 mm hollpt pis	350-450	S6	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
9 mm hollpt pis	350-450	S7	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
9 mm hollpt smg	250-400	S1	316	3.01	475.56	266	2.534	336.98	50	0.476	138.58
9 mm hollpt smg	250-400	S2	318	3.029	481.6	265	2.524	334.45	53	0.504	147.15
9 mm hollpt smg	250-400	S3	323	3.077	496.87	269	2.524	344.63	54	0.515	152.25
9 mm hollpt smg	350-450	S3	280	2.667	373.38	227	2.162	245.41	53	0.505	127.97
9 mm hollpt smg	250-400	S4	328	3.124	512.37	277	2.638	365.43	51	0.486	146.95
9 mm hollpt smg	250-400	S5	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
9 mm hollpt smg	250-400	S6	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
9 mm hollpt smg	250-400	S7	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
5.56 rif	1000-1030	S1	1013	3.625	1836.28	936	3.35	1567.73	77	0.275	268.55
5.56 rif	1000-1030	S2	1018	3.643	1854.45	934	3.343	1561.04	84	0.3	293.41
5.56 rif	1000-1030	S3	1021	3.654	1865.4	942	3.371	1587.89	79	0.283	277.51
5.56 rif	1000-1030	S4	1023	3.661	1872.71	945	3.382	1598.02	78	0.279	274.69
5.56 rif	1000-1030	S5	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
5.56 rif	1000-1030	S6	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
5.56 rif	1000-1030	S7	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL

Table 2.5 (Continued)

Ballistic data	velocity range	shot	striking velocity (m/s)	striking MV (m/s)	striking energy (J)	remaining velocity (m/s)	remaining MV (m/s)	remaining energy (J)	loss of velocity (m/s)	Loss of MV (m/s)	loss of energy (J)
5.56 car	700-770	S1	701	2.509	879.34	622	2.226	692.31	79	0.283	187.03
5.56 car	700-770	S2	703	2.516	884.36	634	2.269	719.28	69	0.247	165.08
5.56 car	700-770	S3	706	2.527	891.93	632	2.262	714.75	74	0.265	177.18
5.56 car	700-770	S4	714	2.555	912.25	640	2.290	732.96	74	0.265	179.29
5.56 car	700-770	S5	715	2.559	914.81	641	2.294	735.25	74	0.265	179.56
5.56 car	700-770	S6	720	2.577	927.65	628	2.248	705.73	92	0.329	221.92
5.56 car	700-770	S7	723	2.588	935.4	658	2.355	774.77	65	0.233	160.63
7.62 M70	800-850	S1	807	7.634	3080.41	755	7.142	2696.22	52	0.492	384.19
7.62 M70	800-850	S2	819	7.748	3172.7	771	7.294	2811.71	48	0.454	360.99
7.62 M70	800-850	S3	821	7.767	3188.21	768	7.265	2789.87	53	0.502	398.34
7.62 M70	800-850	S4	831	7.861	3266.35	778	7.360	2862.99	53	0.501	403.36

2.4 The glass characteristics

The composition in soda lime glass panes will produce fracture patterns after the penetration of bullet. The fracture pattern shows the characteristics of impact, direction of force, sequence of firing and the type of bullet that causes the fractures. Table 2.6 shows the compasition of general properties of soda lime glass (Hotar & Novotny, 2013). Generally, the properties of soda lime glass composition contained SiO_2: 70- 73%, Alkaline material, R_2O: 13- 15%, CaO: 7- 12%, MgO: 1.0- 4.5%, Al_2O_3: 1.0- 1.8% and Fe_2O_3: 0.08- 0.14%.

Table 2.6: Composition and general properties of soda lime glass

Composition	General Properties
SiO_2: 70- 73%	Refractive index: 1.52
Alkaline material, R_2O: 13- 15%	Coefficient of linear expansion: 8.5 x 10^{-6} cm/cm/°C
CaO: 7-12%	Hardness: 6.5°
MgO: 1.0-4.5%	Compressive strength: 6000-12000 kg/cm^2
Al_2O_3: 1.0-1.8%	Young modulus: 730,000 kg/cm^2
Fe_2O_3: 0.08-0.14%	Poisson’s ratio: 0.23

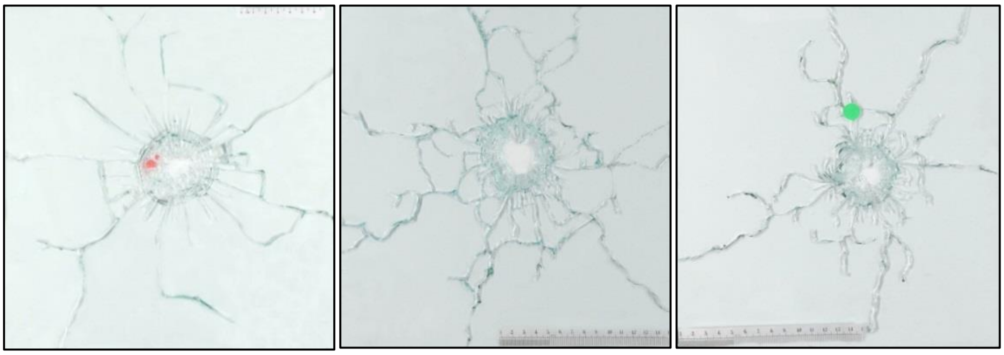
The study of the fracture pattern characteristics done by Syed-MohdDaud (2012) involved low velocity impact using lead ball impact on surface of glass. Some tests were also performed with glass panes of varying thicknesses (2, 3, 5, 8, 10 and 12 mm) with dimension of 300 width x 300 height x 5 mm^3 thickness and 450 x 450 x 5

mm^3. Glass fracture patterns on soda lime window glass pane Figure 2.3 with the size of 200 x 200 mm shown the velocity impact.

Figure 2.3: Glass fracture pattern on soda lime window glass pane from the study by Syed-MohdDaud (2012)

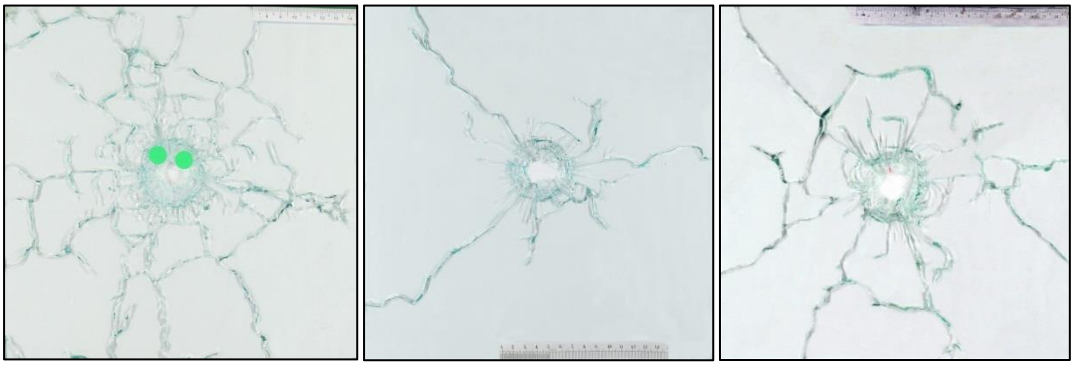
The composition in soda lime glass panes will produce the fracture pattern after the penetration of the bullet showing the characteristics of impact, direction of force, sequence of firing and the type of bullet that causes the fractures.

In the study done Syed-MohdDaud (2012), soda lime silica glass was shot by 7 types of firearms and 7 types of bullets to produce the fracture patterns with different types of bullets in different types of glass panels. The fracture pattern on the surface of the soda lime silica show the characteristics of the bullets. Figure 2.4 shows various fracture patterns characteristics of the soda lime silica glass.



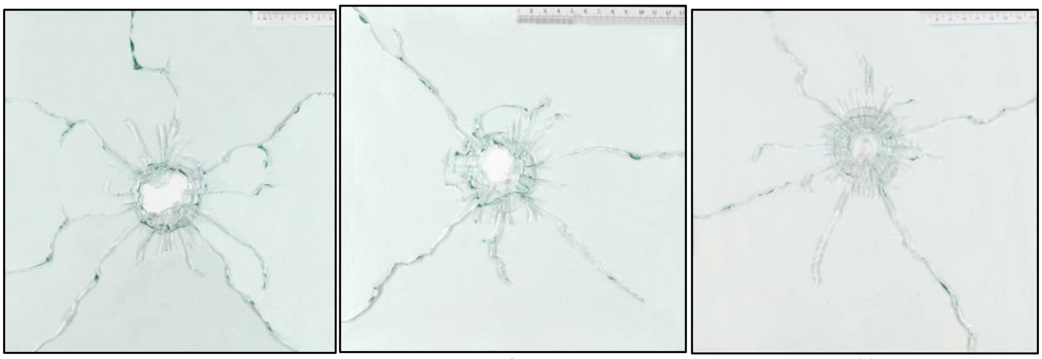
(a) (b) (c)

(a) SME 00.38 in. Special (b) 5.56 mm rifle (c) 5.56 mm Carbine 15- Cal.223



(d) (e) (f)

(d) 7.62 mm M70 rifle Winchester (e) 7.65 mm FMJ Walther Semi- auto pistol
(f) 9 mm Flat Nose G-Lock 9 × 19 mm pistol



(g) (h) (i)

(g) 9 mm Hollow point G-Lock 9 × 19 mm pistol (h) 9 mm Bushmaster SMG Carbon- 15. Cal (i) 9 mm G-Lock 9 × 19 mm pistol

Figure 2.4: various fracture pattern characteristics on soda lime window glass panes caused by bullet impact done by Syed-MohdDaud (2012)

The result of the bullet impact on soda lime window glass fracture caused by the bullets were shown in the Table 2.8 that describes the characteristic patterns of the cross sectional, radial crack and deflected radial crack and shooting range on the glass pane induced by the bullet.

Table 2.9 describes the characteristics of the glass fractures that was shot by firearms; i) Diameter hole, ii) Diameter crater, iii) Crater area, iv) Cone angle, v) Segment number, vi) Radial crack long, vii) Radial crack short, viii) Radial crack short and ix) Bifurcated crack.

Table 2.7: Description of glass fracture characteristics (Syed-MohdDaud, 2012)

bullet	Firearm, Serial number	cross sectional	radial crack	deflected radial crack	velocity range (m/s)	characteristic range
9 mm pis	EAH 523	More number of mirror regions present	Long and fine	Long and fine	300 - 360	- Only a few of radial cracks were extending to the frame - Very few or no deflected cracks were present - Patterns are simple
7.65 fmj	315314	More mirror regions. But, more hackles were present at the end of the crack	Long and fine	Long and fine	300 - 350	- Produced neat and clean bullet hole - Less number of radial, deflected and bifurcated radial cracks were produced - Deflected cracks were present close to impact point - Bifurcated cracks were formed away from impact point
0.38 rev	J 477682	More mirror regions	Long and coarse	Long and coarse	200 - 250	- Produced largest diameter of hole, crater and cone angle - Radial cracks were smooth and straight - Deflected and bifurcated cracks were present away from the impact point

Table 2.7(Continued)

9 mm smg	HO 3404	More hackles regions	Long and coarse	Long and coarse	370 - 400	- Produced greater crater diameter, and number of segments - An opaque region was present at bullet holes - Many short and fine radial cracks were present near to impact point - Tree branching was present - Independent concentric cracks were present close to the crater area - A large number of bifurcated and deflected cracks were formed
9 mm flatnose pis	EAH 523	Anomalous, where very small number of mirror regions were present	Long and fine	Long and fine	350 - 400	- Produced clean and neat bullet holes - Thick opaque region was present on crater - Deflected cracks were formed from tree branching of radial cracks at the crater area - Deflected cracks were present circularly and very close to the impact point and intact with the glass - Only a few radial cracks extended to the frame
9 mm flatnose smg	EAH 523	Anomalous, where very small number of mirror regions were present	Long and fine	Long and fine	400 - 430	- Produced clean and neat bullet hole - Thick opaque region was present on the crater - Deflected cracks were formed from tree branching of radial cracks at the crater area - Deflected cracks presented circularly and very close to the impact point and intact with the glass - Large bifurcations were present away from impact area

Table 2.7(Continued)

9 mm hollpt pis	HO 3404	More number of mirror regions present	Long and fine	Long and fine	250 - 300	- Produced large sized crater, and radial segments - Deflected and bifurcated cracks were present near to impact area - Tree branching was present near the crater area but did not deflect - Radial cracks were less jagged
9 mm hollpt smg	HO 3404	More number of mirror regions present	Long and fine	Long and fine	300 - 350	- Produced large sized crater, and radial segments - Deflected and bifurcated cracks were present near to impact area - Tree branching was present near the crater area but did not deflect - Radial cracks were less jagged
5.56 rif	9287710	More hackle regions rather than mirrors	Long and fine	Long and thick	1000 - 1030	- An opaque region was present at bullet holes - Clean and neat bullet holes were formed - Many short and fine radial cracks were present near to impact point - Large number of radial segments was present - Deflected and bifurcated radial cracks were present dominantly - Formed many wing cracks near to the crater - Independent concentric cracks were present close to the crater area - Small pockets of deflected cracks were formed