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Author(s):	**Robert C. Maher**
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Final Summary Overview

Agency: National Institute of Justice

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Project Title: Advancing audio forensics of gunshot acoustics

PI: Robert C. Maher

Department Head and Professor

rmaher@ece.montana.edu

406-994-7759

Submitting official: Robert C. Maher (PI)

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Recipient Organization: Montana State University

ECE Dept., 610 Cobleigh Hall, Bozeman, MT 59717-3780

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Signature of Submitting Official:

1) What is the purpose of the project?

This project addresses the need for improved scientific understanding of audio forensic evidence, particularly analysis and interpretation of recorded gunshot sounds.

The primary applied research goal is to create an apparatus and methodology for scientific and repeatable collection of firearm acoustical properties recorded anechoically (without early sound reflections). The primary development goal is to evaluate the extent to which useful forensic acoustical information can be obtained from recordings made by personal audio recorders of the type typically used by law enforcement officers.

The primary accomplishment has been achieved in the applied research goal: obtaining good, repeatable gunshot recordings using the specialized audio recording equipment and the standardized firearm test procedure. The result is a comprehensive set of directional recordings of ten successive shots from nine different firearms.

2) Project design, methods, and data analysis

The acoustical characteristics of a firearm depend upon the type of gun and ammunition, and the azimuth with respect to the gun barrel. Therefore, forensic gunshot acoustical analysis must include the overall sound level and the angular dependence for comparison to the recorded evidence.

For this project, we designed, built, and implemented a test rig containing omnidirectional instrumentation microphones placed at 15 degree intervals on a semicircular (180°) arc of 3 meter radius. A high speed multichannel digital audio recorder served each microphone. Each firearm under test was fired from the center of the arc while the microphone system simultaneously and synchronously recorded the acoustical waveforms from each angular position.

The approach and methods are summarized next.

(1) Assembled and tested the microphone mounting system. The rig is designed to support the 12 recording microphones in a semicircular pattern, radius 3 meters, and elevated above the ground by 3 meters (see Figure 1).

Figure 1: 3 meter radius x 3 meter tall aluminum custom-designed bracket with twelve instrumentation microphones attached for recording simultaneously at multiple azimuths.

(2) Performed the first round of gunshot recordings using 9 different firearms: Glock 23 handgun, Glock 19 handgun, Sig 239 handgun, Colt 45 handgun, Ruger SP101 handgun, 22 rifle, Remington 12 ga. Shotgun, AR14 M4 Carbine, and 308 rifle. Each firearm was fired 10 times in succession, with digital audio recordings made at a 500kHz sampling rate (see Figure 2).

Figure 2: Marksman in position to perform shots with test recording.

(3) Analyzed the new recordings for consistency and reliability. The recording process produces highly repeatable and consistent results. In future tests the position of the firearm's muzzle will be identified more precisely to be the center of the semicircular recording arc, and the presence of wind at the shooting range will be mitigated to the extent possible.

(4) Analysis of shot-to-shot variability. In our experiment we made up to ten successive shots from a particular firearm. We are interested in the shot-to-shot variability, since any future forensic use of gunshot audio will require an assessment of random variation inherent in gunshot signals.

For example, Figure 3 shows a recording of a single shot from a .308 rifle.

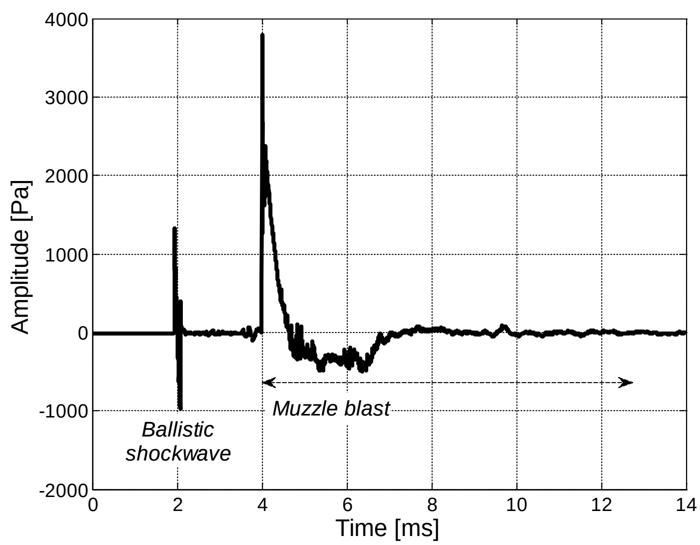

Figure 3: Recording of .308 rifle shot, 3 meters on-axis, no reflections. The initial trace is the ballistic shockwave from the supersonic bullet.

Overlapping the ten successive gunshot recordings for the .308, we see the general similarity but subtle differences, as shown in Figure 4.

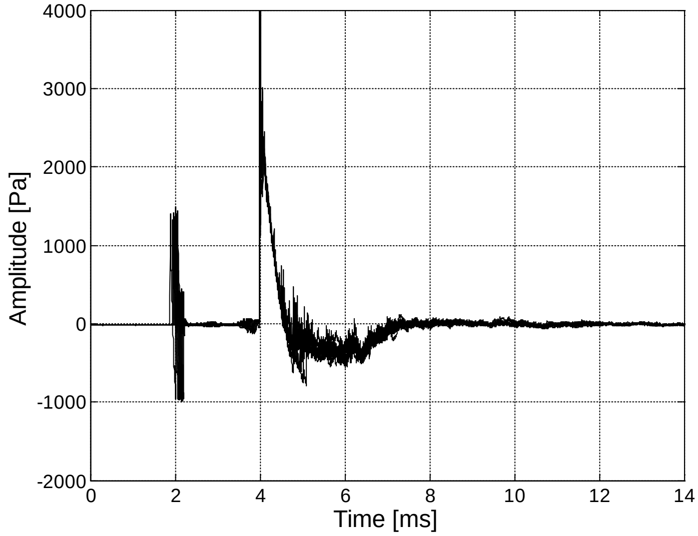

Figure 4: Overlapped plot of ten successive gunshots from the .308 rifle. The shots are similar, but exhibit measurable shot-to-shot differences.

We also compared the relative timing of the ballistic shockwave and the muzzle blast (see Figure 5), which indicates the shot-to-shot tolerance of the marksman's manual positioning and aiming of the rifle, or possibly a variation in the nominal speed of the bullet (2,650 ft/s = 807.8 m/s) from cartridge to cartridge resulting in a difference in time-of-flight for the bullet to the vicinity of the microphone. Future work will seek to understand the muzzle velocity and shockwave behavior.

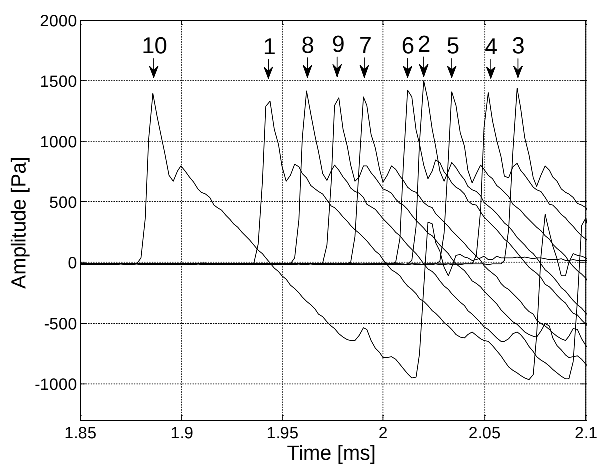

Figure 5: Enlargement of Fig. 4 ballistic shockwave section for ten successive shots from the .308 rifle with time alignment based on the muzzle blast. Numerical labels indicate the order of the ten shots.

(5) Analysis of muzzle blast duration. The duration of the muzzle blast varies from firearm to firearm, and also varies from one shot to the next for a given firearm. The explanation for the duration variability is not yet known, but this variation will have an impact on forensic analysis of recordings that include gunshots of unknown origin. Figure 6 shows an indication of the duration variability for different firearms, and for 10 successive shots by each firearm.

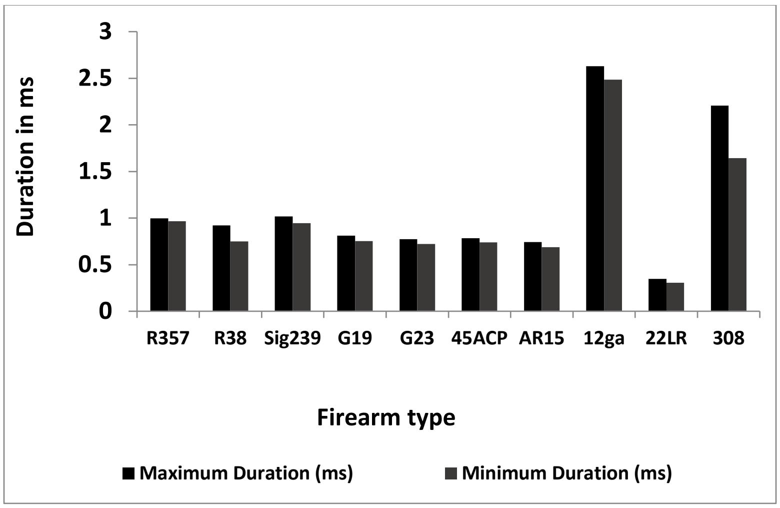

Figure 6: Maximum and minimum muzzle blast durations of different firearms at the line of fire based on 93% of total muzzle blast energy (for 10 shots)

(6) Comparison of signal level as a function of azimuth and selected firearm. One of the key aspects of this project is observing the change on gunshot characteristics as a function of azimuth. Typical firearms show a sound level approximately 20 dB higher in the direction of fire compared to the direction behind the shooter. Details of the waveforms also vary (see Figure 7 and Figure 8).

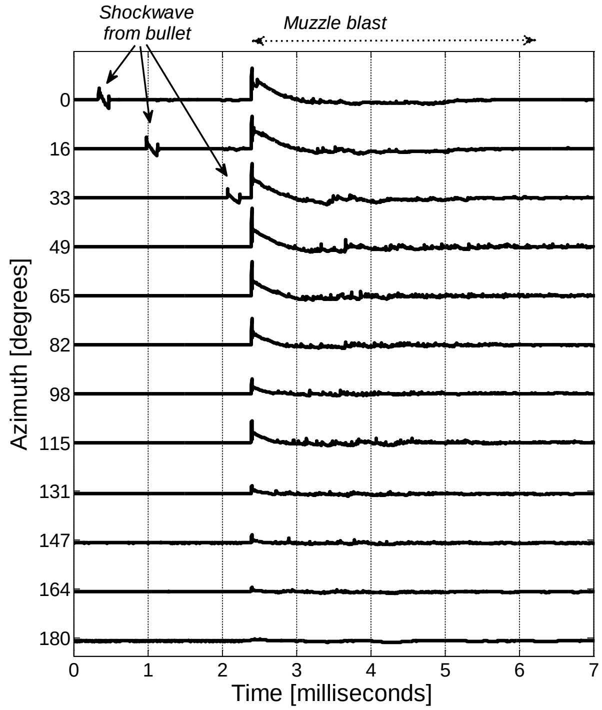

Figure 7: Recordings of a .308 rifle shot as a function of azimuth (0° azimuth is on-axis in front of the barrel, 180° is behind the shooting position).

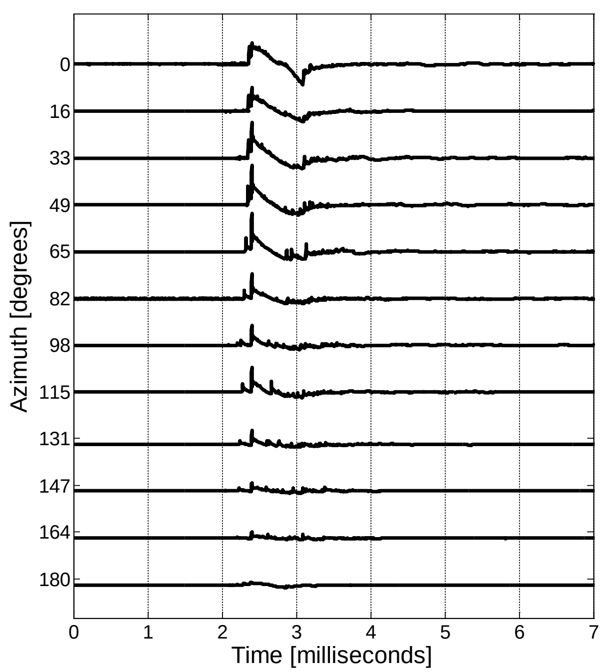

Figure 8: Recordings of a Glock 19 handgun shot as a function of azimuth

(7) Initial work on modeling and identification. We have prepared a preliminary analysis of a gunshot classification scheme using a wavelet-based comparison technique. Visiting engineering and collaborator Angelo Borzino (Brazil) has focused his efforts in this area. An example of the transform characteristics is shown in Figure 9.

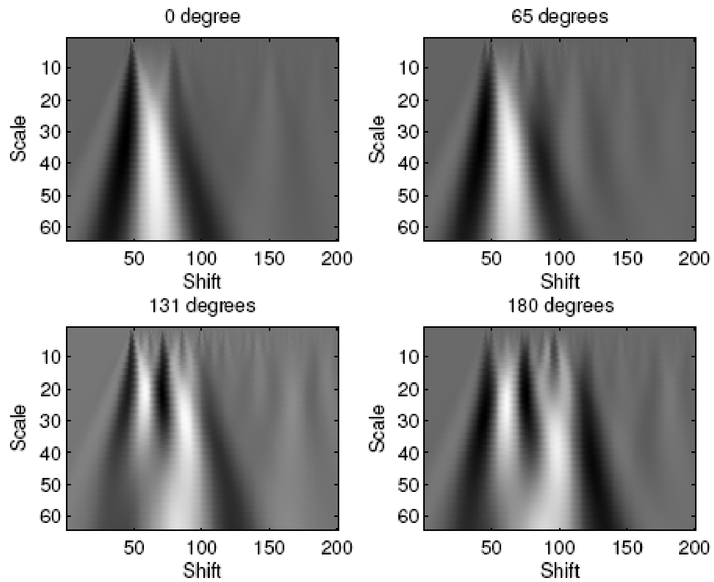

Figure 9: Wavelet Transform of the muzzle blast for a firearm recorded at four different azimuths, showing the distinctive features that may allow identification and classification.

3) Scholarly products

We have produced a set of presentations and publications in the audio engineering and acoustics literature, some popular press articles and interviews, a Master's Degree (MS electrical engineering) thesis, and expect to have additional presentations and publications based on this project.

1. Maher, R.C., "Lending an ear in the courtroom: forensic acoustics," Acoustics Today, vol. 11, no. 3, pp. 22-29, 2015.
2. Maher, R.C., and Routh, T.K., "Advancing forensic analysis of gunshot acoustics," Preprint 9471, Proc. 139th Audio Engineering Society Convention, New York, NY, October, 2015.
3. Routh, T.K., "Observing variation of acoustical characteristics of several common firearms in a quasi-anechoic environment at a high sampling rate," M.S. thesis, Department of Electrical & Computer Engineering, Montana State University, Bozeman, MT USA, July, 2016.

4. Routh, T.K., and Maher, R.C., “Recording anechoic gunshot waveforms of several firearms at 500 kilohertz sampling rate,” Journal of the Acoustical Society of America, vol. 139, no. 4, part 2, p. 2066 (abstract), April, 2016.

5. Maher, R.C., "Gunshot recordings from a criminal incident: who shot first?" J. Acoust. Soc. Am., vol. 139, no. 4, part 2, p. 2024 (abstract), April, 2016.

6. Maher, R.C., and Routh, T.K., “Wideband audio recordings of gunshots: waveforms and repeatability,” Proc. 141st Audio Engineering Society Convention, Los Angeles, CA, September, 2016.

7. Routh, T.K., and Maher, R.C., “Determining the muzzle blast duration and acoustical energy of quasi-anechoic gunshot recordings,” Proc. 141st Audio Engineering Society Convention, Los Angeles, CA, September, 2016.

8. R.C. Maher and T.K. Routh, "Gunshot acoustics: pistol vs. revolver," Proc. 2017 Audio Engineering Society International Conference on Audio Forensics, Arlington, VA, June, 2017.

Popular press / layman’s articles:

1. Science News, “Sounds from gunshots may help solve crimes,” by Meghan Rosen, June, 2016. https://www.sciencenews.org/article/sounds-gunshots-may-help-solve-crimes

2. Forbes.com Tech, “Acoustic gunshot analysis could help solve crimes,” by Jennifer Hicks, June, 2016. http://www.forbes.com/sites/jenniferhicks/2016/06/30/acoustic-gunshot-analysis-could-help-solve-crimes/#2f8baa5470aa

3. Acoustics.org, “Gunshot recordings from a criminal incident: who shot first?” Robert C. Maher, lay-language article, May, 2016. http://acoustics.org/2aaaa7-gunshot-recordings-from-a-criminal-incident-who-shot-first-robert-c-maher/

4. National Public Radio "Here & Now" (WBUR-Boston), "How Audio Analysis Of Gunshots Helps Solve Crimes," interview by Ms. Robin Young (2017 May).

5. BBC News article "Gunfire audio opens new front in crime-fighting," by Richard Gray (2017 May)

Future:

1. Invited to give an oral presentation entitled “Audio Forensics of Gunshot Sounds” at the 2017 National Institute of Justice Forensic Science Research and Development Symposium, February 14, 2017, New Orleans, LA.

2. Maher, R.C., “Challenges of audio forensic evaluation from personal recording devices,” Proc. 143rd Audio Engineering Society Convention, New York, NY, October, 2017.

Database:

1. Gunshot Audio Recordings examples and full database: http://www.montana.edu/rmaher/gunshots/

4) What are the implications for criminal justice policy and practice in the U.S.?

For at least the past 20 years many law enforcement vehicles have been equipped with Mobile Video Recorder (MVR) dashboard-mounted video camera systems. Video and audio from these systems have been used as evidence in numerous investigations and court proceedings. In the last 5-10 years the availability of small vest-mounted or pocket-sized personal video and audio recorders for police officers has led to a vast expansion in the number of recordings available following an officer-involved gunfire incident. Moreover, the likelihood that civilian bystanders with smart phones and other personal recording devices will witness and record a firearms incident has also increased dramatically in recent years. Thus, the availability of these forensic gunshot recordings and the need to analyze their characteristics using the laboratory-quality recordings we have obtained in this project can have a major impact upon criminal justice policy and practice in the United States. It is now critical for forensic examiners to understand the strengths and weaknesses of the audio recording systems used in mobile audio recorders, particularly the miniature digital voice recorders carried by many law enforcement officers, in the context of gunshot interpretation.