Detection and analysis of firearm propellants by fluorescence chemical imaging

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Abstract

This study investigated the potential use of fluorescence chemical imaging for the detection and analysis of firearm propellants. Unfired and fired propellants were analysed under several excitation wavelengths using the VIS/NIR Condor chemical imaging system (ChemImage Corp. Pittsburgh, USA). Resulting spectral information was analysed to determine if discrimination between different types of ammunition was possible.

The preliminary results have shown that chemical imaging is able to distinguish between some brands of ammunition using fluorescence spectra while simultaneously recording the shape of the propellant grains for comparison against reference samples in a database. Further discrimination of propellants within brands is also possible using this method. In addition, results indicate that fluorescence data from unfired propellants can be compared to the data from propellant particles recovered after test firings to assist in the inclusion or exclusion of possible sources.

Introduction

Firearm propellant evidence can be encountered in numerous ways in casework. The presence of propellant may help determine if a firearm was involved in a crime. Examination of unburnt or partially burnt particles can provide intelligence on the type of ammunition used, or compared to a particular ammunition type to either include or exclude suspect ammunition. Muzzle-to-target distance may also be estimated by examining the spread of propellant particles. Given that firearm propellants are readily available (e.g. bulk quantities purchased for ammunition reloading), they have also been used in improvised explosive devices (Bender, 1998).

Traditional techniques for firearm propellant detection include the use of forensic light sources to observe possible fluorescence of propellant particles, especially in cases where the substrate is dark or highly patterned, making the detection of the particles difficult. Chemical tests can detect the spread of nitrites for range determination through the comparison of the spread with those obtained from test firings at known distances. Destructive analytical techniques may also be employed to examine the chemical composition of a propellant sample. Previous work has shown that some firearm propellants exhibit weak fluorescence (Elworthy, 1996).

Chemical imaging detects light intensity as a function of wavelength and as a function of location, effectively combining molecular spectroscopy and digital imaging. The potential for the use of visible and near infrared chemical imaging in forensic applications has been demonstrated previously (Exline et al., 2003; Payne et al., 2005a; 2005b; 2007). Various applications include fingerprint detection, ink analysis, and bruise age estimation.

In terms of firearm propellant analysis, chemical imaging provides the advantage of being able to examine spectral data simultaneously with visualising the shape, size and spread of propellant particles. The technique also has the benefits of being fast and non-destructive, with the ability to analyse particles in situ.

This study investigated the potential use of fluorescence chemical imaging for the detection and analysis of firearm propellants.

Materials & Methods

Instrumentation

The chemical imaging instrument used in this study is the Visible / Near-Infrared (VIS/NIR) Condor chemical imaging macroscope (ChemImage Corp., Pittsburgh USA). The instrument is capable of scanning from 400nm to 1100nm through the utilisation of two liquid crystal tunable filters (LCTFs). The VIS/NIR Condor also incorporates a 1024x1024 back-illuminated charged-coupled device and a 16:1 macro zoom lens. The combination of a variable filter and digital camera allow for images and spectral information to be collected concurrently.

Sample Preparation

A variety of .22 rimfire ammunition was selected for the study. The selection of ammunition covered several brands, produced from many different countries. The bullet from each cartridge was removed and the unfired propellant grain was sampled. The unfired propellant was placed on black cloth for chemical imaging analysis.

An initial study was also carried out to determine if it was possible to detect and collect spectral data for fired propellant. Test firings were carried out using one of the ammunition samples included in the unfired propellant study (Winchester Super Speed, Super X). The ammunition was fired at a distance of 300mm onto a black cloth target using a S&W Model 63 revolver.

Data Collection – Unfired Propellant

The unfired propellant was examined using the VIS/NIR Condor. Data was collected using multiple excitation wavelengths and appropriate observation settings as listed in Table 1. A bandpass filter was placed between the light source and sample (Filter 1) and a longpass filter between the sample and the optics (Filter 2) to remove artefact peaks.

Excitation	Start	End	Steps	Exposure	Filter 1	Filter 2
415 nm	470 nm	1100 nm	10 nm	10 sec	415 nm	455 nm
450 nm	530 nm	1100 nm	10 nm	10 sec	450 nm	495 nm
505 nm	550 nm	1100 nm	10 nm	10 sec	505 nm	550 nm

Table 1: VIS/NIR Condor conditions

The resulting datasets were examined and spectral information extracted. A region of interest (ROI) was selected over 5 propellant grains for each ammunition to determine the variation within the samples. Each ROI produces a spectrum, which is the average for all the spectra in that region (each pixel has its own associated spectrum). The 5 spectra were then averaged to produce a representative spectrum for each ammunition sample. The spectra were imported into Microsoft Excel and plotted on the same scale.

Grouping of the resulting spectra was achieved through visual examination. Features such as general shape and peak positions were used to determine the groups.

Data Collection – Fired Propellant

The cloth target, after firearm discharge, was examined using the VIS/NIR Condor, utilising the same conditions as described above. The spectra of detectable grains were extracted and imported into Microsoft Excel for comparison with the unfired results for that ammunition sample.

After data had been collected from the black cloth, an SEM stub with a sticky carbon tab was used to collect debris from around the hole. The SEM stub was then examined using the VIS/NIR Condor, using the same conditions.

Results & Discussion

Unfired Propellant

Fluorescence emission spectra for the propellants were reproducible between grains within the same ammunition sample. Figure 1 demonstrates the typical variation that was observed between 5 different propellant grains.

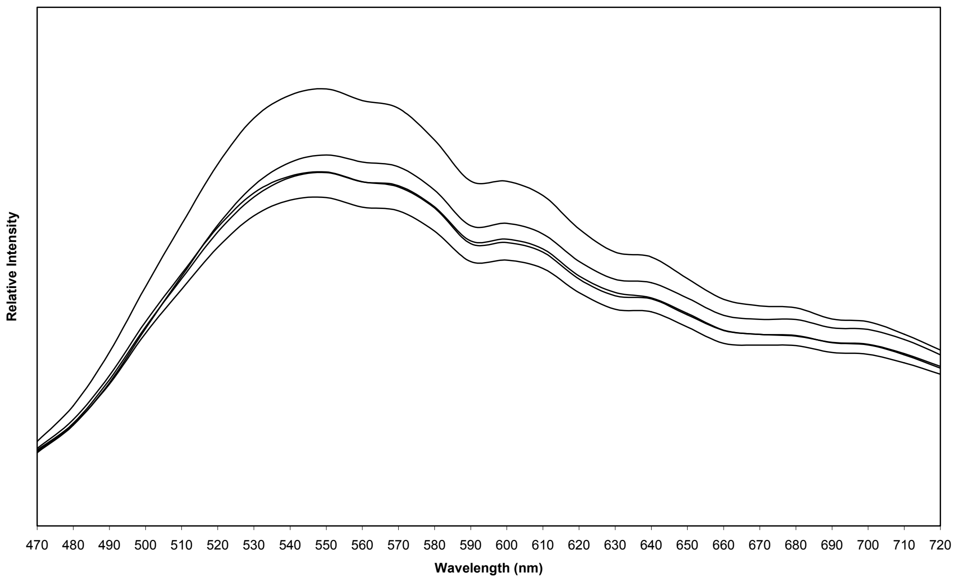

Figure 1: Variation of uncorrected fluorescence emission spectra for 5 propellant grains from a round of IMI Civic ammunition (415nm excitation)

It must be noted that the following groupings are initial results only and that the number of groups may change with the analysis of further propellants. 18 ammunition samples that produced clear, repeatable results were used for the initial groupings.

At 415nm excitation, the propellants could be divided into 3 groups based on spectral characteristics. Group A was defined as having 2 distinct peaks at approximately 540nm and 700nm. Group B had a single distinct peak at approximately 550nm. Group C was relatively featureless with no distinct peaks. Of the 18 propellants analysed, 10 were consistent with group A, 4 consistent with group B, and the remaining 4 consistent with group C.

Using 450nm excitation, the propellants could be divided into 4 groups based on spectral characteristics (Figure 2). Group A was defined as having 2 distinct peaks at approximately 560nm and 700nm. Group B had a single distinct peak at approximately 560nm. Group C had a major peak at approximately 700nm. Group D was relatively featureless with no distinct peaks. Of the 18 propellants analysed, 4 were consistent with group A, 4 consistent with group B, 6 consistent with group C, and 4 consistent with group D.

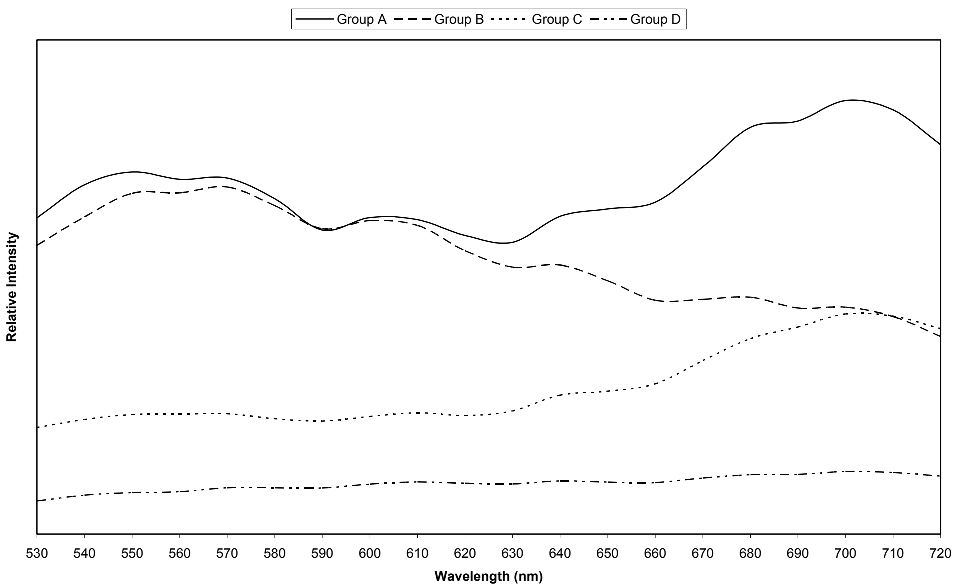

Figure 2: Examples of uncorrected emission spectra for each group using 450nm excitation

The results observed using 505nm excitation allowed the propellant to be divided into 2 groups based on spectral characteristics. Group A was defined as having a single distinct peak at approximately 700nm. Group B was relatively featureless with no clear peaks. Of the 18 propellants analysed, 10 were consistent with group A, and 8 consistent with group B.

The discriminating power for the initial groupings was found to be 0.63, 0.78 and 0.52, for 415nm, 450nm and 505nm excitations, respectively. There was discrimination within brands and also between different brands. The combined discriminating power of all excitation wavelengths was found to be 0.78, the same as 450nm excitation.

Fired Propellant

Initial results indicate that it is possible to detect and analyse unburnt or partially burnt propellant after it has been fired from a weapon. Figure 3 demonstrates the similar emission spectra produced for unfired and fired propellant when examined using 505nm excitation.

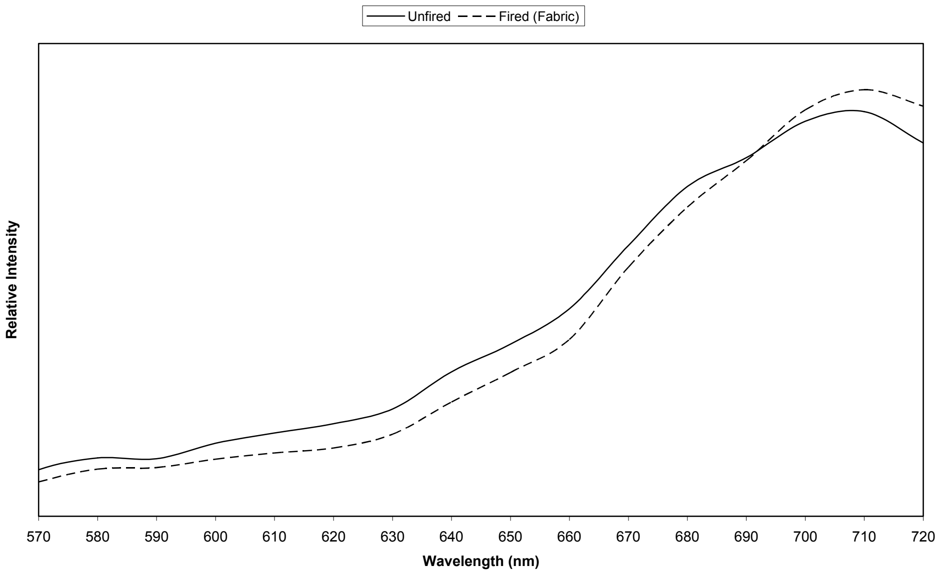

Figure 3: Uncorrected fluorescence emission spectra of Winchester Super Speed, Super X (505nm excitation) unfired and fired onto black cloth

Even if an item has already been sampled for GSR using an SEM stub with a sticky carbon tab, propellant fluorescence analysis is still possible. Figure 4 demonstrates how a stub, loaded with debris such as fibres and soot, can be scanned for the presence of fluorescent propellant particles, which are clearly visible against the dark background of the carbon adhesive.

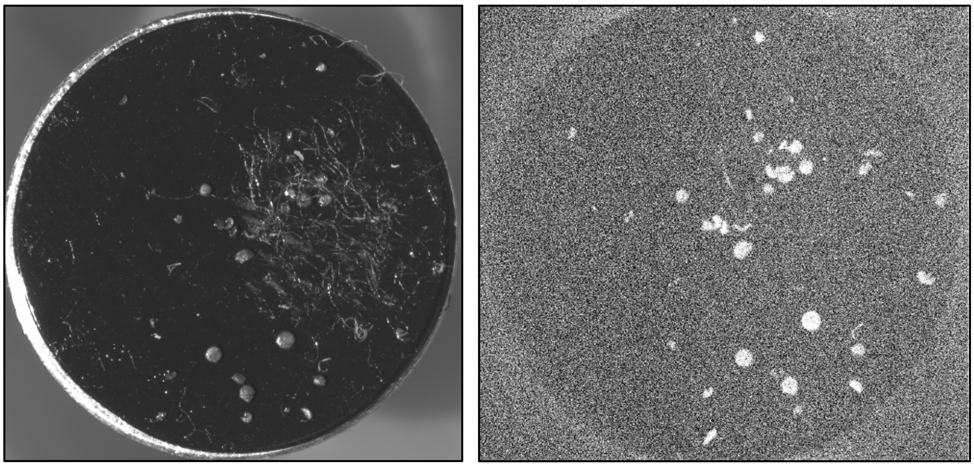

Figure 4: Photo showing propellant grains collected using an SEM stub (left) and image extracted at 630nm (450nm excitation) showing fluorescent propellant grains (right)

The spectral results obtained from propellant on a SEM stub are also similar to those obtained from unfired propellant and fired propellant on black cloth. Figure 5 shows that, even though there are slight differences, all of these results would be classified in the same group (450nm - group C).

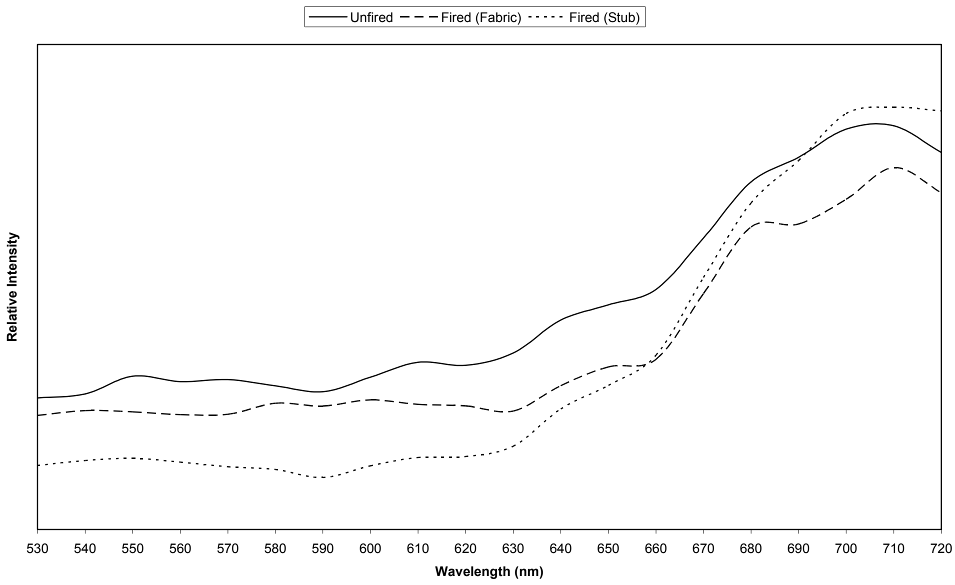

Figure 5: Uncorrected fluorescence emission spectra of Winchester Super Speed, Super X (450nm excitation) unfired, fired onto black cloth, and grains collected on an SEM stub

Future Work

This study is part of an ongoing research project investigating the potential use of chemical imaging for a range of forensic applications.

Future work specifically directed at the detection and analysis of firearm propellants will involve the grouping of a larger number of unfired propellants. A more extensive study will be completed on the potential for the recovery and analysis of fired propellant, and comparisons between fired and unfired samples. Blind tests will also be completed as part of the validation process.

Conclusions

Preliminary results show that chemical imaging is able to distinguish between some brands of ammunition using fluorescence spectra while simultaneously recording the shape of propellant grains for comparison against reference samples in a database. Further discrimination of propellants within brands is also possible using this method.

In addition, results indicate that fluorescence data from unfired propellants can be compared to the data from propellant particles recovered after test firings to assist in the inclusion or exclusion of possible sources.

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