Broadband Terahertz Time–Domain Spectroscopy of Drugs-of-Abuse Mixtures and 'Street' Samples.

Andrew D. Burnett[a*], Wenhui Fan[a†], Prashanth C. Upadhya[a‡], John E. Cunningham[a], Michael Hargreaves[b], Tasnim Munshi[b], Howell G. M. Edwards[b], Edmund H. Linfield[a] and A. Giles Davies[a].

[a] School of Electronic and Electrical Engineering, University of Leeds, Leeds LS2 9JT, UK.
[b] Division of Chemical and Forensic Science, University of Bradford, Bradford BD7 1DP, UK.

***Abstract*—Terahertz time-domain spectroscopy is used to analyze a number of real-world drugs-of-abuse samples, common drug adulterants, and drugs systematically adulterated in the laboratory. Principle component analysis is used to cluster spectra of similar compounds, which could lead to automatic spectral recognition of illicit materials.**

I. Introduction And Background

One of the aims in the development of terahertz time–domain spectroscopy (THz-TDS) has been to investigate its potential for detection of illicit materials for security applications.[1] Over the frequency range 0.1–8 THz, a number of relevant explosives and drugs-of-abuse have spectral features which can uniquely identify the compound. However, many of the samples that have been analyzed to date have been pure compounds, or compounds diluted with a single transparent matrix material, which are unlikely to be representative of samples seized in a real world situation. In the case of plastic explosives, it has previously been shown that many of the various non-explosive additives (such as stabilizers) fortuitously show little contribution to the overall terahertz spectra, enabling the explosive constituent(s) to be identified by THz-TDS, even in a complex mixture.[2]

Illegal drugs are rarely seized in their pure pharmaceutical form but contain impurities arising both from the manufacture process together with adulterants or 'cutting agents' deliberately introduced to dilute the drug to increase profit. This paper investigates a number of common drug adulterants to determine if they could contribute to the THz spectra, potentially confusing drug identification. We also studied genuine 'street' samples confiscated by UK police and customs, together with 'home made' 'street' samples in which cocaine hydrochloride was mixed systematically with known adulterants. All measurements were performed using a broadband THz-TDS system described previously elsewhere[2] with a LT-GaAs photoconductive emitter with a gap size of 400 μm and a 150-μm-thick GaP electro-optic detector.

II. Results

Pure undiluted pellets of eleven common adulterants (benzocaine, benzoic acid, caffeine anhydrous, diltiazem, D-mannitol, griesofulvin, hydroxyzine dihydrochloride, lactose (both anhydrous and monohydrate), lidocaine, and teramisole hydrochloride) were made and the THz spectra recorded – many showed a number of spectral features.

Six cocaine hydrochloride samples, six heroin samples and six ecstasy samples provided by the Forensic Science Service (FSS), were also analyzed. The concentration of drug in each of these seized 'street' samples varied considerably (anywhere between 13% and 80%), with the remainder of the sample comprising impurities and adulterants.

Twenty-four cocaine hydrochloride samples were made in the laboratory, each with a mass concentration of 60% cocaine and the remaining 40% comprising adulterants. Eight samples comprised two component mixtures (the drug and one adulterant), eight samples comprised three component mixtures (the drug and equal amounts of two adulterants), six samples comprised four component mixtures (the drug and equal amounts of three adulterants), and two samples comprised five component mixtures (the drug and equal amounts of four adulterants). These samples were then further diluted with PTFE at four different concentrations, and sample pellets prepared (96 pellets in total).

It was found that for almost all of the cocaine samples (both 'street' and 'home made'), the drug was easily identifiable owing to the strong intensity of the spectral features arising from cocaine hydrochloride. However, for the ecstasy and heroin seized 'street' samples, identification of the drug was very difficult owing to the weak spectral features associated with the drug, and the strong and overlapping spectral features arising from the adulterants.

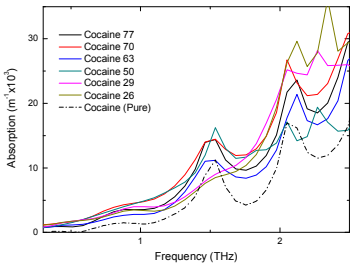

Figure 1: Terahertz spectra of the six 'street' samples of cocaine hydrochloride compared with a spectrum of pure cocaine hydrochloride.

The cocaine spectra were further compared with the spectra of a number of pure drugs using principle component analysis (PCA). Multivariate data analysis was performed using Eigenvectors PLS_toolbox 4.11[3] within Matlab.[4] Pre-processing of

* A.D.Burnett@leeds.ac.uk
† current address: State Key Laboratory of Transient Optics and Photonics, Xi'an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences, Xi'an, Shaanxi 710119, CHINA.
‡ current address: Centre for Integrated Nanotechnologies, Los Alamos National Laboratory, Albuquerque, NM 87185-1315, USA.

978-1-4244-2120-6/08/$25.00 ©IEEE.

the data was performed on the data to reduce inherent noise within the spectra from instrumental or sample variability. First, a Savitsky-Golay[5] smoothing filter was applied using a five-point smoothing window and a second-order polynomial deconvolution. This does not distort the spectra but smoothes the shape of the curves, artificially reducing noise in the spectra. Second, standard normal variate (SNV)[6] was applied to the spectra. This is a normalization method which uses the spectrum itself for correction. It first calculates one mean and one standard deviation value for the entire spectrum and then subtracts this mean value from each spectral point before dividing it by the standard deviation. The effect is to centre the midpoint of the spectrum at zero, and standardize the entire spectrum to its overall variance. This has the effect of reducing differences in baseline and peak intensity between samples. Finally, the data were mean centered, which centers the data around a central point.

The data chosen contained spectra of the 100% by weight pellets of all the 24 'home made' 'street' samples, spectra of the six cocaine seized 'street' samples (seen in Figure 1), spectra of the non-diluted pellets of three pure drugs (cocaine free base, cocaine hydrochloride and morphine sulfate pentahydrate), and the spectra of the 23.5% by weight pellet of heroin and the 19.5% by weight pellet of MDMA. The data were taken over the spectral range 0.3 to 2.2 THz, so the spectra were truncated before the noise floor in all cases. The data were then pre-processed and placed into the PLS_toolbox software and PCA was performed.

The first three principle components (PCs) of the first data set – PC1, PC2, and PC3 – were found to describe 79.9% of the data, and the first eight PCs described 98.4% of the data. A plot of PC1 versus PC2 versus PC3 can be seen in Figure 2. The cocaine hydrochloride samples can be seen mainly clustered on the left hand side of the figure, well separated from many of the other drug samples.

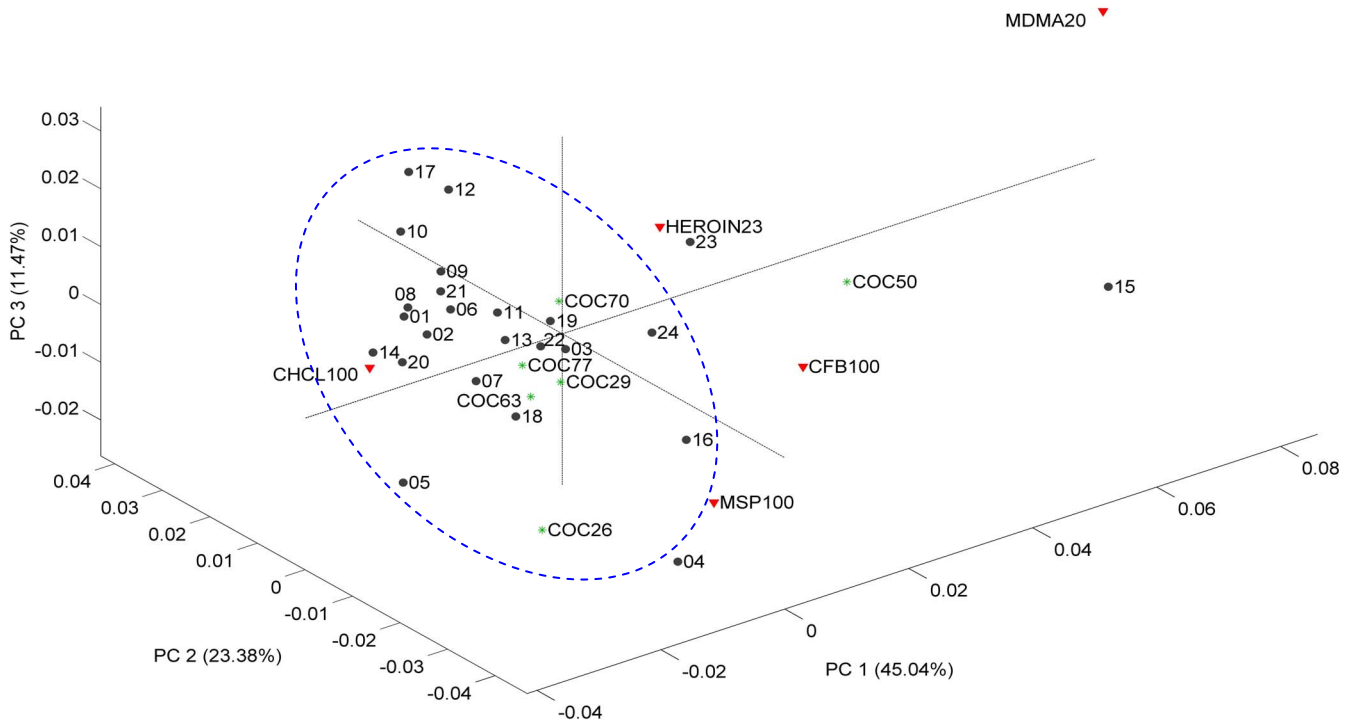

Figure 2: A 3D score plot of PC1 versus PC2 versus PC3. This gives a clear illustration of how this analysis clusters together most of the samples containing cocaine on the left hand side of the plot (circled by the dashed line).

In conclusion, a number of pure and adulterated drugs-of-abuse were analyzed using THz-TDS, and PCA was then used to determine the identity of the drug within the mixture via unsupervised spectral recognition. This demonstrates that PCA could be a valuable tool for the analysis of terahertz spectra.

We acknowledge the support of the EPSRC, RCUK, EC project *TeraNova*, HMGCC, DSTL, HOSDB, and the FSS.

REFERENCES

[1] A. G. Davies *et al.*, Materials Today **11**, 18–26 (2008).
[2] W. H. Fan *et al.*, Applied Spectroscopy **61**, 638–643 (2007).
[3] B. M. Wise *et al.*, PLS Toolbox 4.11 (Eigenvector Research Inc. 2006).
[4] The MathWorks Inc, Matlab 2006b (2006).
[5] A. Saviitsky *et al.*, Analytical Chemistry. **36**, 1627 (1964).
[6] R. J. Barnes *et al.*, Applied Spectroscopy. **43**, 772 (1989).