Optical sensing in context: a twenty-five year retrospective

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ABSTRACT

The author has reviewed the Proceedings archive, and has selected a number enduring themes from the nearly 750 papers submitted across twenty-four years. The author believes these themes serve as important touchstones for the successful development of future capabilities to address CBRNE challenges, whilst admitting a personal bias towards spectroscopic methods for chemical sensing and imaging. Taking a historical perspective reveals impressive developments in foundational and underpinning aspects, as well as novel sensing techniques and their applications; it also provides context to the issues identified, from which lesson can be learned. The author also shares their personal view on the value of the Conference to the community of practice that it brings together.

Keywords: Review, retrospective, context, CBRNE, sensing

INTRODUCTION

Late in 2023 the Organizing Committee offered the author an opportunity to provide a personal retrospective on optical sensing spanning the near twenty-five years of the CBRNE Sensing conference. Having said yes, the size of the task then became apparent. First, the sheer scale of source material available in the Conference archive: some 750 papers, not counting supporting presentations or posters. Second, the extended period in question, that spans the entire working career of some Conference attendees, and includes a number of world events of direct and profound relevance.

For reference, the author's exposure to these events began in the late 1990s, on joining the UK Ministry of Defence's science & technology organization (previously DERA, now Dstl) focused initially on chemical defense at Porton Down - noting the original Conference was ChemBio-focused, before its natural and welcome extension to include other aspects of countering the broader CBRNE threat space.

Given that the Conference archive is such a rich and deep source, it became clear that the only reasonable way to create something of value would be to constrain the scope, through being highly selective – leaving the author open to justified criticism, but also paving the way for additional, alternative narrative from different perspectives; a notion the author finds exciting. The author recommends that others are encouraged to come forward with different perspectives in future reviews, especially those colleagues who have taken a different path through countering weapons of mass destruction (CWMD).

The current paper is therefore offered as an overarching summary generated by sifting the archive, incorporating supporting context, and offering an individual perspective in addition to the learnings already captured. Special mention must be made of the excellent review already presented at twenty years in 2019 by Way Fountain [1], a lynchpin for this Conference for many years, who also captures other key contributors' outstanding efforts in his review. In one sense, his paper might only leave the current author five years to review - albeit five very eventful years. However, the Organizing Committee did not constrain the author in that respect, and full advantage of that freedom has been taken.

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It is inevitable that personal biases emerge from inclusion of individual experience. All opinions expressed herein are those of the author themselves and should not be considered the views or policies of Dstl, the UK Ministry of Defence or wider UK Government. The author alone likewise accepts responsibility for all oversights and partiality of interpretation.

Boundaries and constraints play their part. The author addresses operational context through an open-source perspective, and confidentiality by restricting discussion to material fully in the public domain, placed there by the intellectual owner of the material. All copyright owned by third parties is likewise acknowledged and respected.

The other constraints on the author are purely practical – time and space do not allow deep referencing, developed explanations or extended justification. The many connections between this Conference and others with aligned themes also deserve to be explored: in the author's opinion such connections are vital, as they lead to different perspectives on shared technologies, or provide the audience with exposure to different applications of those technologies.

APPROACH

In addition to the full archive of submitted papers, the structure and composition of each Conference was reviewed, in terms of Sessions offered and papers presented; this somewhat meta-analytic approach sat alongside consideration of some key historical events, to form a backdrop and provide a frame of reference, allowing a qualitative form of longitudinal analysis. Appendix one provides hypertext links to each of the previous twenty-four previous meetings that can be accessed via the SPIE Digital library, for ease of reference.

OVERVIEW OF RESULTS

Taking a longitudinal view reveals the dynamic nature of the Conference: it has regularly incorporated new thematic Sessions focused on an emergent technology or application, alongside enduring sessions detailing steady improvements borne of long-term development. This demonstrates one of the key values of an enduring Conference – that deeper themes (foundational, underpinning) are captured in context over time, whilst others emerge in response to developments in S&T, and to events in the world.

Since 2016 alone session on quantum technology, integrated platforms, integrated systems, remote & distributed systems, modelling & simulation, signatures & algorithms, sampling & presentation, integrated photonics, photonic integrated circuits & plasmonics, and vapor & aerosol sensing have sat alongside those with more traditional hazard-based focus (chem, bio, explosive, rad & nuc) or detection methodology (point, proximal, remote, stand-off - passive or active, imaging or otherwise). The author strongly recommends that the reader does not read too much into these simple titles as the Sessions often contain material of great complexity and are often hugely diverse.

Observing the record in this way also reveals different strands of effort. The first is the consistent and diligent approach taken to address some of the most challenging foundational issues. Two areas illustrate this well: the definition of test & evaluation standards, and associated test capability developments; and the development & application of techniques in spectrometry to establish quantitative optical signatures of hazardous materials.

Persistence is vital to deliver technically excellent outcomes in these areas - and this speaks to the need for continuity. So immediately we see another benefit of this Conference as a forum, in bringing these foundational efforts to early-career colleagues who may in turn become inspired to join those ongoing campaigns.

The same case can be made for organizations and institutions that have championed different sensing modalities over the years, moving them forwards with new discoveries, incorporating enhanced critical components as they become available, as well as developing deeper theoretical understanding and evolving the base techniques into fieldable approaches. Several point and remote sensing modalities fall into this category: photoacoustic, photothermal, Raman and laser-induced breakdown spectrometry all offer good examples – as do many other forms of spectrometry and imaging.

A further theme that emerges is diversity, as measured (amongst other possible metrics) by the agencies engaged, technical approaches discussed, applications described, user communities in attendance, operational environments

considered, and desired outcomes explored. The breadth is quite remarkable, and is again a strength – even without considering the further connectivity offered through co-location in Symposia with other Conferences.

This breadth and depth leads to complexity; but that in turn can lead to the emergence of novel solutions and even to disruptive concepts. The author remembers conversations around posters, coffee dispensers, at evening receptions, and in hotel bars where (increasingly) novel approaches have been sketched-out. These conversations – an experience shared by many – are examples of connectivity and networking within a community of practice, for which the Conference provides a cornerstone.

That complexity can also be a little impenetrable for the first-time attendee, who may not have an extensive network. The author fondly remembers needing to be in three places at once on several occasions. They also remember with grateful thanks members of the community willing to make introductions to further expand their network.

3.1 Areas of endeavor

Using a prism of world events that includes (but is not limited to) conflict in Iraq, former Yugoslavia, Afghanistan, and Syria, the author identified the following themes that might be considered as drivers:

- The need to understand the dynamic hazard presented by release of materials – such as those associated with toxic industrial materials released to air - on different scales and in different contexts: initially the ability to predict and to monitor releases at refinery scale, for protection of a military force or the wider public.

- Evolution of concerns from large scale to smaller scale, with changes of context and actors – potentially the use of materials typically associated with warfighting.

- The diversification of materials that might be of concern, whether that be TICs, potent pharmaceuticals with a toxicological profile like warfare agents, or a broader range of materials specifically prohibited by the CWC.

- A broader range of operational contexts – including a much greater focus on the urban and the austere, across all climatic conditions, with correlated changes in typical atmospheric background (chemical profile).

- Coupled to operational contexts, a diversified set of deployment options to allow a flexible, scalable response – including high-mobility dismounted options, as well as protected mobility.

- Protection of fixed infrastructures, in military and civilian contexts.

- Addressing the distinct needs of different user communities who are using similar capabilities – recognizing differences in the materials of concern to first response and law enforcement, vice those encountered on operations overseas, as well as the differing operational contexts.

- Notwithstanding the increased diversity of challenge and range of operational environments, a desire for presumptive (balance of probabilities) identification to name level whilst in-field.

- Detection of materials associated with production and use of high-hazard materials other than the weaponized end-products themselves, that function as indicators of their production and use.

- An increasing interest in forensic investigation/materiel exploitation, including biometrics, and their recovery from complex mixed hazard samples.

- Understanding the value of adopting UXVs / ROVs: exploring the rational incorporation of uncrewed vehicles – remotely-operated and to a lesser (but increasing) extent autonomous – in high-hazard activities or environments.

- Exploring the impact of data fusion in management of cognitive burden, and the associated requirements on sensor hardware configuration and networking.

This list is far from exhaustive - and although it suffers from the parochialism of the chem-centered author, it is resonant with and reflected across CBRNE.

3.2 Enduring themes

These driving themes provide challenges that in turn create huge opportunities for innovation, encouraging exploration and development by (and includes collaboration between) academic, industrial, government S&T and operational communities – the author notes responding themes that include:

- Defining the hazard's properties, to allow meaningful test and evaluation of capabilities, and development of appropriate techniques – particularly the determination of spectral properties of all states, and associated physicochemcial parameters of relevance such as particle size and shape distribution, in the case of aerosols.

- Defining test protocols that allow capabilities to be robustly assessed, irrespective of sensor, its platform, or the nature of the challenge (solid thru liquid to gases, vapors, and aerosols) – with different strands tailored to specific needs for different hazards.

- Development of existing or novel sensing modalities that better address evolving operational demands such reduced SWaP (hand-held, battery-powered) or address increased diversity of challenge (reconfigurable libraries, sampling devices and inlet adaption options for phase transformation) or lower-cost, wider scale of issue, potentially attritable systems.

- Enhanced algorithms that accommodate expansion of libraries without explicit requalification; or provide improved detection statistics notwithstanding challenging operational environments; or reduce the volume of data transmitted across networks whilst maintaining meaning in context (compressive techniques, multivariate computing)

- Networking and data fusion for reduced cognitive load on decision makers, to manage traffic on sparse nets, for insertion into the wider ISR/FP enterprise, or to facilitate remote access/telepresence/AR for support to operations

- Development or emergence of component-level enablers to reinvigorate progress, by overcoming a previously identified limiting factor – obvious examples include both deep UV and mid IR laser technologies in the context of deployable compact high-power sources.

- Exploration of novel emerging sensing modalities and technologies – such as interest in so-called quantum 2.0 technologies, including magnetometry, ghost imaging, and down-conversion

- Emergence of the concept of proximal sensing – remote detection using stand-off means at operationally-relevant shorter ranges, informed by the missions undertaken in the broader context of today.

- Emergence of novel thinking around achieving stand-off, through remote sensing – as an example, the deployment of point and proximal sensors on robotic crew-served or autonomous platforms, to overcome non-sensor-related challenges (scenario-based limitations) – that offer additional modalities alongside more traditional longer-range, direct standoff approaches.

- Emergence of spectral imaging techniques with high frame rates, spectral and spatial fidelity, in form-factors and using operating principles suitable for deployment on different platforms for different purposes

- Deeper integration of sensing capabilities on UXVs with advanced capabilities (telerobotics with haptics, autonomy as cognitive burden reduction) to provide force multipliers and/or conduct operations in less-permissive/high-hazard environments

There are of course numerous examples where Conference submissions are not specifically or directly correlated with an obvious operational context or problem; instead, they serve to open the community's awareness to innovative ideas, technologies, or applications - whether novel, emerging or previously overlooked (NEO). The role of the wider community is then to imagine what opportunities might arise from these submissions, and so begin the process of exploration and development, with the added context of operational need.

DISCUSSION

The author believes that the themes identified are resonant with current interests, and are supported by an archive that serves both as a contemporaneous historical record and as a benchmark for future efforts. But a key purpose of this review is to encourage debate, complaint, counterclaim, criticism, and presentation of alternative perspective that the Conference is designed to (respectfully) promote. Such responses speak to a vibrant, engaged community of experts - one from which the next generation of thought-leaders can emerge.

It is also clear that each element of the S&T community plays its distinctive part, through offering context from different perspectives. In creating a diverse community of partners, the Conference provides an excellent platform for cross-fertilization. The author would expect that the attendance statistics for the conference to reflect this, although defers to the Organizing Committee for detailed analysis.

The Conference has clearly always embraced change - different foci emerge as required, such as when world events give rise to new challenges, and the science & technology community respond in turn. In rare quieter periods, the organizing committee have shaped the sessions to offer different perspectives on well-trodden themes. They have blended the need for continuity with the need for adaption, in a deft manner: no doubt requiring a good deal of pragmatism.

One of the more subtle but still noticeable changes over the last twenty-five years has been emergence of a counter-WMD narrative with an additional focus on S&T in support of counter-proliferation, to aide in preventing the use of offensive CBRNE capabilities. We see development of capability intended to support prevention of use (reduction of likelihood) alongside more traditional capabilities designed to respond to use (reduce impact) and aide recovery. In this, it is important to avoid potential confusion between preparedness and prevention: being prepared to respond is part of a spectrum of prevention elements, through demonstrating credible deterrence; but is not complete of itself.

In reviewing the archive there are occasional uses of terminology that gave the author pause. For example, the term threat is sometimes used where hazard seems the more appropriate, when referring to materials. The author was pleased to find the archive free from the (hard-to-justify) notion of standing-down capability designed for previous generations of material. Using descriptors such as legacy or historic for earlier generations of hazardous materials should probably be limited to the context of munitions, as the materials may still be relevant in contexts other than their original intended use.

4.1 The future

Sensing a wider range of materials across a wider range of environments remains a source of exciting challenges. New approaches will emerge, some based on those already captured in the archive, alongside rational combinations of technologies that operate synergistically, and more evolutionary developments in existing methods. Sensor fusion methodologies and data analytics employing machine learning will continue to unlock significant benefits.

Taking a broader perspective, connectivity between CBRNE Sensing and wider ISR enterprise are evident, through shared interests in sensing technologies such as hyperspectral sensing and imaging; these synergies seem particularly clear in the Prevent space. Maintaining clear lines of communication between the communities that support these enterprises will ensure that best value is realized by both, and that a strong cross-fertilization of technologies continues.

It is also interesting to consider what skill-set the CBRNE expert of the future might be advised to invest in. The author believes they would benefit from a formal background in systems engineering/systems thinking – whilst being well-versed in data science, particularly machine learning, should be taken as read.

The complexity of S&T involved in addressing the issues laid-out in the themes above is self-evident; but it is also replicated across other crucial lines of development involved in creation of capabilities – be they test & evaluation, operator training, logistic support, development of tactics techniques and procedures, and so on. A deep expertise in specific sensor technology may be an S&T prerequisite – but it is unlikely to be sufficient in capability development terms.

A word in this section must go to a matter close to the author's heart: enhancing the provision of scientific advice to operations. Engagement with subject matter experts who understand operational context can offer real benefit to operational communities. This may involve embedding scientists, or remote access via reachback through secure communications, or both.

Deeper analysis of the questions routinely asked via existing reachback channels has always proven very valuable – to understand why a particular question was asked, as well as understanding the question itself - thereby better understanding the context of the request, and better able to identify where the appropriate remedy lies, in capability terms – enhanced operator training, more robust reachback mechanisms, optimizing techniques, or new equipment sets.

In the simplest cases, effective reachback requires sensor outputs to be routinely transmissible over available networks. Despite great strides already made in user interfaces and networking, the author believes there are further gains to be made, specifically around providing resilient reachback – essentially making the process automated in the background, essentially invisible to the operator.

This area is also ripe for further investigation of human-machine teaming, augmented reality and telepresence, which may in turn create the possibility of a virtual, forward-projected science advisor. In capability terms, this could act as a force multiplier – allowing engagement across a far greater number of operational scenes than might otherwise be possible in-person.

But the final word goes to people: because people are at the heart of the communities we serve – the end-users who benefit from the S&T we deliver, and in turn employ that S&T in serving their communities, that we in turn form part of.

The author believes that engagement, networking, and shared experience are crucial enablers in generating our community of practice, and especially for generating interest within and developing the expertise of early-career scientists, who will become the leaders of the future: this requires opportunities for the community to engage, to develop understanding of context, and gain shared perspective. In that respect, the SPIE CBRNE Sensing conference has played – and continues to play – a very important role.

CONCLUSION

In conclusion, the author believes that the Conference archive captures multiple examples that demonstrate the value of optical techniques in CBRNE Sensing. It also represents an important and continuing contemporaneous record of S&T developments, in response to evolving requirements influenced by world events; and that its analysis offers insights that have current relevance for scientists, technologists and capability developers.

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Sensing or provide opportunities to put theory into practice across a 25-year career. This conference paper is recorded for Dstl's Athena collection with DIIS identifier DSTL/CP158125. The manuscript is marked UK OFFICIAL (see Government Security Classifications - GOV.UK (www.gov.uk) for details).

REFERENCES

[1] A W Fountain III "CBRNE Sensing at 20 years: A Retrospection and Prospects for the Future", Proc SPIE 11010, CBRNE Sensing XX (2019)

APPENDIX 1 – SPIE DIGITAL LIBRARY TOC LISTINGS BY YEAR

Table 1. CBRNE Sensing conference Table of Contents pages from SPIE's Digital Library (2000-2023).

Year	Hyperlink
2000	https://www.spiedigitallibrary.org/conference-proceedings-of-SPIE/4036.toc
2001	https://www.spiedigitallibrary.org/conference-proceedings-of-SPIE/4378.toc
2002	https://www.spiedigitallibrary.org/conference-proceedings-of-SPIE/4722.toc
2003	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/5085.toc
2004	https://www.spiedigitallibrary.org/conference-proceedings-of-SPIE/5416.toc
2005	https://www.spiedigitallibrary.org/conference-proceedings-of-SPIE/5795.toc
2006	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/6218.toc
2007	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/6554.toc
2008	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/6954.toc
2009	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/7304.toc
2010	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/7665.toc
2011	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/8018.toc
2012	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/8358.toc
2013	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/8710.toc
2014	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/9073.toc
2015	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/11749.toc
2016	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/9824.toc
2017	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/10183.toc
2018	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/10629.toc
2019	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/11010.toc
2020	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/11416.toc
2021	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/11749.toc
2022	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/12116.toc
2023	https://www.spiedigitallibrary.org/conference-proceedings-of-spie/12541.toc