A Review of Millimetre-Wave and Terahertz Technology for Detection of Concealed Threats

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Abstract—**There has been intense interest in the use of millimetre-wave and terahertz technology for the detection of concealed weapons, explosives and other threats. This paper reviews the progress which has been made in recent years and identifies the challenges and prospects for these technologies in checkpoint people screening, stand-off detection of person-borne improvised explosive devices (PBIEDs) as well as more specialized screening tasks.**

Index Terms— **Millimetre wave, Millimeter wave, terahertz imaging, terahertz spectroscopy, security screening, explosives detection, stand-off detection**

I. Introduction

THE increased threats of criminal or terrorist action in recent years have led to development of many techniques for detection of concealed weapons, contraband, explosives or other objects. Systems based on electromagnetic radiation between 30-300GHz in the millimetre-wave and 300GHz-3THz in the terahertz region [1] have particular advantages that:

- Radiation penetrates many common barrier materials enabling concealed objects to be seen;
- Wavelengths are short enough to give adequate spatial resolution for imaging or localisation of threat objects;
- Radiation at these frequencies is non-ionising and, at modest intensities, safe to use on people.
- At terahertz frequencies some materials such as explosives have characteristic spectra which can be used to identify them

Concealed-threat detection applications include screening of people, screening for people such as stowaways and mail screening. These focus on detection of metallic and non-metallic weapons and explosives in aviation security and protection of sensitive facilities; detection of contraband by customs authorities and stolen items in loss-prevention applications; as well as stand-off suicide bomber detection and detection of weapons carried by potential intruders or assailants. Mail screening applications include detection of drugs-of-abuse.

Detection of hidden objects depends on the transmission of radiation through barrier materials as well as through the atmosphere. At millimetre wavelengths the atmosphere and many barrier materials are relatively transparent and differences in the thermal emission and reflection of hidden objects and the body provide image contrast.

At terahertz wavelengths materials absorb more strongly and refractive indices tend to be lower leading to smaller reflectivity. The increased absorption is due both to resonances in the materials and scattering by the microstructure of many substances. In addition, many crystalline solids including common energetic compounds (e.g. RDX, PETN, HMX, TNT) exhibit resonances due to intermolecular, phonon modes. The features are broad, several tens of GHz wide, however a typical organic solid may have between 2 and 6 features in the frequency range 0.5–3THz which can serve as an effective fingerprint. Practical detection systems operate in reflection geometry where the spectral features due to the resonances are weaker but still visible.

II. Millimetre-Wave State-of-the-art

Developments of millimetre-wave systems over a number of years have recently led to commercial mm wave systems, mainly operating at 30GHz or 94 GHz. This has largely been enabled by the availability of monolithic millimeter-wave integrated circuit (MMIC) low noise amplifiers at frequencies up to 94GHz. Approximately 10 vendors have systems on the market designed for a range of checkpoint and stand-off security applications. These use a range of passive radiometer and active detectors. Most use a linear array of between 8 and 128 detectors, mechanically scanned using a variety of scanning and optical configurations. The biggest change in the last 1-2 years is that these systems are starting to be deployed in operational applications. We estimate that there are approximately 250-500 systems in operation around the world.

III. Millimetre-Wave Trends and Challenges

A number of trends and challenges for millimetre-wave systems can be identified:

- Multiple system deployments – after a long period where users have evaluated and trialed individual systems, there are now several published examples of users deploying multiple systems. These include active millimetre-wave whole body imagers at Schiphol Airport in the Netherlands and the use of passive millimetre-wave cameras for contraband detection by the UK HM Revenue and Customs
- Product Differentiation – as another sign of sophistication in the marketplace, several different

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types f product have and are being developed to meet the differing requirements of specific security applications in terms of close range *vs.* stand-off, cooperating *vs*. non-cooperating subject and small (aviation security, prisons) *vs*. large (guns, PBIED) threat objects

- Active and passive systems – are both being accepted and finding use in different applications
- Automatic threat detection (ATD) – is seen as important in reducing operator cost and potential privacy concerns. It is a strong requirement for high volume applications such as screening in mass transportation. Several indoor passive systems where detected objects appear as dark or light 'blobs' have been successfully deployed with ATD. For active systems ATD is more challenging due to the 'glassy' appearance of the imagery.
- Higher frequencies – enable smaller apertures, improved detection of small and thin objects, as well as being less subject to glint from cold sky reflection in outdoor operation. However the costs are significantly higher due to the need for more advanced receiver technology
- Electronic scanning – has the potential to reduce the cost in volume and the footprint of systems. Several prototype systems have been developed and it is expected that flat-panel systems with no moving parts will soon become available.
- Integration – all sensors have their strengths and weaknesses. Programmes, such as the US Department of Homeland Security Standoff Technology Demonstration Program (SOTDP), are investigating how multiple and orthogonal sensors can be combined to realize more effective security architectures.

IV. Terahertz State-of-the-art

At the higher terahertz frequencies there has been good progress in recent years in a number of areas. Materials properties including threat, barrier and confusion materials spectroscopic features, absorption and reflection properties are now reasonably well understood. A range of source and detector technologies has been developed, mainly operating at low microwatt power range. Laboratory systems have demonstrated proof-of-principle spectroscopic detection, for example, of explosives at stand off distances around 1m, in real time.

V. Terahertz Trends and Challenges

At the lower end of the terahertz range, in what is also known as the sub-millimetre range, 300-600GHz, a number of groups are developing imaging systems to benefit from the smaller footprint and increased detectability of some objects as noted above. At frequencies above 600GHz, where material-specific spectroscopic detection of solids starts to become possible, although progress has been good and an increasing number of research groups are working in the field, significant further development is in a number of areas is needed before deployable systems can be produced:

- Source power – most of the generation techniques only produce powers in the microwatt level. Due to atmospheric absorption and the need to scan large areas quickly, significantly higher powers in the 100's of milliwatts are needed, particularly sources which are low cost and/or frequency agile. There are several promising technologies under development including quantum cascade lasers and the use of nano-engineered vacuum tube technologies.
- Detector sensitivity – sensitive and practical detectors are needed, particularly ones which can be coupled to powerful sources and provide high sensitivity coherent detection. Cryogenic cooling and the use of superconducting detectors are becoming increasingly practical due to developments in closed-cycle cryocoolers.
- Arrays – the majority of work in terahertz systems has been done with single source-detector pairs. In order to image areas at realistic speeds, detector arrays are needed. Whilst good progress has been made in microbolometer arrays, further work is needed in integration approaches to develop arrays of other detector types
- Measurement artifacts – scattering and interference effects from surface irregularities and structure in clothing and other materials on similar length-scales to the terahertz wavelength (100-500µm) can cause significant measurement artifacts. These need to be better understood and techniques developed for overcoming them.

VI. Conclusions

Developments of millimetre-wave systems over a number of years have led to commercial mm wave systems, mainly operating at 30GHz or 94 GHz, designed for a range of checkpoint and stand-off people screening applications and these are now beginning to become more widely used in the field. Higher frequencies enable more compact systems and these are also starting to appear. Before terahertz systems can be produced for operational use, further development is required, both in source and detector technology and in system architectures. Nonetheless terahertz continues to show promise as a technique for people screening due to its potential for materials specific detection, an area where few other candidate technologies exist.

Acknowledgment

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Reference

[1] M. C. Kemp 'Millimetre Wave and Terahertz Technology for the Detection of Concealed Threats – A Review', Proc SPIE 6402, 2006.