Institution:	**University of Manchester (UoM)**
Unit of Assessment (UoA):	**B10 (Mathematical Sciences)**

Title of case study:
X-ray tomography for airport security

1. Summary of the impact

RTT (Real Time Tomography) scanning systems for airport baggage are becoming increasingly important due to growing air traffic and greater security concerns. Prior to our research, Rapiscan, a leading producer of baggage scanners, had been unable to make full use of the hardware in their latest generation of scanner prototypes. Our novel theory and image reconstruction algorithms are now a core part of a commercially successful 3D scanner that is significantly faster and more accurate than previous generations. The two models, RTT80 and large RTT110, have been approved by regulatory authorities and have already been field trialled at Manchester Airport and deployed at Seattle airport**,** with further US$20m orders placed.

The research and impact described herein was flagged in the citation for the UoM's 2013 Queen's Anniversary Prize for Higher and Further Education for its work in imaging techniques to support advanced materials and manufacturing.

2. Underpinning research

The impact is based on on-going research conducted in the unit of assessment since 2007.

The key researchers were:

Professor William Lionheart (1999 – date)
Dr Marta Betcke (PDRA 2007-2010)
Dr Nicola Wadeson (PhD student 2007 – 2010, KTA intern 2012, Home Office funded PDRA 2013-)
Dr Will Thompson (PhD student 2007 – 2010, KTA intern 2010 – 2013, PDRA 2013-)

The prototype Rapiscan RTT system used a novel geometric configuration of X-ray emitters and detectors, which required the development of new algorithms to reconstruct three-dimensional images of the scanned objects from the data collected. This geometry is the result of the design of the RTT, with no moving parts, which dramatically increases scanning speed and reduces maintenance. The key insight, which formed the basis of a patent [1], was that multi-surface rebinning, a new algorithm we developed for the RTT, would lead to a faster, more accurate and more reliable reconstruction algorithms [2,3]. In addition, our research characterised the instability inherent in reconstruction from RTT data, proved a uniqueness result that demonstrates the RTT collects sufficient data for a reliable reconstruction, and lead to an optimal source firing order that improves resolution of the image [4]. A final important step was the use of Monte Carlo simulation to calculate scattered X-rays and thus develop a scatter correction procedure and simulation software that has been used as an aid to the design and development of RTT systems including the new RTT110 [5].

3. References to the research

The research has been published in the leading journal in the field: Inverse Problems, as well as in refereed conference proceedings.

Three key references:

[1] Granted Patent: M. M. Betcke, W.R.B. Lionheart, E.J. Morton. X-ray tomography system i.e. real-time tomography system, for generating three-dimensional image of object, has controller

generating three-dimensional image from reconstructed images on surface. Patent Number: WO2011008787-A1, 2011. https://www.google.com/patents/WO2011008787A1?cl=en&dq=WO2011008787

[2] M. M. Betcke, W. R.B. Lionheart. Multi-Sheet Surface Rebinning Methods for Reconstruction from Asymmetrically Truncated Cone Beam Projections. I: Approximation and Optimality, Inverse Problems, vol 29, 115003, 2013. doi:10.1088/0266-5611/29/11/115003

[3] M. M. Betcke, W. R.B. Lionheart. Multi-Sheet Surface Rebinning Methods for Reconstruction from Asymmetrically Truncated Cone Beam Projections. II: Reconstruction on Multi-Sheet Surfaces and Axial Deconvolution.Inverse Problems, vol 29, 115004, 2013. doi:10.1088/0266-5611/29/11/115004

Additional references

[4] W. Thompson, W. R. B. Lionheart, E. J. Morton. Optimization of the Source Firing Pattern for X-Ray Scanning Systems. US Patent application US20120219116 A1, 2011. https://www.google.com/patents/US20120219116

[5] N. Wadeson, E. J. Morton and W. R. B. Lionheart. Scatter in an Uncollimated X-Ray CT Machine Based on a Geant4 Monte Carlo Simulation. SPIE Medical Imaging 2010: Physics of Medical Imaging, 15-18 February 2010, San Diego, USA. doi 10.1117/12.843981

4. Details of the impact

Context

With constant growth of air traffic and greater security concerns, RTT scanning for airport baggage has become increasingly important in recent years. Current aviation hold baggage screening systems can deliver high speed and resolution, but with a high false alarm rate. Rapiscan Systems is a global leader in high quality security inspection solutions and advanced threat identification techniques, with more than 70,000 systems installed worldwide. Rapiscan reported 33% growth in revenue in 2012 and the parent company, OSI, had annual revenue of $793m in 2012 [S1].

The Rapiscan RTT scanner combines high speed, high resolution and a low false alarm rate at the first level of screening. The key to Rapiscan RTT's innovative design is that, unlike other CT baggage screening systems, it does not use a moving gantry – one revolving around the bag, typically taking 12 to 15 views. Instead, Rapiscan RTT adopts a new technology: a stationary array consisting of a very large number of micro X-ray emitters, which captures tens of thousands of views of a typical bag, therefore generating images with significantly better resolution in all planes at much greater speed, and keeping maintenance costs low [S2]. However, reconstructing the three-dimensional images from the planar data collected by the new hardware design required a different approach from the state of the art at the time.

Pathways to the Impact

Realizing the need for major technological improvements in the prototype for RTT scanning, Rapiscan approached our research group with the aim to develop novel theory and more accurate algorithms for such scanning. The underpinning research has been funded jointly by Rapiscan and EPSRC including 3 KTA projects and two sponsored PhD studentships. This industry-driven project ensured rapid incorporation of the novel algorithms into the new generation of RTT scanners [S3].

Dr Wadeson had a KTA secondment with Rapiscan for a year in order to enable technology transfer; specifically this was to use Geant4 modelling within Rapiscan. Dr Thompson has completed a KTA concept and feasibility study to implement his reconstruction algorithms on a GPU, again with Rapiscan, and a further year's secondment to Rapiscan to complete GPU implementation and systems integration.

Reach and Significance of the Impact

By improving the accuracy of the reconstruction, using our algorithms and scatter correction, the RTT80 and RTT110 scanners are better able to detect threat objects and reduce the false alarm rate [S2]. By determining the presence and position of a threat, our industry-leading resolution and reconstruction process delivers optimal performance for the detection of materials in configurations typically difficult to detect [S2], which improves baggage handling efficiency, while lowering operational costs. RTT can also measure density levels in liquids, identifying threat liquids and alerting the operator to potentially concealed explosives [S2].

The prototype RTT80 scanner won The Engineer Innovation and Technology Award 2010 in the Defence and Security category [S4] and was the first ultra-high speed system to pass ECAC's Standard 3 threat detection test [S5], the highest such standard. Rapiscan already has substantial orders for RTT80 systems and has begun manufacturing in a UK factory [S3]. The larger RTT110 (110 cm diameter aperture in the scanner) was field-tested in Manchester Airport in 2010 [S6] and has recently been ECAC (Standard 3) certified (2013) [S7]. From 2014, all European airports must install Standard 3 certified equipment for any new hold-baggage screening equipment and the RTT110 will form part of the new terminal 4 ECAC Standard 3 test facility at Heathrow airport [S8].

The new scanners capture detailed 3-D images at speeds of between 1200 to 1800 bags per hour, compared to legacy CT rates of 600 bags per hour, and at higher resolution. When comparing the RTT maintenance costs with current CT technology, due to need for fewer machines, higher throughput and the revolutionary stationary gantry design, annual maintenance cost savings of 35-50% can be realized [S2]. Moreover, the significantly improved resolution, combined with built-in diagnostic tools, allows the operator to quickly resolve alarms [S2].

In 2011 Rapiscan received a US$20m order to provide multiple units of the new RTT scanners to Manchester Airport Group [S9]. The RTT110 machines have been deployed in Seattle airport. RTT systems have European regulatory approval and RTT110 systems are currently being manufactured in the UK [S3].

The new scanners are "*positioned to change the aviation security screening industry*" [S5] and "*are making air travel safer*" [S6], which will reduce risks to the security of all nation states.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[S1] OSI Systems Annual Report 2012 (supports financial claims)

[S2] Rapiscan RTT Brochure (supports technical claims about the RTT device)

[S3] Letter from Technical Director, Rapiscan Systems (supports our involvement with the project)

[S4] RTT80 Baggage Scanner, The Engineer, 3rd Dec 2010. http://www.theengineer.co.uk/awards/rtt80-baggage-scanner/1006324.article (supports claim that the work won Engineer Innovation and Technology Award)

[S5] Press releases for RTT80 certification and 'Rapiscan RTT Ultra-High Speed Checked Baggage Scanner Sets New Bar with EU Security Certification', April 2012. Rapiscan: http://www.rapiscansystems.com/en/press_releases/article/rapiscan_rtt_ultra_high_speed_checked_baggage_scanner_sets_new_bar_with_eu
(supports claim of RTT80 passing ECAC Standard 3 test)

[S6] http://www.manchestereveningnews.co.uk/news/local-news/a-clear-winner-the-high-speed-new-scanner-850776 (supports claim of field-testing in Manchester airport)

[S7] RTT110 'OSI Systems Receives Highest Level European Approval for Large Tunnel RTT™ Ultra-High Speed Checked Baggage Inspection System', June 2013. OSI: http://investors.osi-systems.com/releasedetail.cfm?ReleaseID=773801
(supports claim of RTT110 passing ECAC Standard 3 test)

[S8] http://www.baglogix.com/projects-clients/terminal-4-apv-ecac-standard-3-test-facility-london-heathrow-airport/ (supports claim that RTT110 will be used at Heathrow Terminal 4)

[S9] Press release: Rapiscan Systems Receives $20M Order for Advanced Checked Baggage Inspection Systems Based on RTT, June 6, 2011.
http://www.rapiscansystems.com/en/press_releases/articlerapiscan_systems_receives_20m_order_for_advanced_checked_baggage_inspection
(supports claim that Manchester airport have placed order for RTT machines)