Threat liquid identification in hand-held baggage.

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Eurostars E!7308 DCXScan project

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The Threat - 2006 transatlantic aircraft plot

Liquid Explosives Precursors: Acetone Peroxide (AP) or Hexamethylene Triperoxide Diamine (HMTD) prepared from hydrogen peroxide, hexamine or acetone and a catalytic acid.

Requirements	Ban on liquids on aircraft – August 2006
Type 'A'	Liquid Explosive Detection (LED) – Opened Bottles
Type 'B'	Checking liquids outside of bags (single bottles).
Type 'C'	Checking multiple bottles
Type 'D'	Multiple bottles in sealed bags
Type 'D+'	Multiple bottles in sealed bags containing electronics

Type 'B' bottle scanner – standard 3 – capable of scanning **all** bottles types

The Requirements & Problem Specification

Requirements	Description – Type ‘C’ Scanner – To enhance airport throughput
1	Checking liquids outside of bags.
2	Check multiple bottles (***Type ‘C’*)**.
3	System with customer throughput of 120 passengers/hour.
4	ECAC approval.
5	Achieve a False Alarm Rate (FAR) sub 5%
6	Cost effect or embedded system?

Problem	Description
1	A cost effective rapid screening ***Type ‘C’*** solution?
2	There are no ***Type ‘C’*** *systems* meeting ECAC standard 3
3	***Type ‘B’*** standard 3 systems based on multispectral x-ray have proved effective but can’t support 100% bottle inspections.

Realisable Solution

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Consideration	Description
1	Develop detector technology to take advantage of multispectral channel (colour) / photon counting X-ray imaging.
2	Develop a method to efficiently determine bottle geometry parameters with minimum hardware overhead.
3	Develop a method to classify threat /benign materials based on material properties.
4	Achieve low False Alarm Rate to allow minimal cross-checking with ***Type'B'*** system.

Key Considerations:

Imaging Capability

Can we accurately determine bottle geometry from a minimum number of views (dual)?

Detectors

Can we make and calibrate multispectral (MS) detectors to fit specifications required?

Materials ID

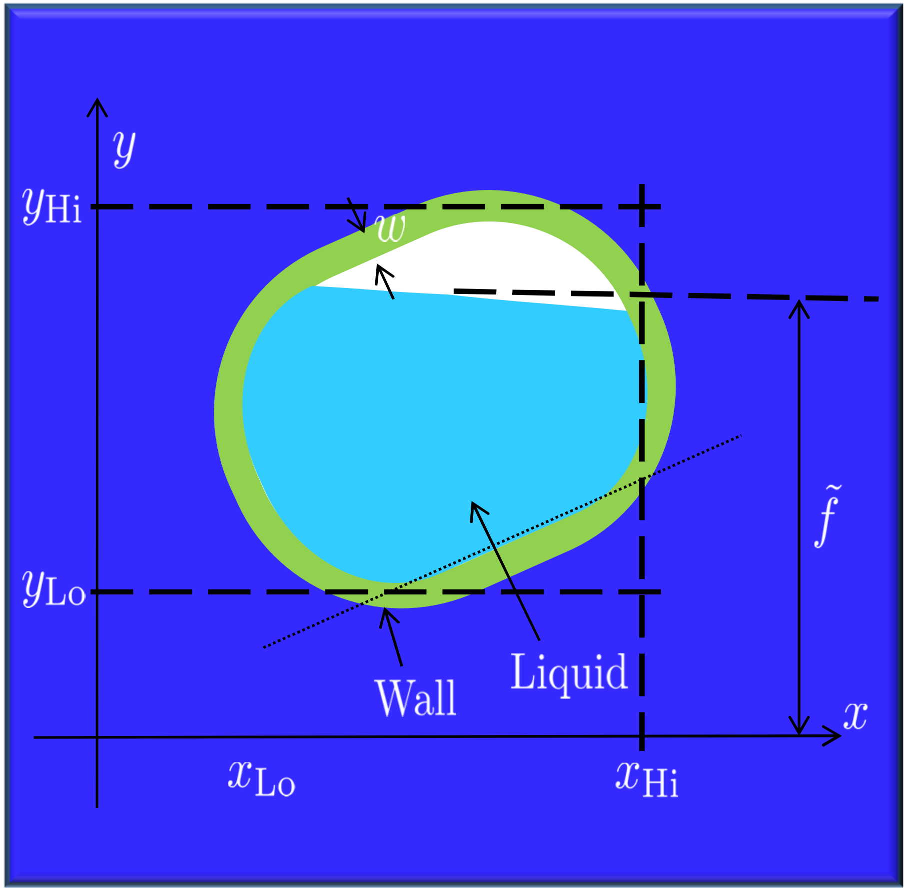
Can we measure material properties accurately enough to discriminate threat/benign materials of interest?

Solution method:

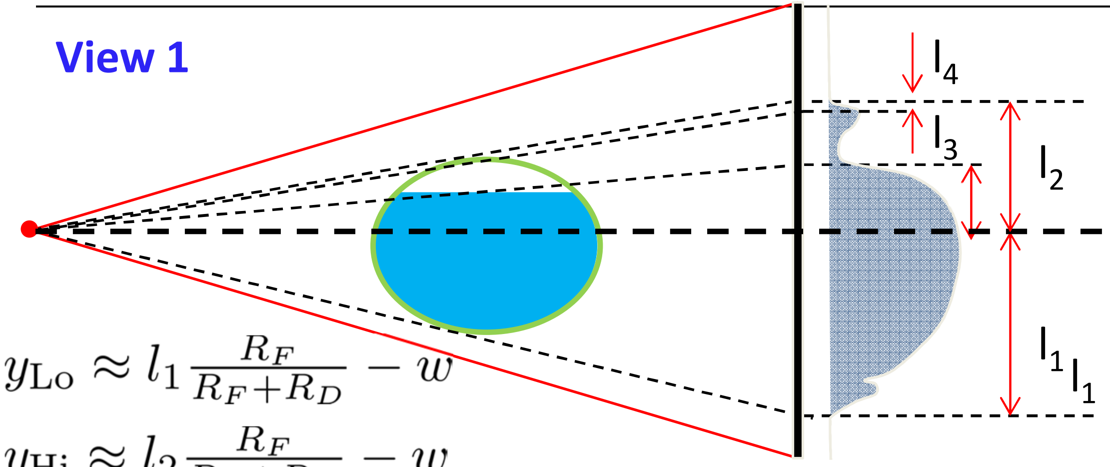
•X-ray scanning probes bottle contents / compatibility with existing scanning systems. Multispectral (colour) x-ray analysis provides a means of classifying bottle contents.

• Parameterisation of irregularly shaped bottles necessitates at least a dual view system.

•Extensive computational simulation is required to estimate optimum operating parameters including number of spectral channels, other hardware specifications and ultimately the theoretically false alarm rates achievable (sub 5% being an important goal).



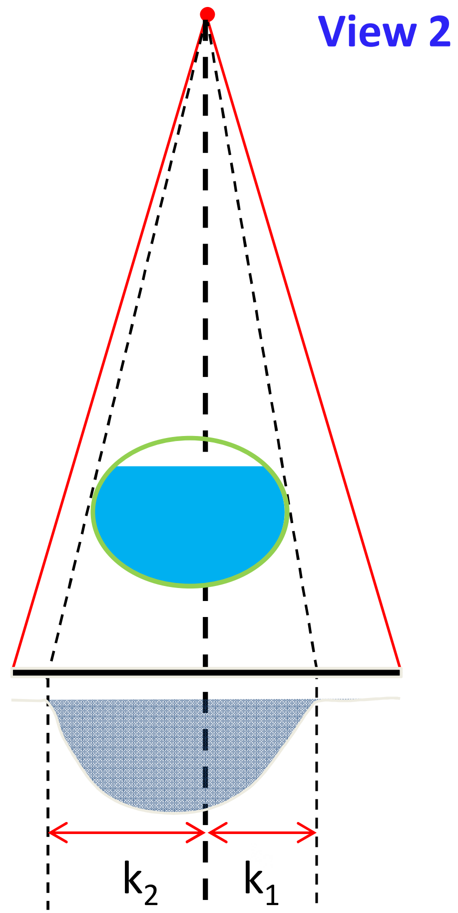
Solution method:



$$y_{\mathrm{Lo}} \approx l_1 \frac{R_F}{R_F+R_D} - w$$

$$y_{\mathrm{Hi}} \approx l_2 \frac{R_F}{R_F+R_D} - w$$

$$w \approx l_4 \frac{R_F}{R_F+R_D}$$



$$x_{\mathrm{Lo}} \approx k_1 \frac{R_F}{R_F+R_D} - w$$

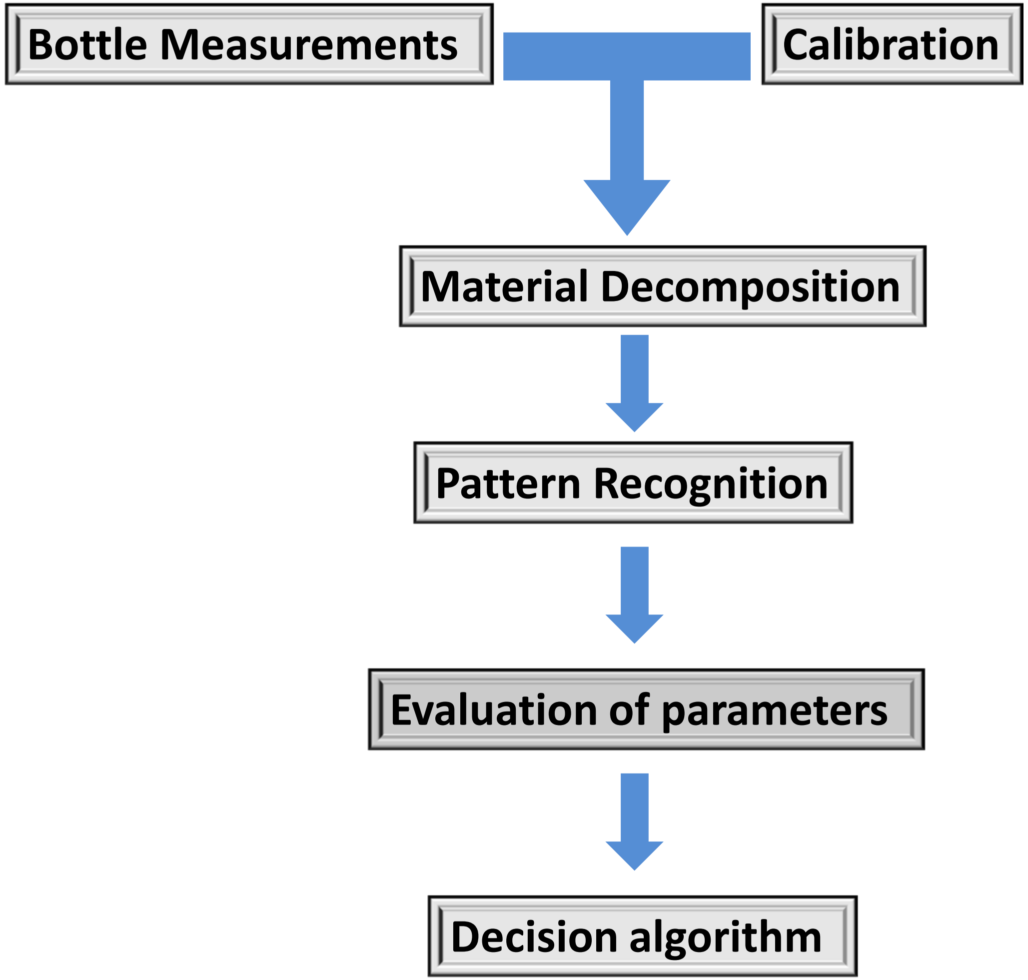
$$x_{\mathrm{Hi}} \approx k_2 \frac{R_F}{R_F+R_D} - w$$

The values can be used to parameterise using iso-axis-source/detector distances (R), and :

1. the bottles dimensions in terms of a bounding box location (x,y).
2. Bottle shape
3. bottle wall thickness (w),
4. a rotation angle,
5. a fill level,
6. a shape factor(s).

These are all fitted to the measured data parameters using a minimisation routine.

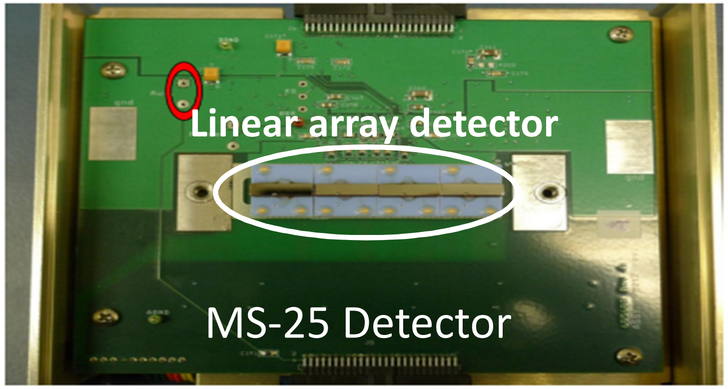
Methodology

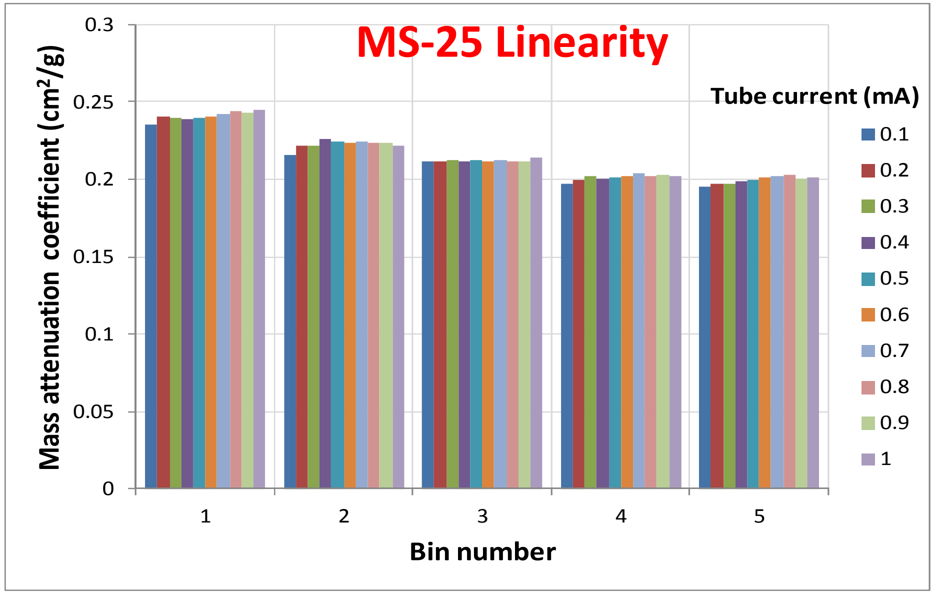


“Colour” X-ray detector – MS-25

- Linear array detector package of 64 (4x16) strips
    - Strip size : $2.7 \times 0.7 mm^2$
    - Thickness: 3mm
    - Width : 3mm
    - Pitch :0.8mm
    - Linear array size : 51.2mm

    - $V_{detector\ bias}$ = -1000V
    - Cathode illumination

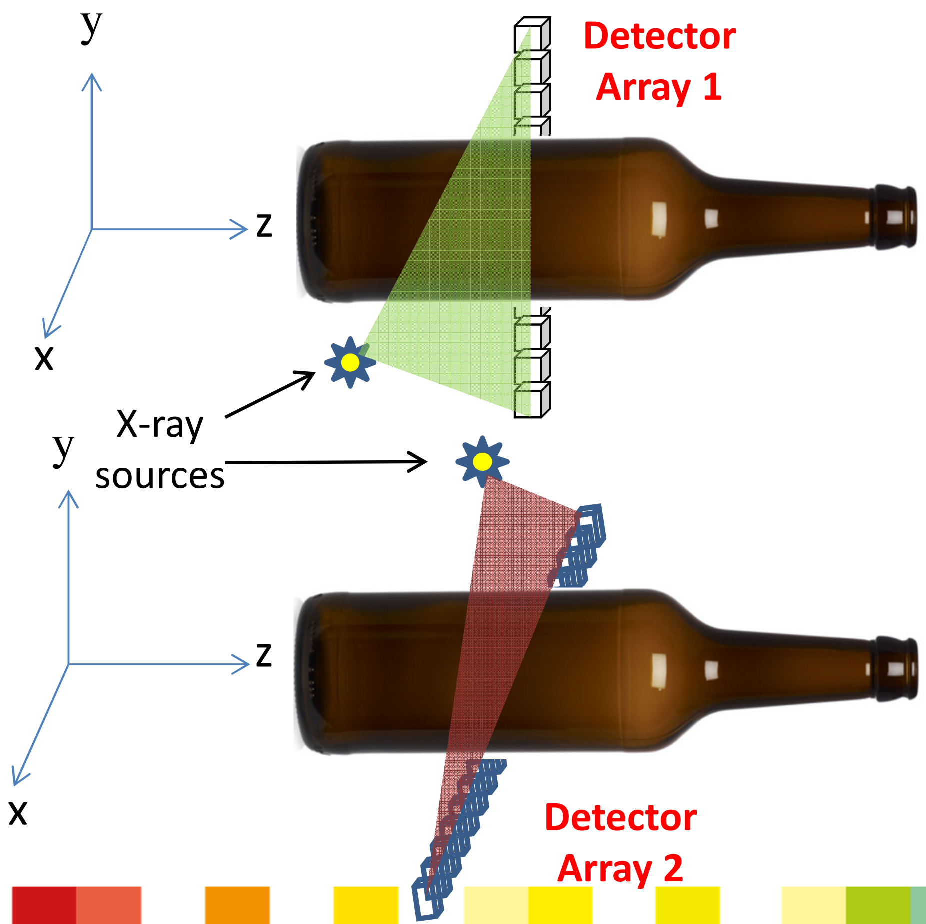


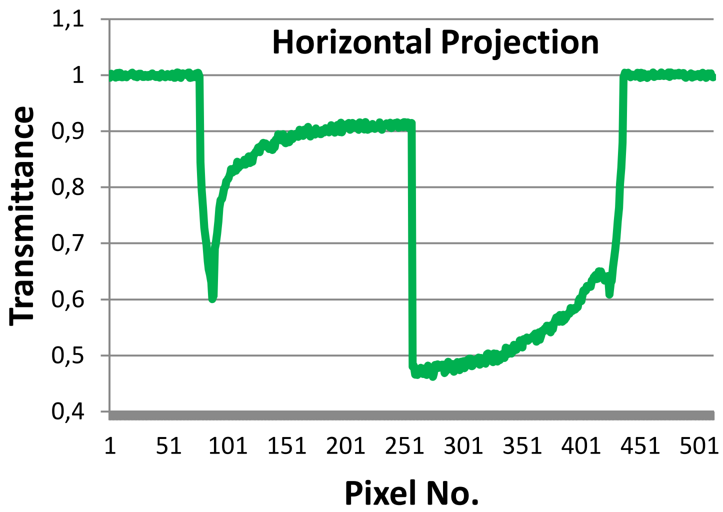


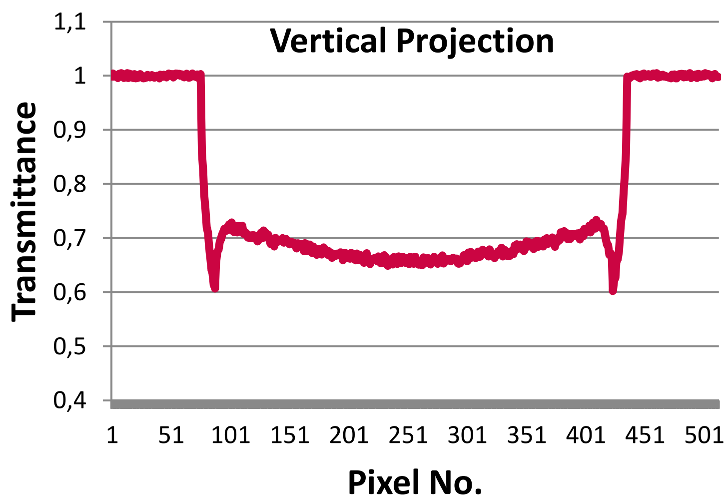
The achieved linearity to count rate is suitable for required material measurements. ***Ayoub et al. (R1-06)***

Minimum scanner configuration – Orthogonal Dual View

For the reason described earlier, a minimum hardware configuration for an X-ray realisation of a Type 'C' system is outlined below:







Solution method -
Bottle Parameterisation Examples

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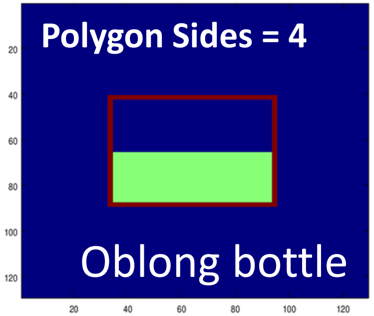

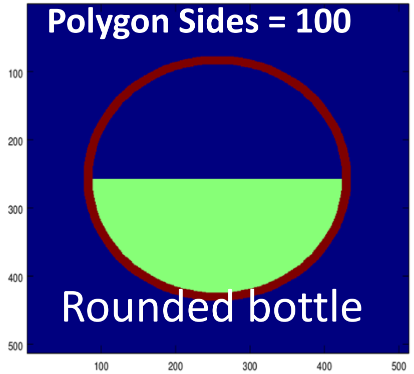

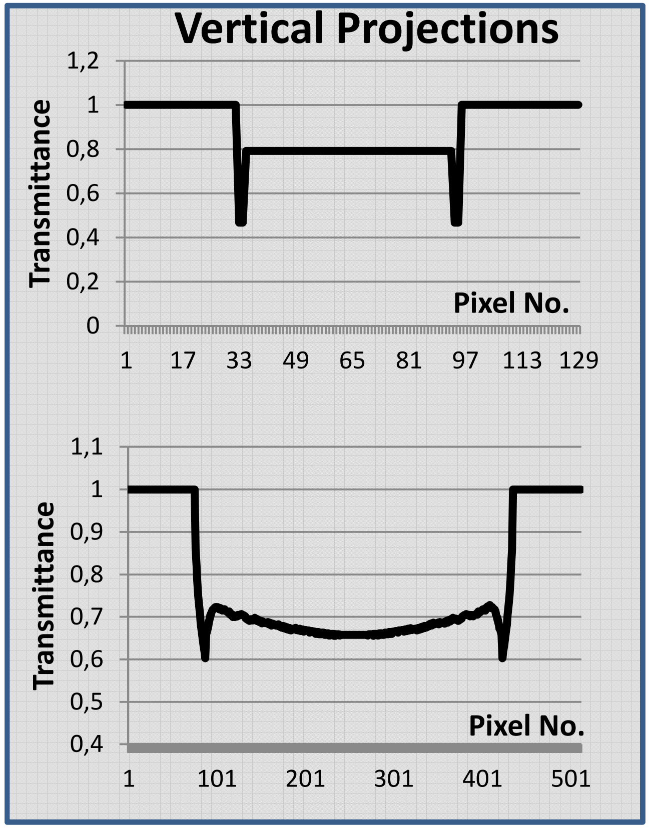

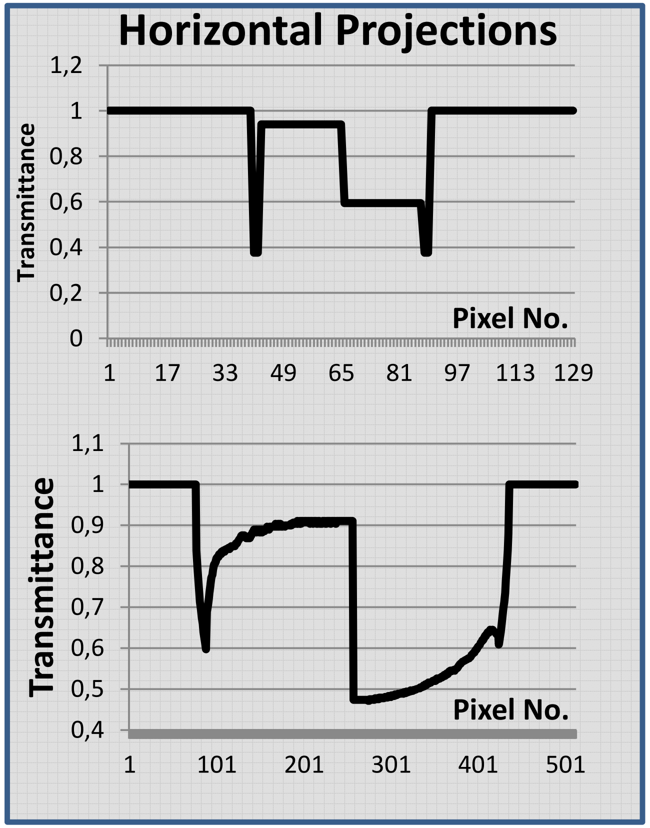

Orientated irregular polygon model:
Parameterised bottle description matched to orthogonal sinograms from which dimensions, shape, wall thicknesses and fill levels are estimated.
Other parameterisations can be considered for computational efficiency and to enhance solution robustness in the presence of signal noise.

Basis Material Decomposition - Achromaticity

1. Construct forward model to estimate absolute photon counts **λ** parameterised in ‘**b**’ spectral ranges by intersection lengths ‘**p**’ of ‘**m**’ basis materials (polychromatic to monochromatic transformation) to exploit achromacity condition.

2. Use maximum likelihood formulism to describe these photon counts in spectral ranges (two or more) as a forward model in the presence of Poisson distributed noise to derive the log-likelihood function.

3. Minimise the derived negative log-likelihood function over a cost function **c** between estimated and calculated projection lengths iteratively for **n** (2) viewing angles**, m** (>=2) basis materials and **u** detector pixels number.

4. Obtain estimated monochromatic projection lengths of defined and calibrated basis materials. Then, in general, energy dependent material properties which can be represented from the determined interaction lengths or “concentrations” of the chosen basis materials.

Glass-like basis material Image - simulated

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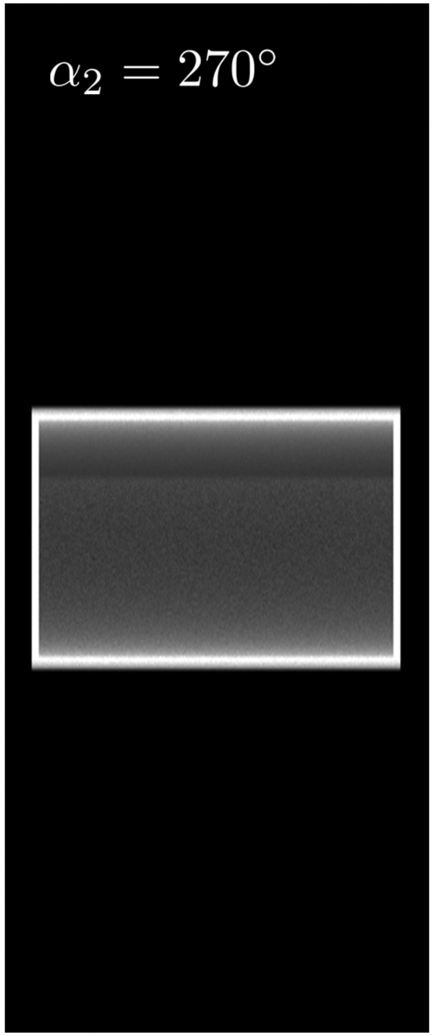
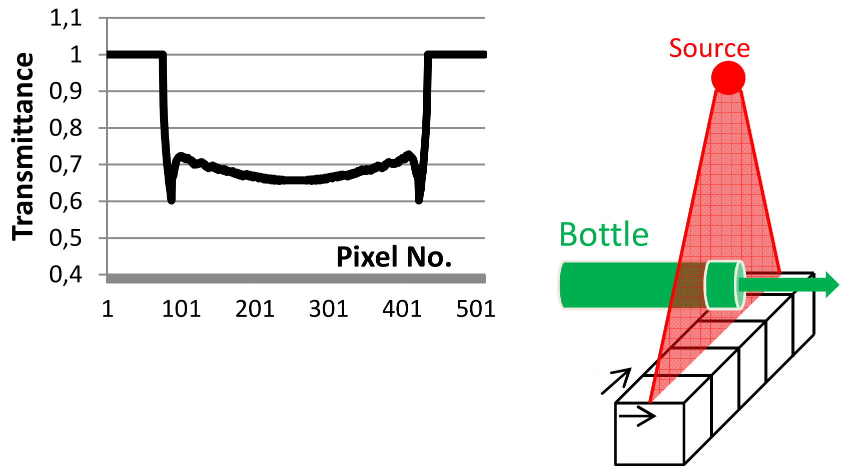
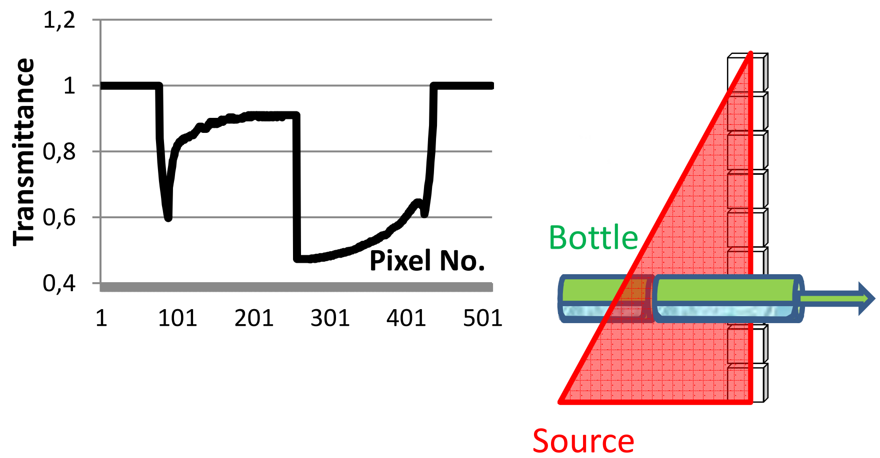
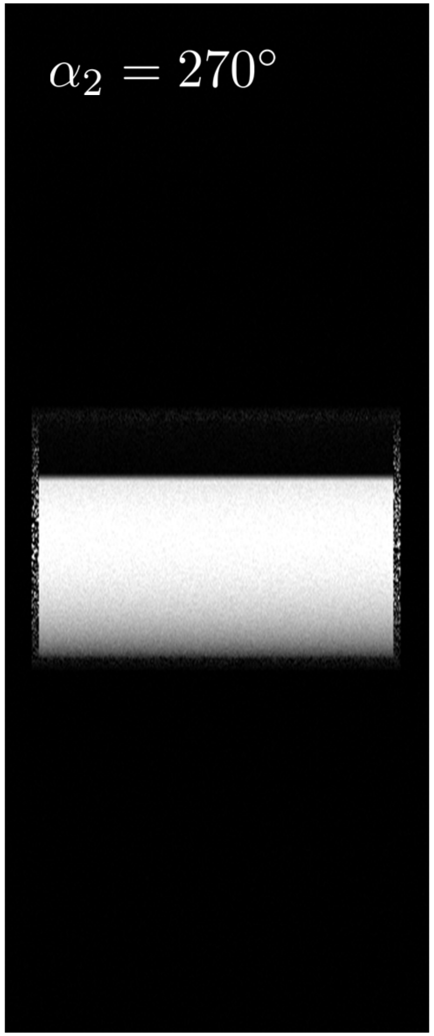
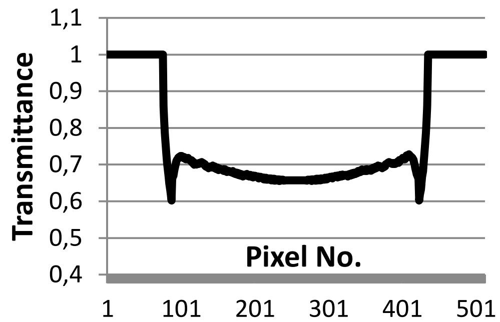


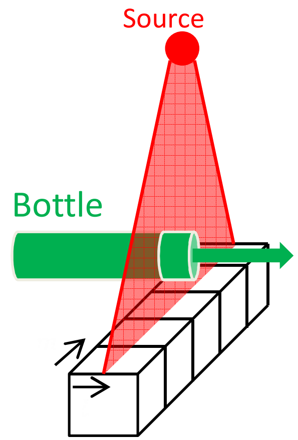


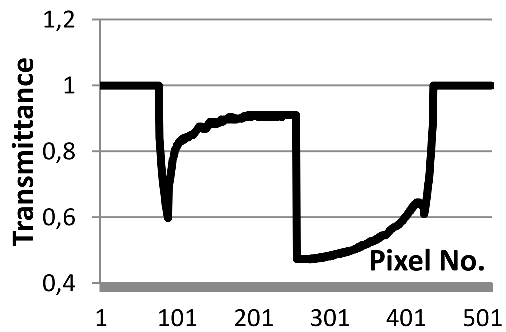


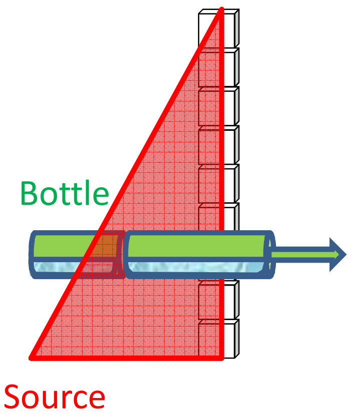
Water like basis material Image - simulated









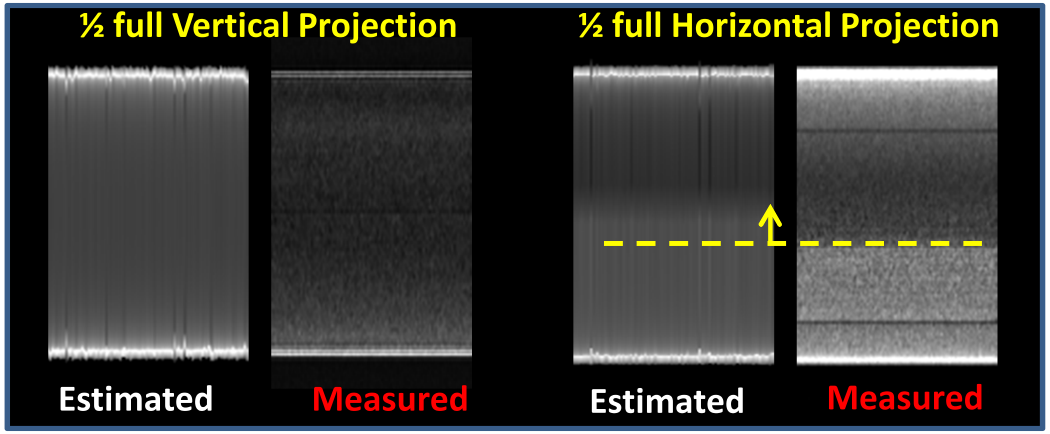


Basis material Images - Measured

The basis material projections were obtained from a proto-type system based around a modified RapiScan system. The plots are the sinograms for 2000 repeat slices.

Glass-like Material Component

Water-like Material Component



Glass like material projections for estimated and measured vertical and horizontal projections. The fill level of the liquid and bottle walls are discernible although some artefacts have arisen from imperfect alignment and no calibration having been done. The two dark lines in the right hand image are joining seams in the glass wall.

The choice of basis materials can be used to highlight particular material content (at any choice of energy). Here we see dominant contributions from the glass wall (left) and void space within .

Results & Validation

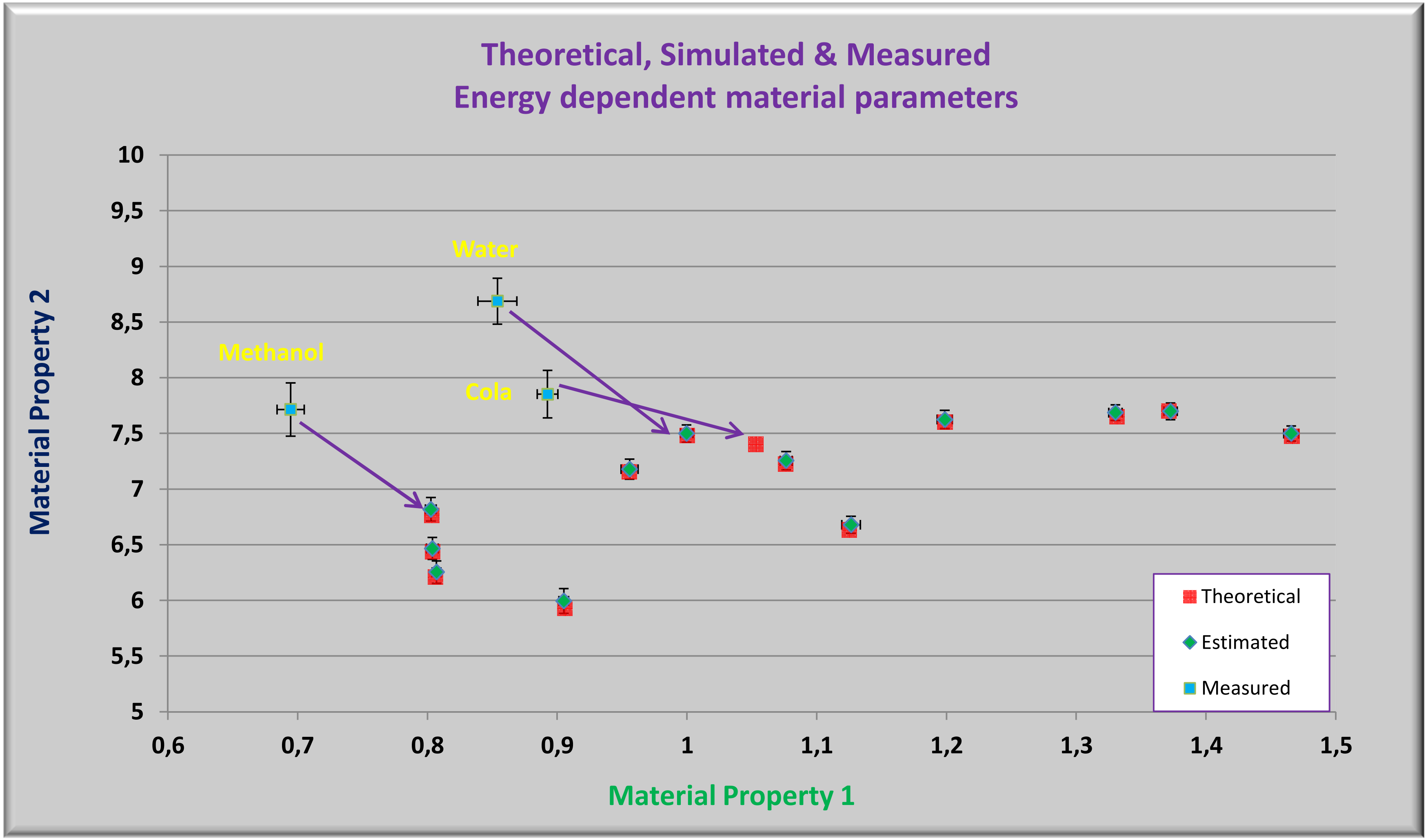
Simulated and theoretical material parameters were compared with the following variability:

1. Noise levels/photons per frame.
2. Bottle size scaling
3. Selection of threat/benign liquids
4. Differing fill levels
5. Differing bottle shapes.
6. Differing pixel sizes

These were then compared to measured values in a materials uncalibrated system (causing displacement in axes). The measured values show good material property discrimination but the errors margins are approximately double the simulated results calculated for a range of bottle situations. This is a result of imperfect system alignment. The simulated limit for FAR suggest a value at 2.3%

The results for simulated values were used to populate a 2D space spanned by two material parameters. A simple classification algorithm was then applied to establish a false alarm rate for the simulated system to generate an expectation value.

Results -
Different Bottle Scenarios



Summary

- System robust to bottle shape
- False Alarm Rate predicted @2.3% with state-of-the-art MS-25 detector
- False alarm rate an estimated factor of x2 worse with dual energy
- Method flexible to any number of spectral channels (>1)
- Method quite general to any basis set decomposition exploiting multispectral properties.
- Optimise prototype system.

Thank You

End