AS&E
Detect the difference.

Simulating XBS for Personnel Screening & Handheld X-Ray Backscatter Imaging

Dan Cristian Dinca
American Science and Engineering, Inc.

May 13, 2015

Simulating X-ray Backscatter for Personnel Screening

AS&E
Detect the difference.

- **Benefits of using simulations**
  - Indirect
    - Faster and easier to develop, lower NRE leading to lower price and shorter time to market
    - Retire/mitigate risk earlier in the development process
    - Virtual testing
      - Model system response to “exotic” materials that cannot be safely handled in an regular lab
      - Study effects of changing different components or configurations
  - Direct
    - Lower cost of estimating the performance of a new system, without the need to build a prototype or demonstrator
- **Drawbacks**
  - Results are model dependent (GIGO effect)

How Common XBS Systems Work

- X-rays are collimated in the shape of a pencil beam
- The pencil beam raster scans the person being imaged
- Detectors collect the scattered X-rays and create electrical signals
- Signals are converted into an X-ray image

Image from B. Tracey et al., Combined use of backscattered and transmitted images in X-ray personnel screening systems, DOI: 10.1117/12.917114

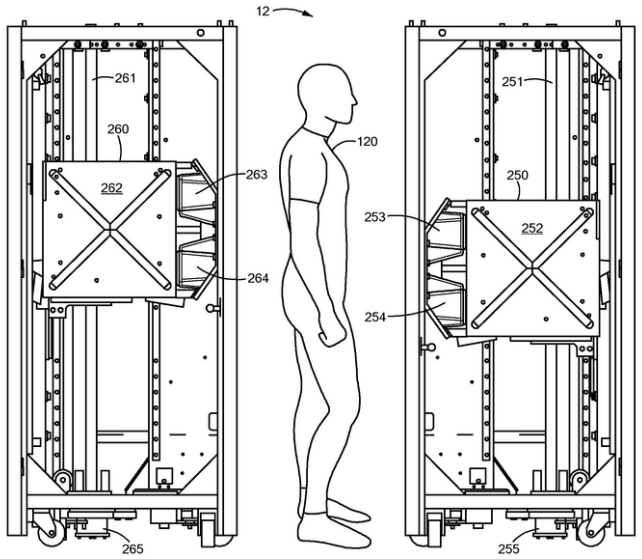
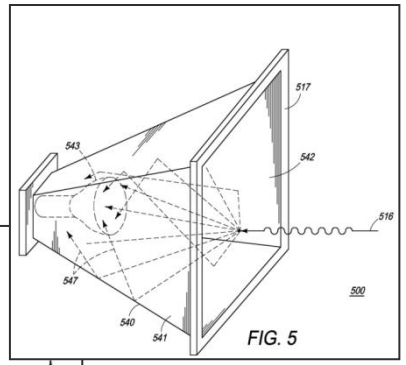


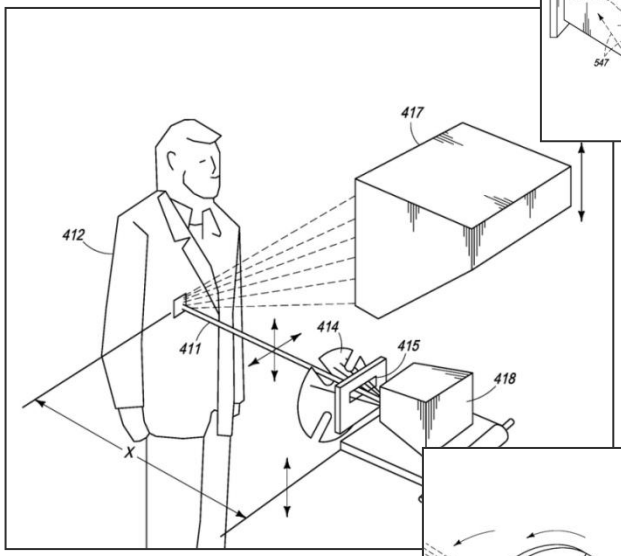
Figure from US Patent 7,796,734 B2

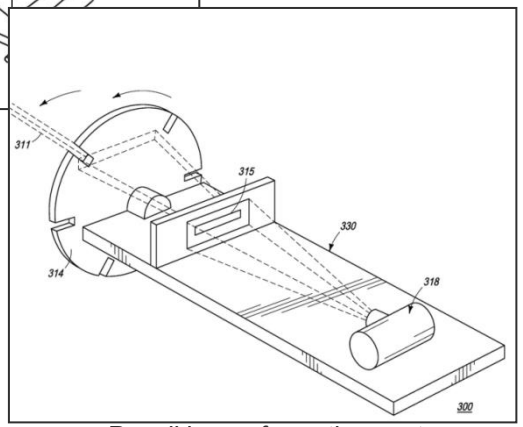
X-ray Backscatter System Components

- X-ray source
- Pencil beam formation and sweeping
- Detectors
- Electronics and signal processing algorithms
- Image processing algorithms



X-ray detector





Pencil beam formation system

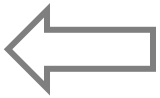
All figures from US Patent 5,181,234

System Parameters from Different Perspectives

AS&E
Detect the difference.

Customer's Side

- Dose to person, operator, environment (exclusion zone)
- Contrast sensitivity for thin objects
- Spatial resolution
- Scan time
- Image graininess



Designer's Side

- X-ray tube: energy, current, filtration, leakage, focal spot size and distribution
- Collimators, apertures, other parts of the pencil beam formation components
- Detectors: scintillators, stopping power, light collection, light readout, front-end electronics

- Ability to identify a small and thin organic layer (e.g. explosives) or small object (e.g. ceramic knife) attached to a non-uniform surface (human body) with similar density and effective atomic number.
- Conflicting requirements of image quality and radiation safety and scan speed

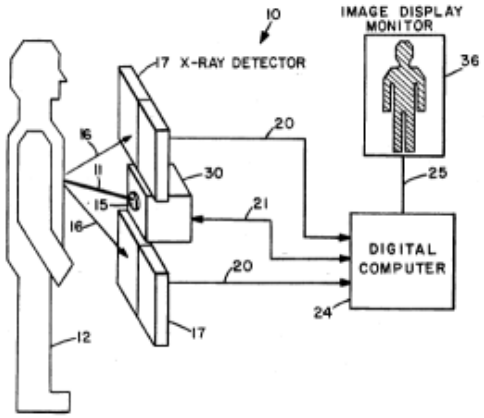
Modeling and Simulation

AS&E
Detect the difference.

- Physics – X-ray source, beam formation, detection, input to front-end electronics, raw X-ray image
- Mechanical and electrical engineering – mechanical stresses, thermal management, air flow, electronics, safety, controls
- Software and image processing – user interface, processing algorithms
- Human factors and ergonomics – usability

Sample System Parameters

- **Example of system parameters (taken from US Patent 5,181,234)**
  - X-ray source: 50 kV, 5 mA
  - Raw image size: 120 pixels horizontal x 320 lines vertical
  - Time to acquire 1 pixel: 50 microseconds
  - X-rays on object per pixel: 11500
  - Backscattered X-rays intercepted by detectors per pixel: 800
  - DQE ~ 50%
  - 8 MHz total count rate. Not uniformly distributed over all detectors
  - Total detector area: 4 CaWO4 detectors, 35.5 cm × 43.0 cm front face, 80 mg/cm2
  - Dose to person: 3 microRem/scan



Simulation Tools and Challenges

AS&E
Detect the difference.

Challenges

- In transmission X-ray, in the first approximation, scatter can be neglected. For backscatter this is not possible → Limited use analytical models
- Near-surface imaging → Optimize for high contrast sensitivity for thin objects on background with similar density and Zeff
- Low dose to scanned object → Need to account for all sources of variance (Poisson, electronics, etc.)
- Conflicting requirements of image quality and radiation safety and scan speed

Tools

- Semi-analytical models based on experimental data
- Monte Carlo radiation transport codes (e.g. Geant4, MCNP)
- Deterministic codes (e.g. discrete ordinates), mainly for shielding of complicated geometries

What is Simulated

- X-ray tube (energy, beam current, target type, angle, focal spot)
- Beam formation (direct/internal scattered beam, apertures, collimators)
- Interaction with simulated threats of different compositions and thicknesses
- Performance prediction based on simulated ANSI test objects
- Detector response (stopping power, sensitivity in specific energy ranges, light collection efficiency)
- System configurations
- Radiation safety (leakage, dose to person/operator)
- Raw image data fed into image processing algorithms

XBS raw image (left) denoised using Weiner filtering (middle) and NLM (right)

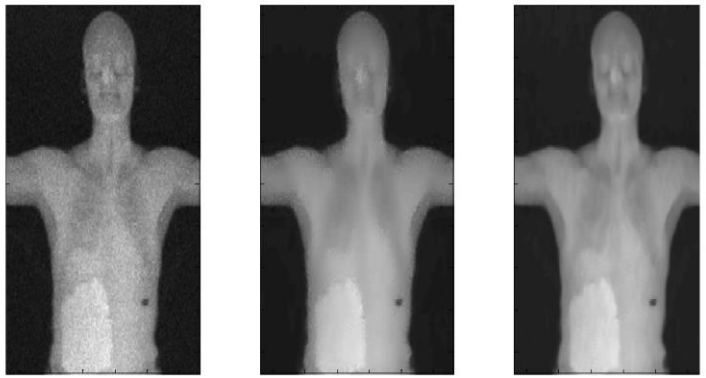


Image taken from Brian H. Tracey et al., Denoising approaches for X-ray personnel screening systems, DOI: 10.1109/THS.2012.6459848

Simulating X-ray Backscatter for Personnel Screening

AS&E
Detect the difference.

- **Benefits of using simulations**
  - Indirect
    - Easier to develop, lower NRE leading to lower price
    - Retire risk earlier in the development process
    - Virtual testing
      - Model system response to “exotic” materials that cannot be safely handled in an regular lab
      - Study effects of changing different components or configurations
  - Direct
    - Lower cost of estimating the performance of a new system, without the need to build a prototype or demonstrator
- **Drawbacks**
  - Results are model dependent (GIGO effect)

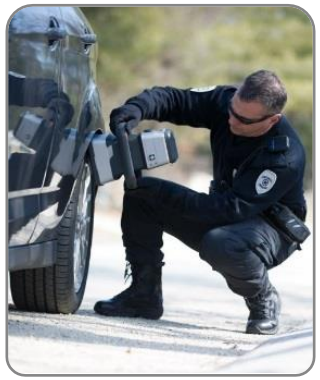
Handheld X-Ray Backscatter Imaging

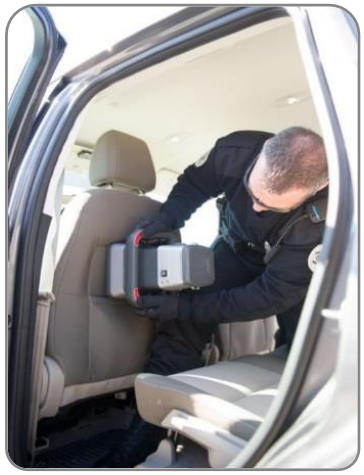
AS&E
Detect the difference.

- **Portable, easy to carry and operate**
- **No setup time, fast scanning**
- **One-sided inspection**
  - Fits multiple inspection scenarios
  - Useful when access to the far side of the object is limited or impractical
  - Smaller footprint
- **Images highlight organic materials - organic threats or contraband materials such as explosives and drugs can be more easily detected in the backscatter images than in the corresponding transmission images**
- **Photographic in appearance - easier to interpret**
- **Battery operated**
- **Negligible dose to scanned object, operator, and environment**

MINI Z™
HANDHELD Z BACKSCATTER® SCREENING SYSTEM

The world's first handheld Z Backscatter screening system that delivers fast, real-time images to detect drugs, contraband, and explosives in hard-to-reach locations





POPULAR SCIENCE 2014 BEST OF WHAT'S NEW AWARD

ASIS 14 accolades Security's Best Winner

MINI Z™ On-the-Go Detection

AS&E
Detect the difference.

Z Backscatter technology in the palm of your hands

- Using the same technology that made the ZBV® system the top-selling cargo and vehicle inspection system, but in a small form factor.
- Provides effective detection of organic threats, contraband, and explosives for public safety, customs and border enforcement, and security officials.

Goes where other systems can't reach

- Compact, single-sided imager that can be used to scan objects in hard-to-reach areas, such as:
  - Walls, furniture, small boats, aircraft, vehicle tires, and car interiors.
- Unlike density meters, trace detectors, or portable transmission X-ray systems, MINI Z produces an easy-to-interpret image to quickly locate organic contraband behind non-metallic surfaces.

MINI Z Easy-to-Use

AS&E
Detect the difference.

Completely self-contained

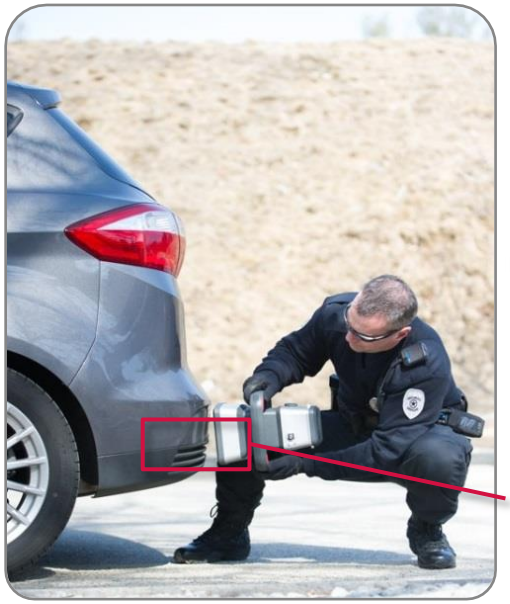
- Does not require physical set-up: enabling immediate operation
- Battery operated, wireless communications (Wi-Fi)
- Intuitive operation: as an operator scans a target, an image appears in real-time on the system's dedicated tablet.

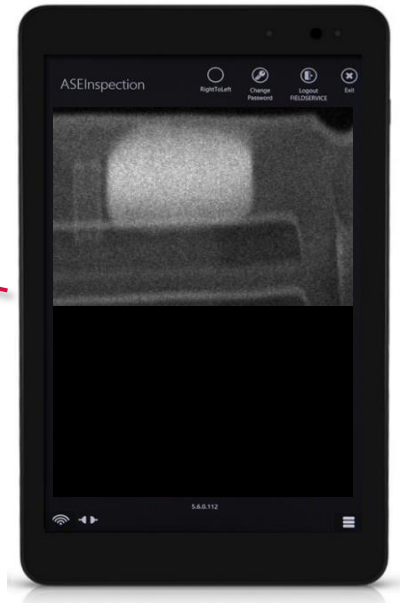
Tablet-based GUI provides simple operation

- Windows 8.1 tablet with ASEInspection Software-Tablet Edition for dedicated image viewing and analysis
  - Provides simple operation and management of the scan data.
  - Contains suite of tools for enhancing and analyzing images
- Training materials already loaded onto the companion image viewer tablet
  - Accessed through the home screen help icon

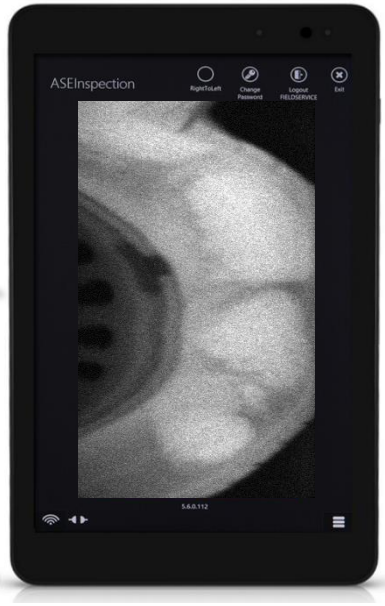
See Through Non-metallic or Thin Metallic Objects and Produces Images of Potential Threats and Contraband

AS&E
Detect the difference.





Narcotic simulant in bumper



Narcotic simulant concealed in tire

Dose to operator less than 50 urem/h for 100% duty cycle

Image Objects in Places Hard to Screen

AS&E
Detect the difference.

Fast, portable detection of organic objects (drugs, explosives, etc.) located in voids behind non-metallic surfaces

- Examination of walls, vehicle interiors, airplane interiors, pleasure boats, packages, furniture…

Narcotic simulant in a car seat

Multiple Security Applications

AS&E
Detect the difference.

Passenger Vehicles

- Screening vehicle bumpers, tires, and interiors for contraband

Public Spaces

- Screening left behind/suspicious bags for threats/contraband

Drug Enforcement

- Searching suspected drug labs/houses for hidden drugs and currency

VIP Security

- Screening rooms, walls, and furniture for threats

Maritime

- Screening boat walls/hulls/bulkheads for drugs or currency

General Aviation

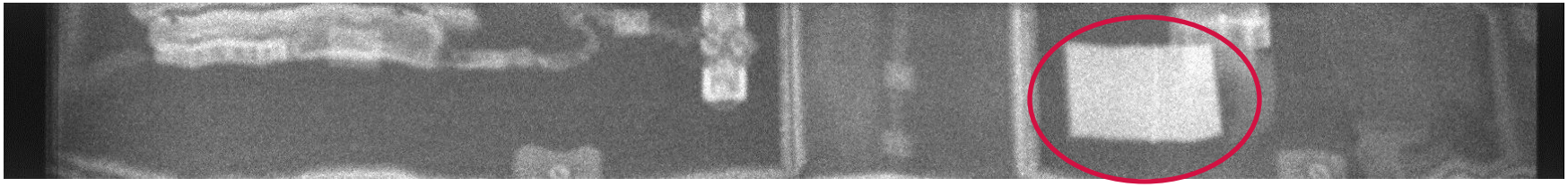
- Screening small planes for contraband

Commercial Airliners

- Screening the interior of commercial aircraft for drugs

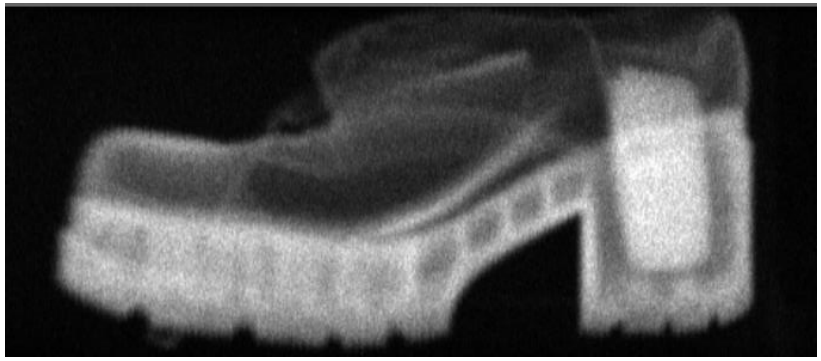
MINI Z Images
Aircraft Overhead Bin with Simulated Drugs

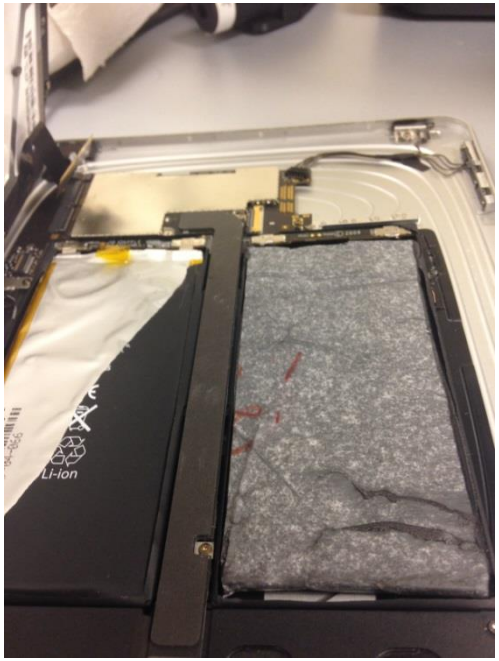
AS&E
Detect the difference.

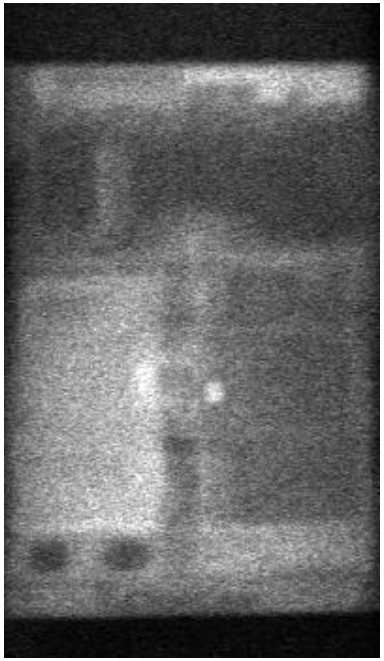


MINI Z Images
Shoe and iPad with Simulated Explosives

AS&E
Detect the difference.



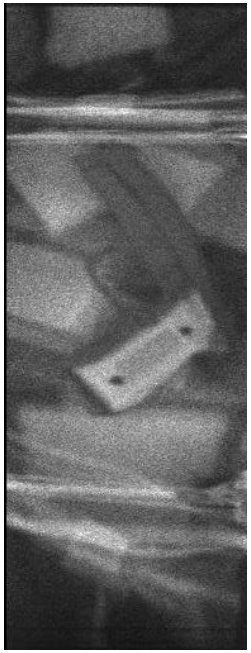


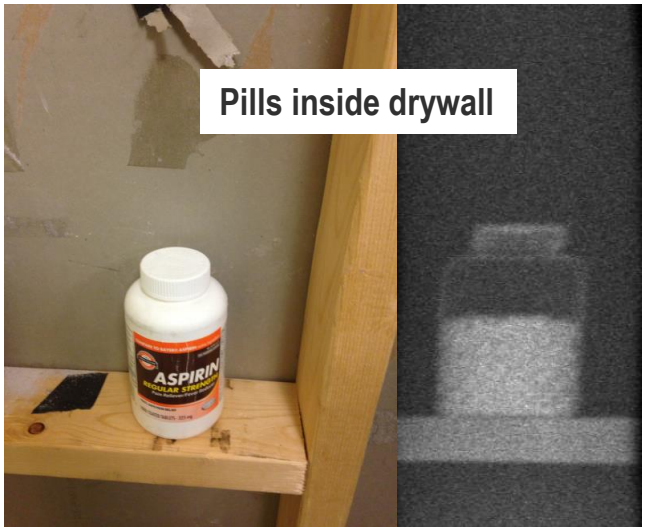


MINI Z Images
Objects Containing Simulated Threats

Detect the difference.

Gun on top of money in duffel bag





Handheld X-Ray Backscatter Imaging

AS&E
Detect the difference.

- **Portable, easy to carry and operate**
- **No setup time, fast scanning**
- **One-sided inspection**
  - Fits multiple inspection scenarios
  - Useful when access to the far side of the object is limited or impractical
  - Smaller footprint
- **Images highlight organic materials - organic threats or contraband materials such as explosives and drugs can be more easily detected in the backscatter images than in the corresponding transmission images**
- **Photographic in appearance - easier to interpret**
- **Battery operated**
- **Negligible dose to scanned object, operator, and environment**