X-Ray Image Analysis

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Explosive Detection

- The most useful information that x-ray technology may provide is related to an object density \( (d) \) and effective atomic number \( (Z_{eff}) \)
- Theoretically, an object’s material type can be uniquely determined by using \( d \) and \( Z_{eff} \)
System Architecture

Detector plane

“Spot” (x, y)

Forward scatter

Transmission

Conveyer

Backward scatter

Detector plane

X-ray Source

“Spot” (x, y)
Single Transmission X-ray

\[ \ln \left( \frac{I_0}{I} \right) = \sigma(Z,E) \frac{N_A}{A} \rho t \]

- There are too many unknowns in the above equation to get some information from a single measurement.
- A thin, high Z material will have the same attenuation signal as a thick, low Z material.

\( \sigma \) is the total cross section, \( \rho \) is the density, \( t \) is the thickness, \( N_A \) is the Avogadro Number (atom/mole), \( A \) is the atomic weight (g/mole)
Dual Energy X-ray

- The logarithmic attenuation signal obtained at X-ray energy $E_1$ is given

$$\ln\left(\frac{I_{01}}{I_1}\right) = \sigma(Z, E_1) \frac{N_A}{A} \rho t$$

- At the second x-ray energy $E_2$

$$\ln\left(\frac{I_{02}}{I_2}\right) = \sigma(Z, E_2) \frac{N_A}{A} \rho t$$

- The ratio of the above two measurements obtained with two different energies eliminates the density and thickness

$$R = \frac{\ln\left(\frac{I_{01}}{I_1}\right)}{\ln\left(\frac{I_{02}}{I_2}\right)} = \frac{\sigma(Z, E_1)}{\sigma(Z, E_2)}$$
R vs. $Z_{\text{eff}}$
$R$ vs. $Z_{\text{eff}}$ (Cont ..)

- Using dual energy transmission technology, $R$, a $Z_{\text{eff}}$ related information can be determined.
- Organic materials can be separated from inorganic materials and metals using $R$.
- But it has troubles to separate innocuous organic materials from illicit materials.
Scatter X-ray

- A density related information, $L$, can be computed using scatter technology.
- $L$ is computed from the observed scatter and transmission signal:

\[
L = \frac{\alpha I_{fs} + \beta I_{bs}}{I_{trans}}
\]
Scatter X-ray (cont ...)
$R-L$ Value for Explosive Detection
## Test Case

<table>
<thead>
<tr>
<th>Year</th>
<th>Composition</th>
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</thead>
<tbody>
<tr>
<td>1864 to 1942</td>
<td>95.0% Copper and 5.0% Zinc &amp; Tin</td>
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<tr>
<td>1943</td>
<td>Steel with Zinc coating</td>
</tr>
<tr>
<td>1944 to 1946</td>
<td>95.0% Copper and 5.0% Zinc &amp; Tin (slightly off color)</td>
</tr>
<tr>
<td>1947-1962</td>
<td>95.0% Copper and 5.0% Zinc &amp; Tin</td>
</tr>
<tr>
<td>1963-1982</td>
<td>95.0% Cu and 5.0% Zinc</td>
</tr>
<tr>
<td>1983-2002</td>
<td>97.5% Zinc and 2.5% Copper</td>
</tr>
</tbody>
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Bayesian Classifier

- Bayes Formula
  \[ p(w_j | x) = \frac{p(x | w_j) p(w_j)}{p(x)} \]
- Where \( p(x) \) is
  \[ p(x) = \sum_{j=1}^{N} p(x | w_j) p(w_j) \]
- Informally
  \[ \text{posterior} = \frac{\text{likelihood} \times \text{prior}}{\text{evidence}} \]
- Decide \( w_1 \) if
  \[ \frac{p(w_1 | x)}{p(w_2 | x)} > \alpha \]
- Decide \( w_2 \) if
  \[ \frac{p(w_2 | x)}{p(w_1 | x)} > \beta \]
# Coin Recognition Accuracy

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>1963-1982</td>
<td>100%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>1983-2002</td>
<td>14%</td>
<td>84%</td>
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</tbody>
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Theoretical vs. Practical Cases