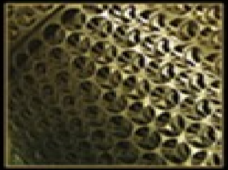
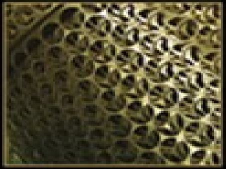




Detection of the Security Feature in the New £1 coin

Sarah Rogers & Rhys Thomas

October 2017

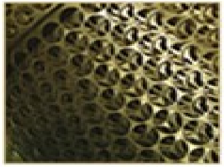


How the battle against counterfeiting in the coin industry has driven innovation

Sarah Rogers

October 2017



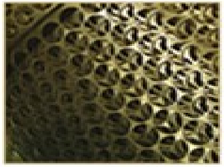


Contents

- The Royal Mint
- The history of coin security
- What makes a secure coin today
- The future of Coin Technology
- First look at the new UK £1 launching 2017

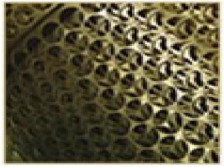
Our History






Tower of London
1250 - 1812
Tower Hill, London
1812 - 1968
Llantrisant, Wales
1968 to present

Our Businesses



Circulating Coins

Producer of all legal tender UK Circulating Coins and the world's leading export mint

Commemorative Coins

Design and manufacture precious metal coins and medallions to celebrate national events

Medals

Decorations, Awards and Honours including London 2012 Olympic and Paralympic Medals, military service medals, OBEs and MBEs

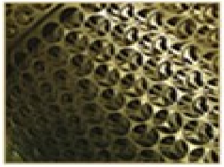
Bullion

Production and distribution of high quality, trustable investment grade gold coins

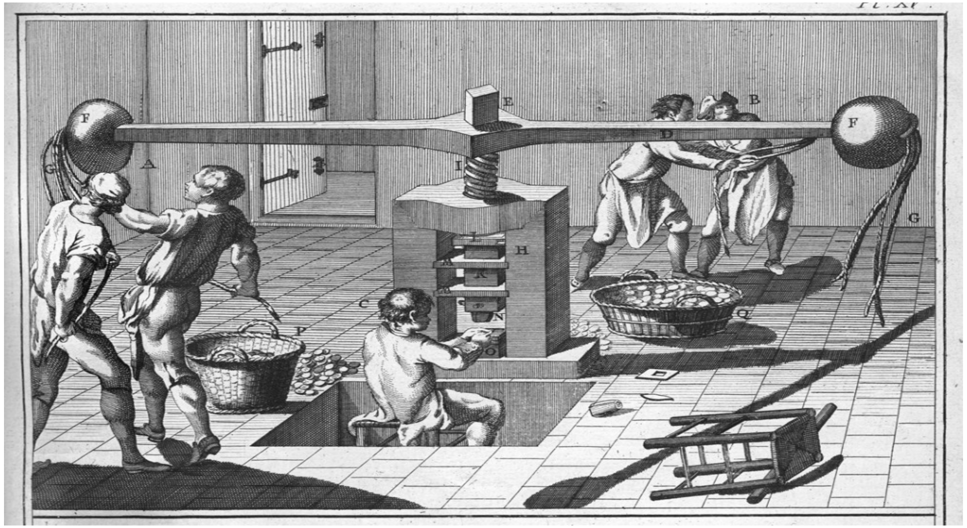
The Royal Mint

The History of Coin Security



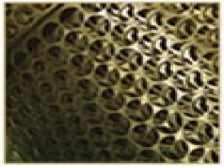


- The battle between coin minter and counterfeiter has waged for thousands of years
- Up until the 20th Century most coins were made from gold and silver
- The 17th Century was a golden age of coin innovation
- Milling and edge lettering. First widely used on coins from the 1660s when the coining process is modernised and machinery introduced for the production of coins



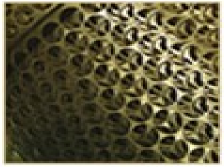
The Royal Mint & Sir Isaac Newton





- Isaac Newton makes the point that having the highest quality coin is the best way to deter counterfeiting.
- This incorporates the coin as a whole – accuracy of the specification and the highest quality design.
- Raises the bar to which the counterfeiter must match.
- Independently verified at The trial of the Pyx

Oververt Security Features



Edge Lettering

Text impressed into the coin edge

Latent Feature

Reveals 2 different images as angle is changed

Fine Engraving

Similar to the lines used on banknotes

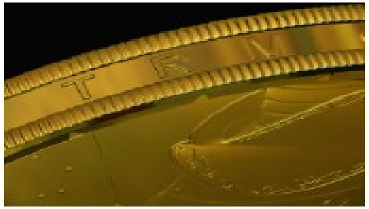
Micro-dots and Micro-lettering

Dots or symbols positioned at precise location

Beading

Raised beads in a groove around the coin's circumference

Groove Raised Lettering



Raised lettering in a groove around the coin's circumference

Bi-colour or Bi-metallic Coins

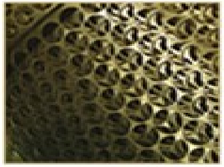
Two composite parts are struck together creating a secure bond

Shape

Quick public recognition

The Royal Mint

Coin Security Features Today



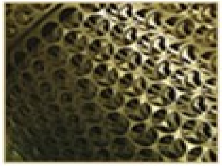
Overt Security

Visible security features

Covert Security

Hidden security features





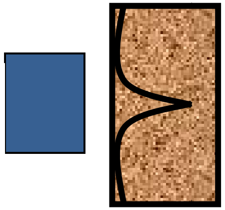
Covert Security
Electromagnetic Signature

Used in most vending machines

A mixture of high and low frequencies used to determine composition and validity

- High frequencies do not penetrate into the core of the coin and are therefore sensitive to the surface material.
- Lower frequencies penetrate deeper into the coin and are therefore sensitive to both surface and core material.

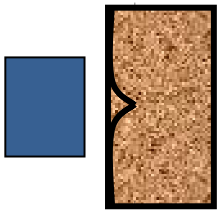
Inductive sensor



Low Frequency

Deeper penetration

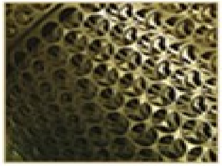
Inductive sensor



High Frequency

Shallower penetration





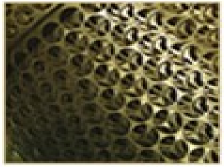
The next innovation in coin security

- Used in many high security industries such as tax stamps, passports and luxury goods
- The Royal Mint has found a way to incorporate this feature into a coin to create a new generation of 100% machine-readable, coins that offers banknote strength security

The Royal Mint

The New UK £1 Launched 2017





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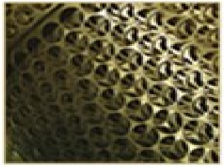
The Royal Mint

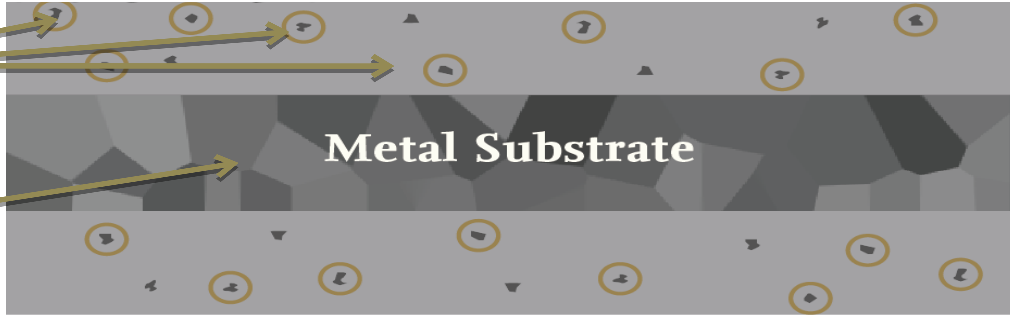
The High Security Feature

The high security feature is incorporated into the plated layer during the production process



High security feature clearly visible throughout the plated layer

Metal Substrate

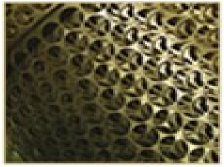


The Royal Mint

How Does it Work?

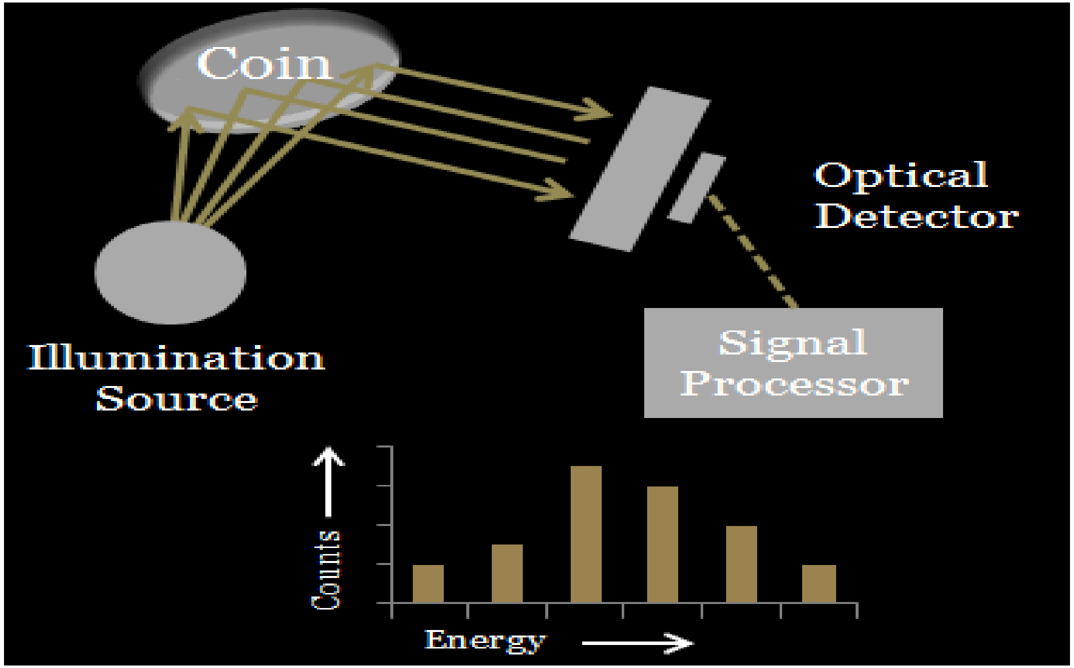
Detected using stand alone optical readers

Readers can be incorporated throughout the cash cycle

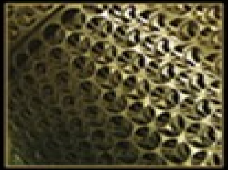


The technology is able to check and verify coins at a rate of thousands per minute

Provides a categorical Yes/No answer







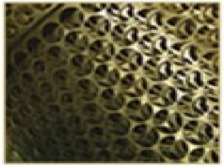
The High Security Feature

Rhys Thomas

October 2017

The High Security Feature

Patented metal matrix composite deposition process developed by The Royal Mint



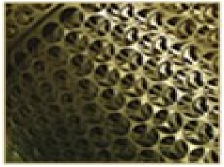
Security feature is present only a deposited nickel layer, reducing costs but ensuring validation is possible throughout circulatory lifetime

Deposit retains the ductility, wear and chemical resistance of the nickel matrix

Optically detected in a similar way to banknote and passport validation methods

The Royal Mint

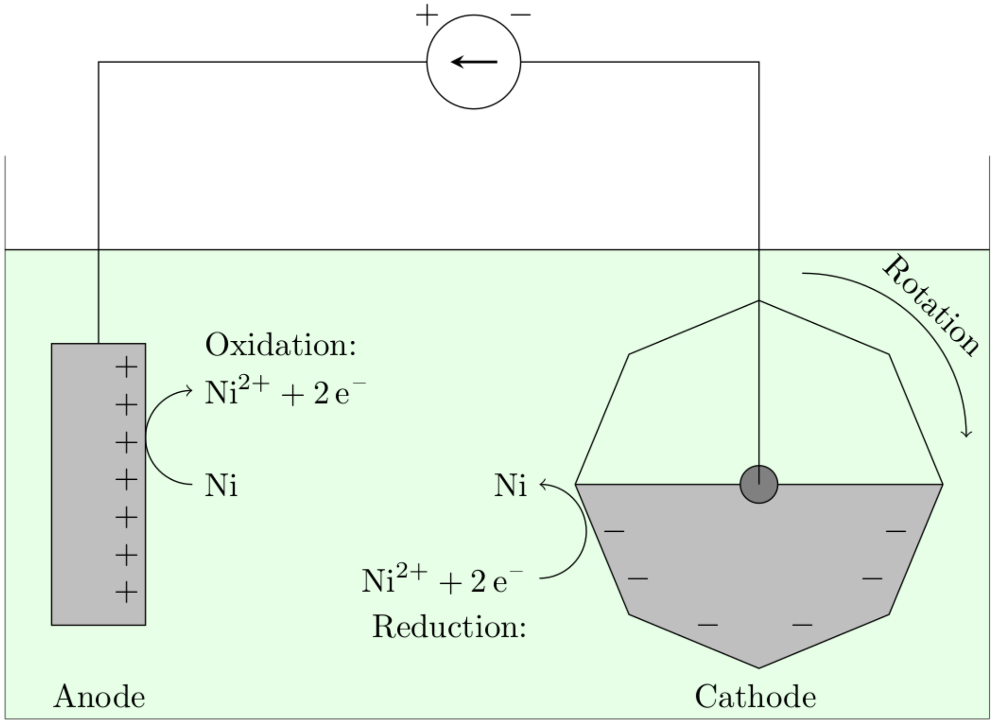
Electroplating Process



Nickel anode and coins immersed in nickel electrolyte

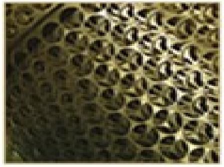
Application of external potential difference drives thermodynamically unfavourable electrode reactions

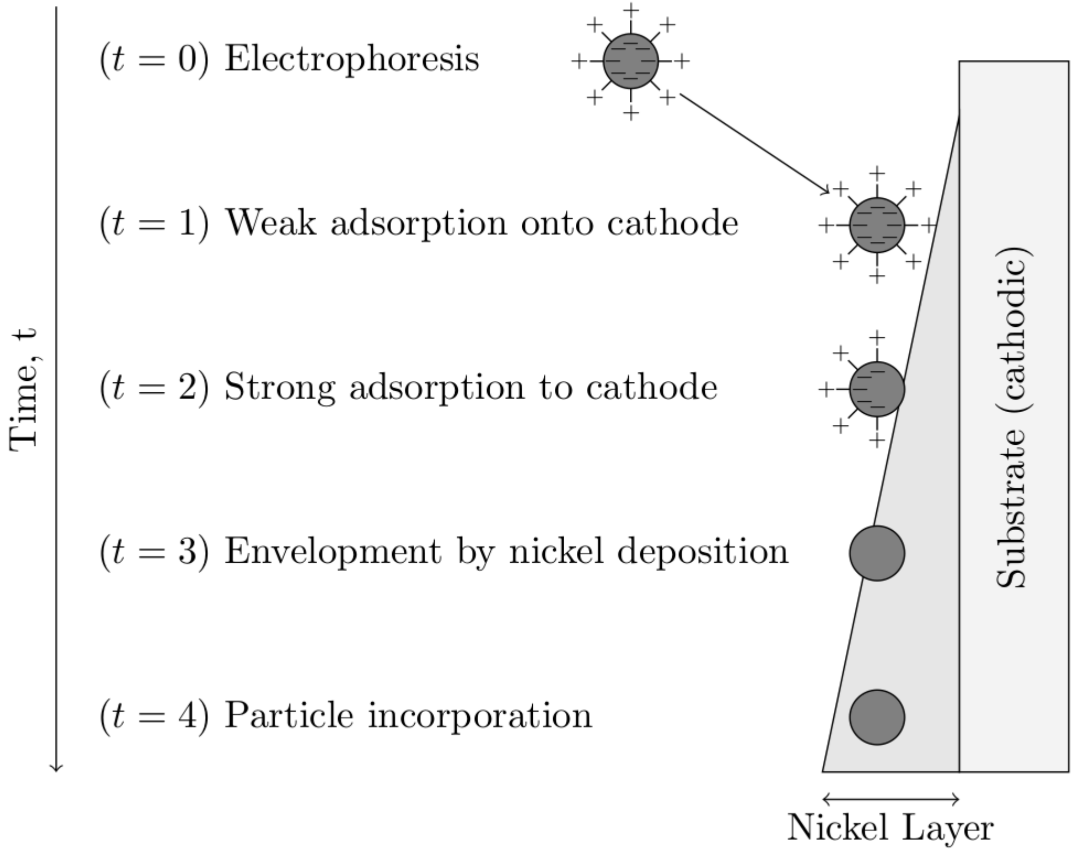
Nickel dissolves at anode and is deposited on coins at the cathode



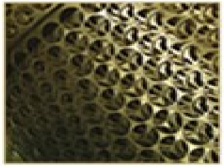
Composite Electroplating











Deposition Models

Inputs

Electrolyte
- Temperature
- Composition
- pH
- Additives
- Colloidal stability
- Turbulence

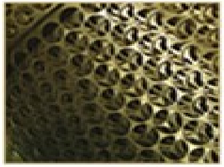
Electrochemical
- Charge transfer
- Mass transfer
- Polarisation

Model →

Outputs

Deposit Properties
- Ductility
- Chemical resistance
- Surface finish
- Volume fraction
- Optical properties
- Wear characteristics
- Dispersion

Deposition Models



All useful composite deposition process models are empirical

Model requires both inputs and outputs

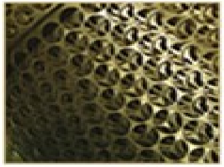
Specific experiments must be performed to determine operating parameters

MATLAB was used extensively to develop and apply models at laboratory and pilot scale and to solve process issues at production scale

Over 500 experiments were performed at the laboratory and pilot scale to characterise the system

The Royal Mint

Example Applications



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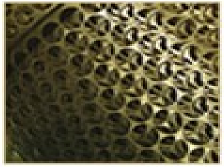
- **Volume fraction**
- Optical properties
- Wear characteristics
- Dispersion

The Royal Mint

Volume Fraction

The volume fraction of the security feature incorporated into the electrodeposit was quantified using the Image Processing Toolbox

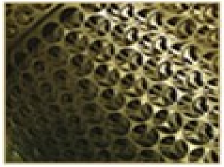


Electron micrographs were produced from coin cross sections

Over 4000 cross sectional micrographs were analysed during the development phase

Automated methods were developed to speed up the analysis process



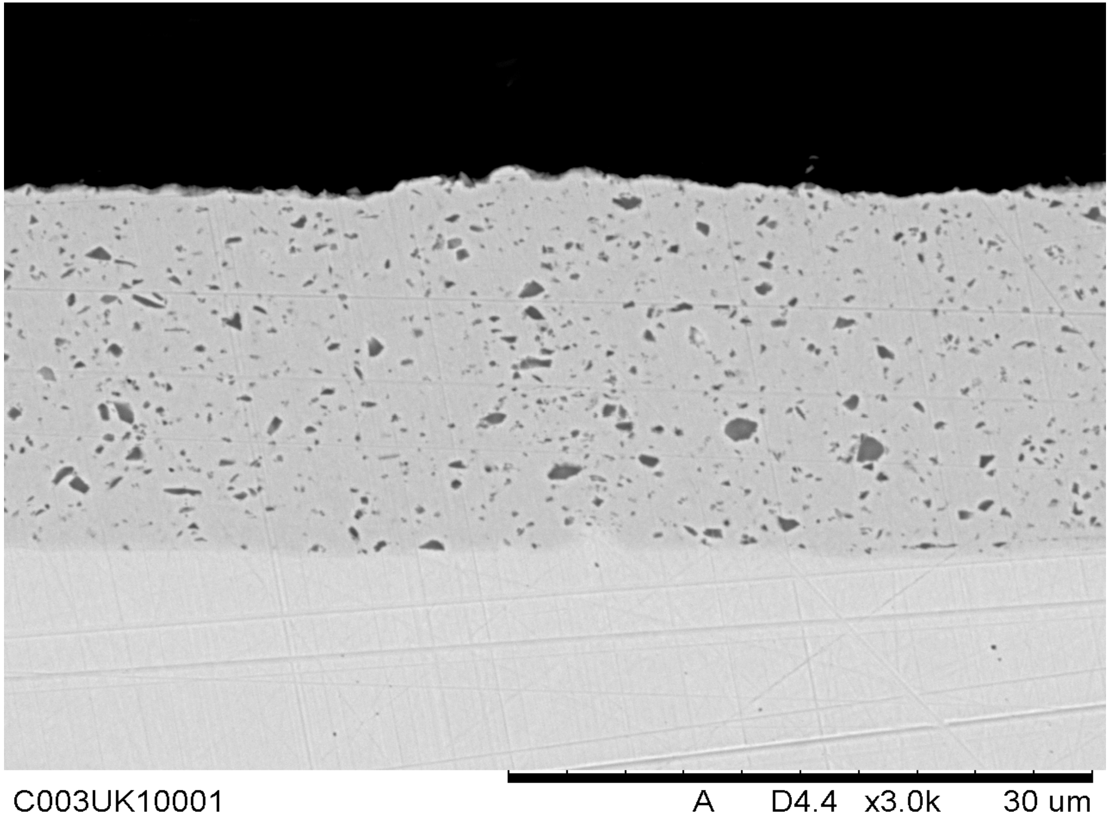


Volume Fraction

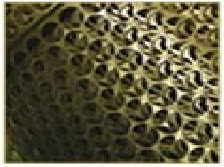
Mounting resin

Nickel deposit containing security feature

Nickel brass substrate



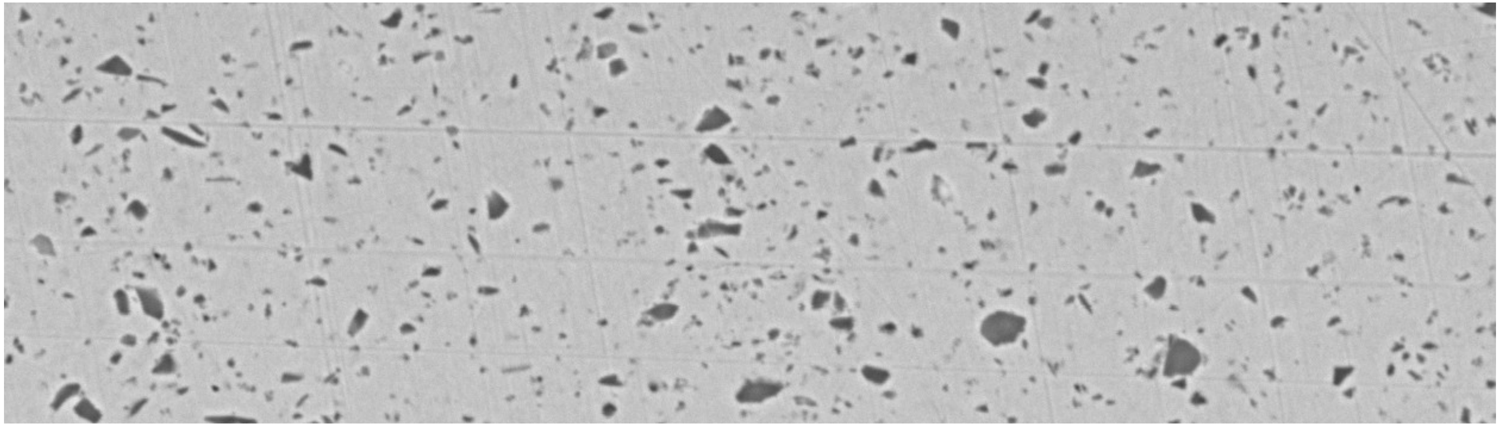


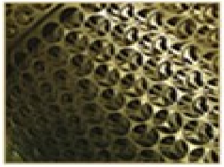


Volume Fraction

Micrograph was cropped to reveal only the composite coating

Image imported as a grayscale numerical array with values between 0 and 1 for each pixel



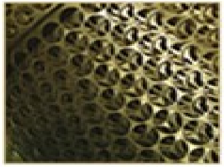


Volume Fraction

Threshold value applied to convert numerical array into a logical array:

$$\text{img} = \text{img} < \text{threshold}$$





Volume Fraction

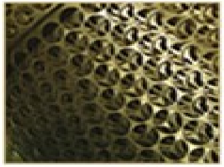
The surface area fraction of the cross section occupied with particles is approximated to the volume fraction

The volume fraction can be determined with knowledge of the sum of the logical array and the size of the array:

```
vf = sum(~img) / numel(img)
```

Volume Fraction

Over 400 laboratory and pilot scale electroplating experiments were performed



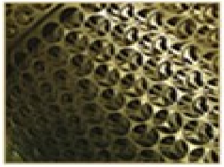
At least ten micrographs were produced from each plating cycle, microscopy and image analysis took approximately 1hr per cross section

Originally volume fraction analysis was performed manually using image manipulation software

Automation with MATLAB reduced measurement time by over 50%

The Royal Mint

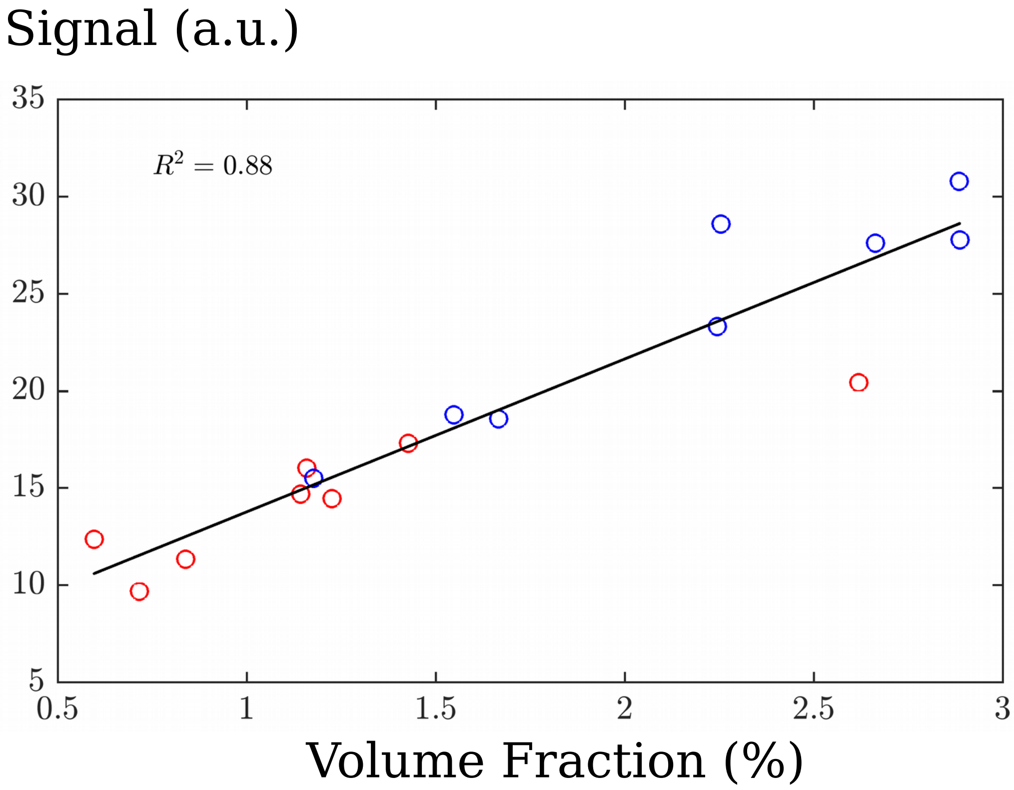
Volume Fraction

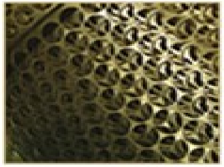


Rapid comparison of process treatments with other measurement methods

Reproducible comparison metrics

Automated report generation using MATLAB + LaTeX





Example Applications

<u>Inputs</u>

Electrolyte
- Temperature
- Composition
- pH
- Additives
- Colloidal stability
- Turbulence

Electrochemical
- Charge transfer
- Mass transfer
- Polarisation

<u>Model</u> →

<u>Outputs</u>

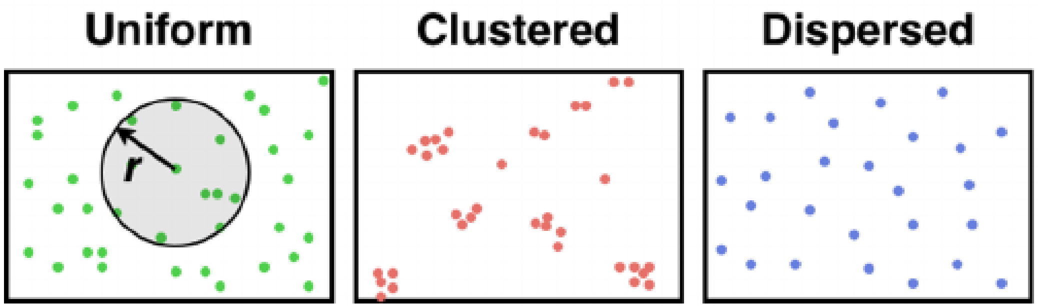
Deposit Properties
- Ductility
- Chemical resistance
- Surface finish
- Volume fraction
- Optical properties
- Wear characteristics
- **Dispersion**

The Royal Mint

Phase Dispersion

A good dispersion of the security feature throughout the nickel matrix is critical for a good quality product

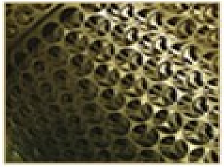
Clustering will produce a product with a variable authentication signal through out the lifetime of the coin



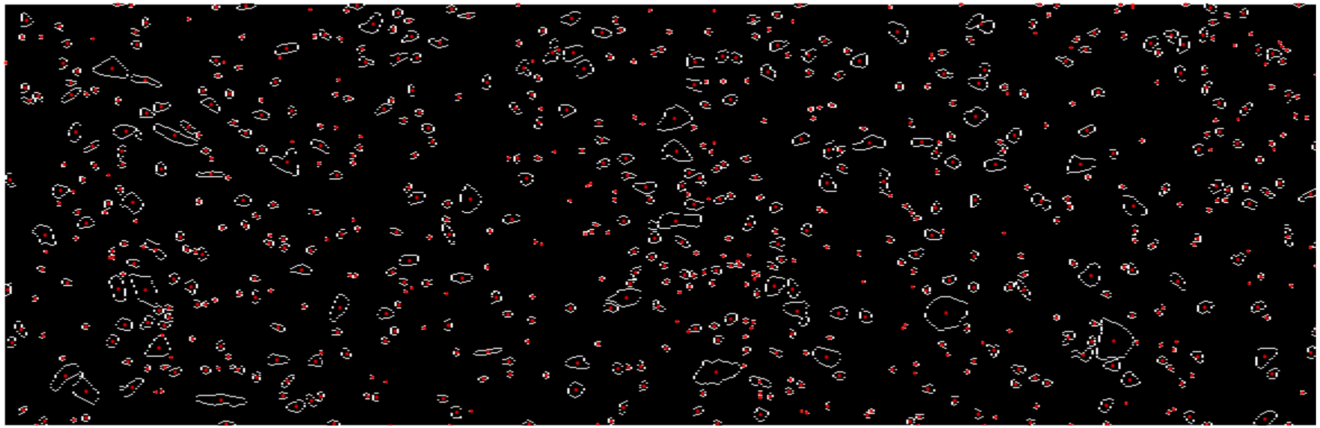
[1] T. Lagache, et al. PloS One (2013)

Phase Dispersion

Edge detection methods provided by The Image Processing Toolbox were used to logically define the perimeters of the security feature inclusions

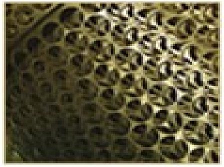


Each centroid was then determined, again using image processing functions



The Royal Mint

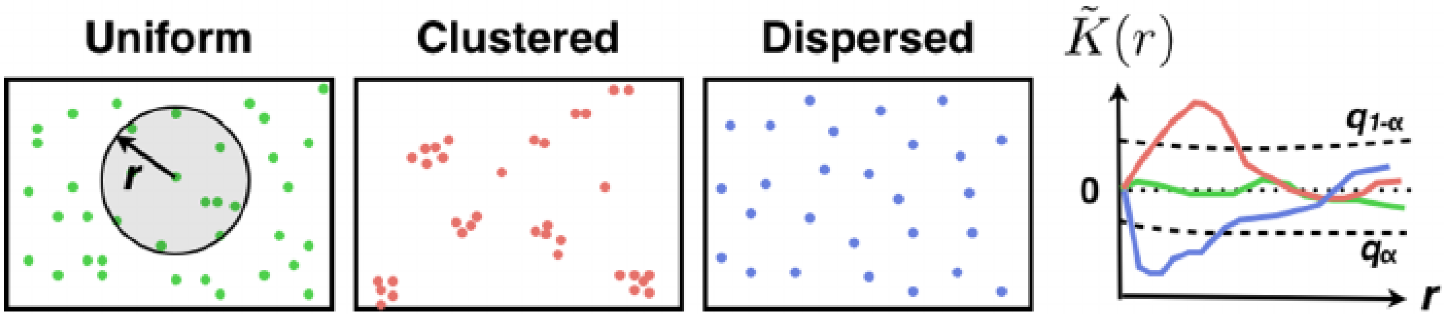




Phase Dispersion

From the centroids, the level of clustering can be determined by applying statistical methods

Ripley's K function was applied to the data to determine the degree of spatial clustering



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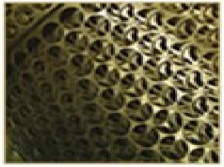
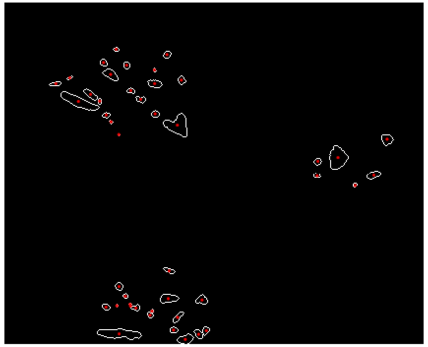
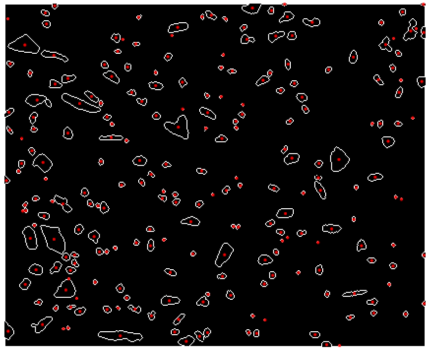
Phase Dispersion

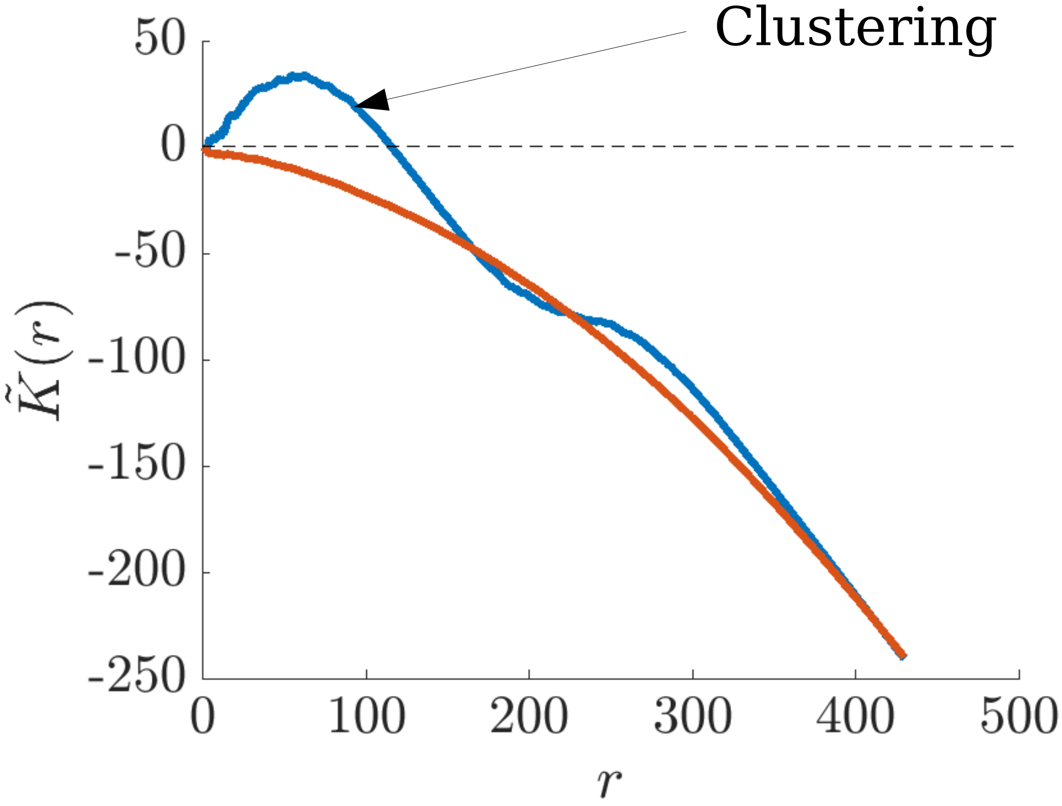


Treatment 1



Treatment 2

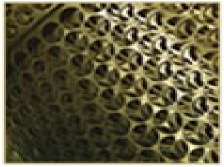




The Royal Mint

Phase Dispersion

Analysis of the dispersion was only performed infrequently due to the lengthy analysis time

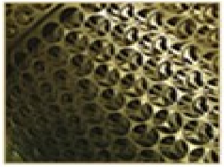


Dispersion analysis, and other validation methods, could be performed with each automated volume fraction measurement - incurring less than a 5s increase in processing time

Statistically significant clustering, not visually discernible was unexpectedly detected from some process treatments

Provided an important metric to analyse treatments that would have otherwise not have been performed





Example Applications

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- Colloidal stability
- Turbulence

Electrochemical
- Charge transfer
- Mass transfer
- Polarisation

Model →

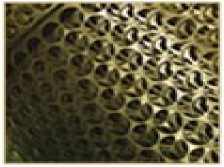
Outputs

Deposit Properties
- Ductility
- Chemical resistance
- Surface finish
- Volume fraction
- **Optical properties**
- Wear characteristics
- Dispersion

The Royal Mint

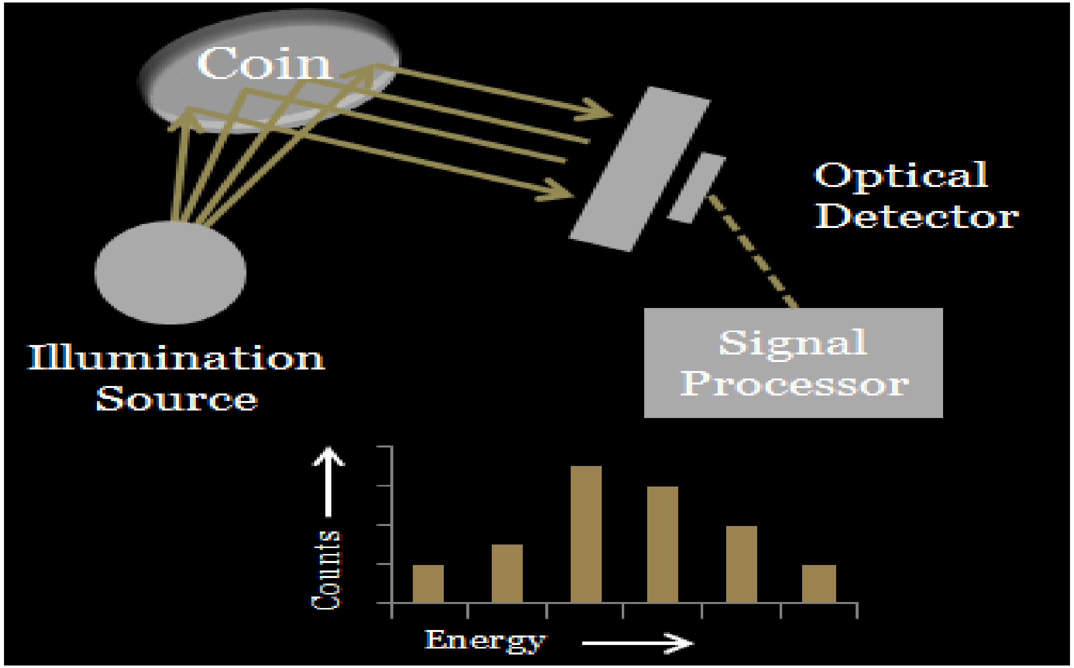
Detection of the Security Feature

Over 100M new £1 coins were manufactured before launch

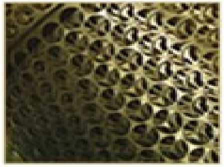


Security feature detectors were not achieving predicted pass rates

Over 50% failure rate after 50M £1 coins were produced!



Detection of the Security Feature



Each of the 50M coins were validated through a coin sorter as part of the telling process

Data recorded includes thickness, gauge, EMS parameters and the high security feature signal data

Historical data was imported into MATLAB

Oscilloscope readings were performed as the coin moved through the detection window and analysed using the Signal Processing Toolbox

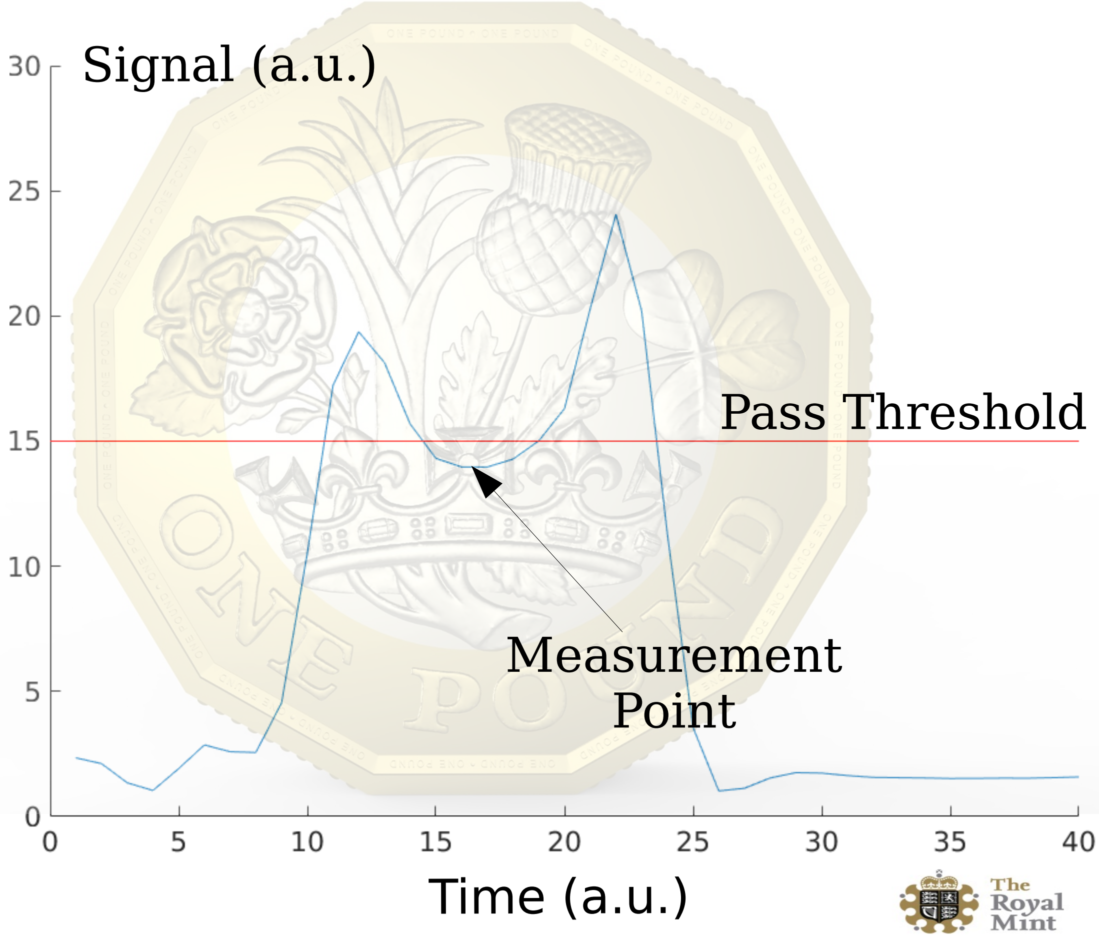
As the coins moved past the security feature detector changes in the measured signal were observed

Detection of the Security Feature

A larger signal near the edge of the nickel plated inner was discovered

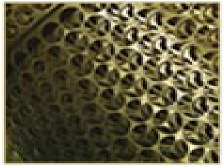
Measurement was performed at the centre of the coin

A narrower detection window was the cause of the unexpected failures



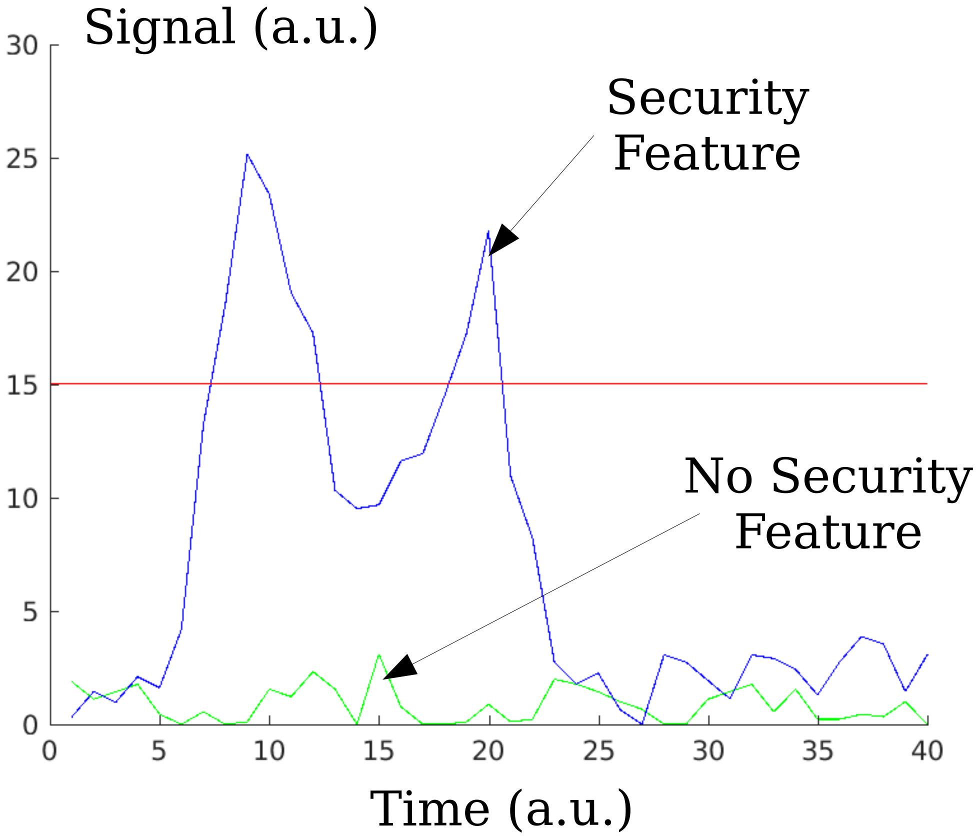
The Royal Mint

Detection of the Security Feature



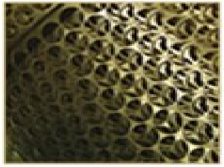
Pound coins without the security feature were compared to coins with the security feature

Data was imported and 100% authentication was achievable using basic signal processing methods



Detection of the Security Feature

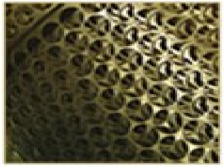
Pass/fail logic was controlled by an embedded system installed in the coin sorters



Alternate functions, mimicking the capability of the embedded controller, were prototyped offline

Accurate pass rates were determined using historic data without reprogramming controllers

Detection of the Security Feature



Once a suitable detection method was determined it was rolled out into production

Problem was solved in only a few days with no downtime of the telling machines

100% of the 25M rejected £1 coins were reclaimed and 100M £1 coins were produced on time in anticipation of the launch!

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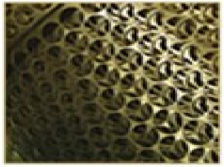

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Established for Tomorrow

Thank you for listening

Any questions?