Department of Food and Nutritional Sciences

University of Reading

# Process Analytical Technology Tools in Dairy Processing

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# INTRODUCTION:
# PAT AND DAIRY PROCESSING

# Process Analytical Technology (PAT)

- PAT system
  - designing, analysing, controlling
  - timely measurements (i.e., during processing)
  - critical quality and performance attributes
  - raw and in-process materials
  - Final product quality
- *Analytical* includes:
  - chemical, physical, microbiological, mathematical, and risk analysis
  - conducted in an integrated manner
- PAT Tools

# PAT Food Industry

- PAT tools & analyzers known within food industry for decades
- Previous focus to implement [illegible]lyzers in the production process just [illegible]e measurements to monitor the pr[illegible]
- More recent [illegible]way from implementation of on-/in-li[illegible] monitoring product attributes
- Now [illegible] PAT technologies to understand and control the whole manufacturing process
- Consistently ensure a predefined quality at the end of the manufacturing process.

Quality by design

# Process Variation

- uncontrolled disturbances
  - milk changes
  - temperature of surroundings

- Ideally -> no change to uncontrolled variables.

- Real world -> change uncontrolled variables -> variable product quality

- Determine optimum settings for the process set point during the manufacturing process

| Product | Unit operation | Technology | | | | |
|---|---|---|---|---|---|---|
| | | NIR | MIR | MW | T | C |
| Raw milk | Compositional analysis | | **** | | | |
| | Authenticity | | * | | | |
| Cheese | Compositional analysis | **** | | *** | | |
| | Fermentation | ** | ** | | | |
| Butter | Compositional analysis of raw materials | **** | **** | | | |
| | Compositional analysis | **** | | | | |
| Cream cheese | Compositional analysis of raw materials | | **** | | | |
| | Fermentation | | ** | | | |
| | Separation | *** | | ** | | *** |
| | Compositional analysis | *** | *** | | | |
| Whey | Compositional analysis | | **** | | * | |
| | Fractionation | | *** | | | |
| WPC | Compositional analysis | *** | | | | |
| WFC | Compositional analysis | ** | | | | |
| Milk powder | Compositional analysis | | *** | | | |

# PAT TOOLS IN CHEESE MANUFACTURE RESEARCH DEVELOPMENTS

# Technological Steps Cheese Processing

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Milk reception

Milk pretreatments

Milk coagulation

Curd Cutting

Syneresis

Molding

Pressing

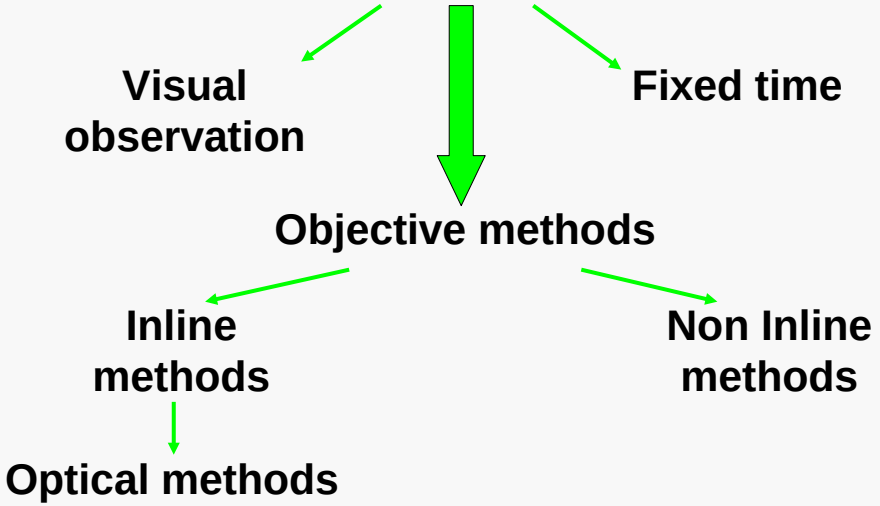
Salting

Ripening


Cheese packaging

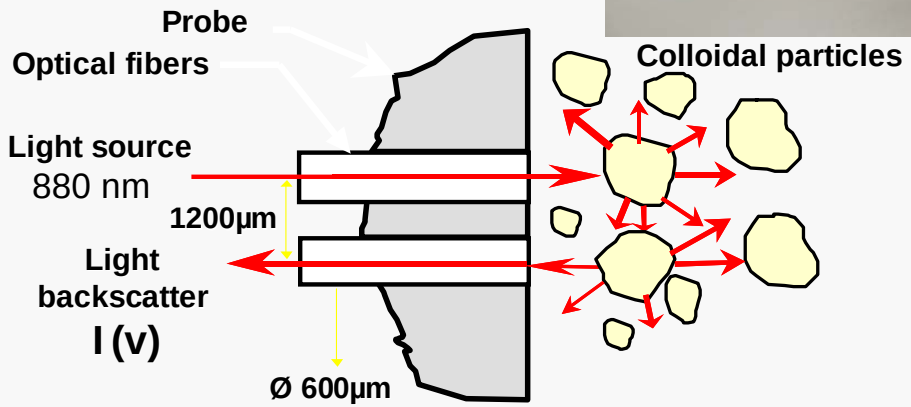
# Milk Coagulation & Curd Cutting

## Cutting time determination




**CoAguLite sensor**

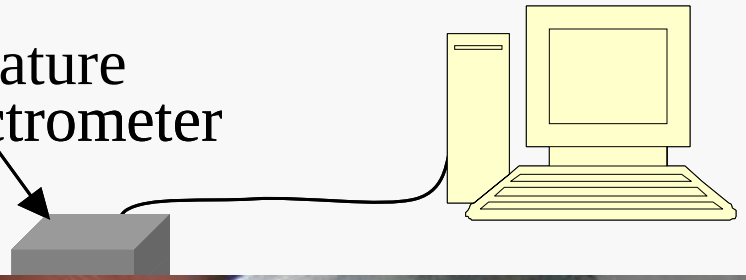
**(Reflectronics, KY USA)**




**Cutting time = $\beta$ * $t_{max}$**

# Curd Syneresis

*Large Field of View (LFV) Sensor*

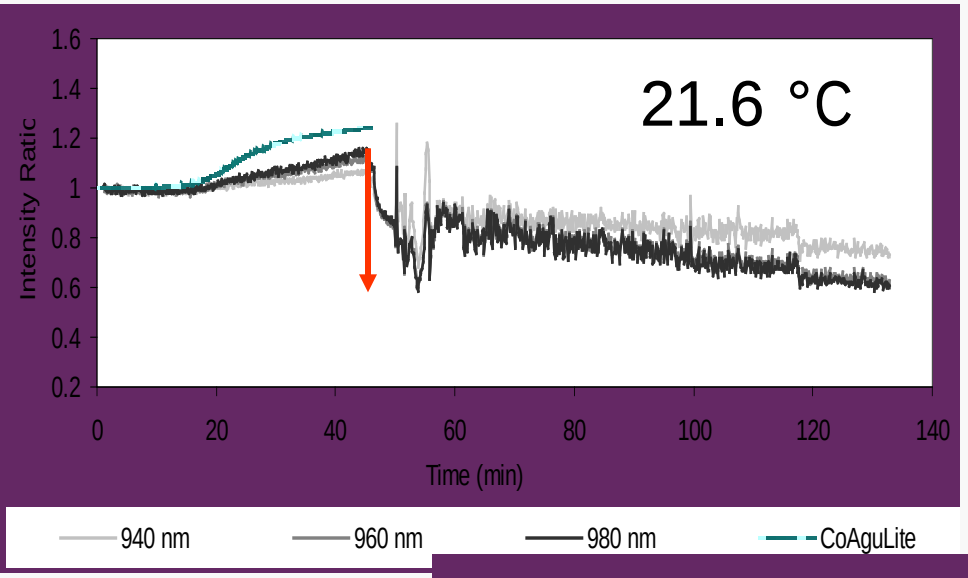


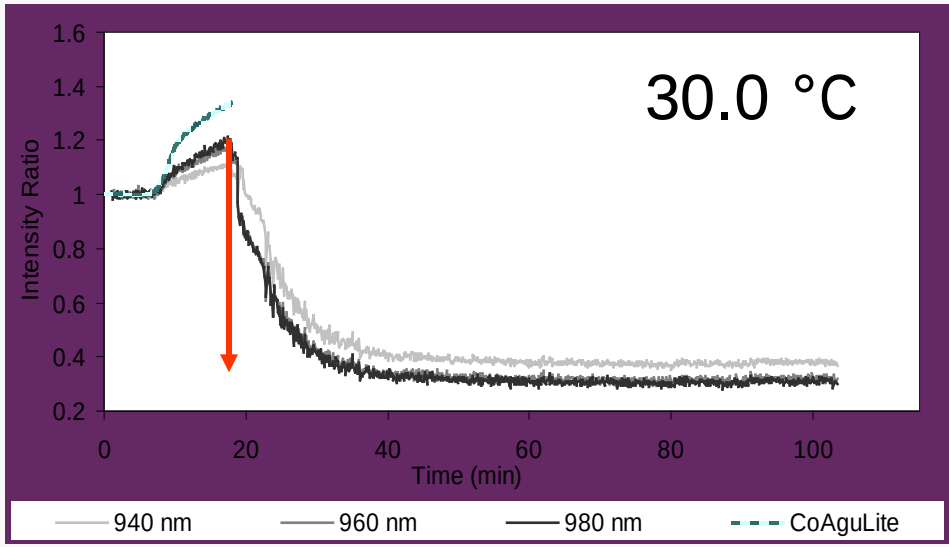

Glass windowprobe

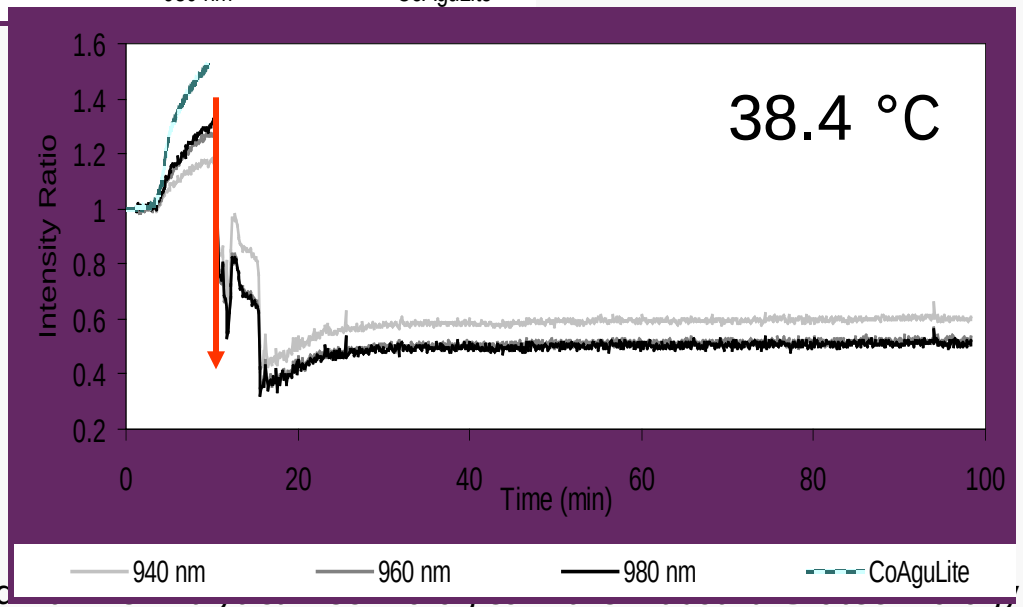
Optical

Light Source

# LFV Response - Temperature




SCI: On-Line and Sector

# Modelling LFV Sensor Response

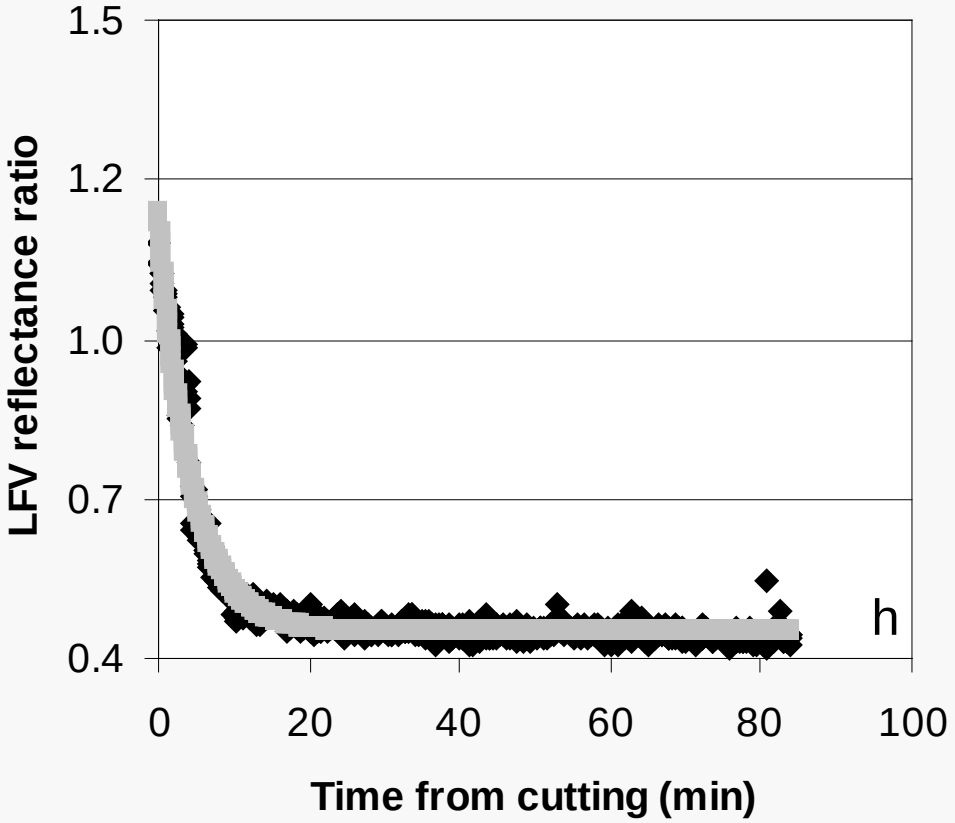
$$R_t = R_\infty + \left(R_0 - R_\infty\right)e^{-k_{LFV}t}$$

$R_t$ = light backscatter ratio during syneresis at time $t$ (min)

$R_\infty$ = light backscatter ratio during syneresis at an infinite time

$R_0$ = light backscatter ratio during syneresis at *cutting time*

$k_{LFV}$ = kinetic rate constant ($min^{-1}$) for the LFV sensor response during syneresis



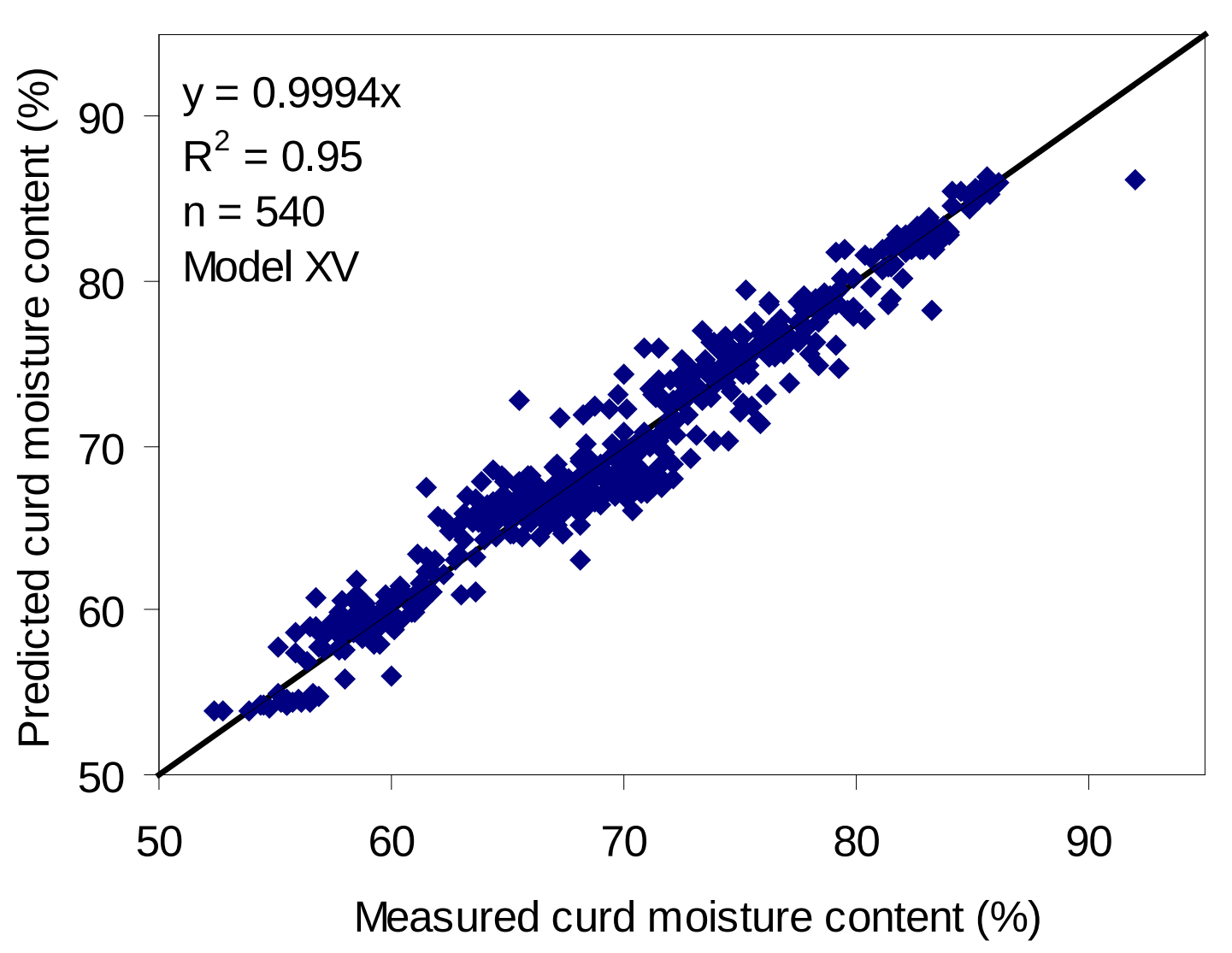
# Prediction Model

- Curd moisture as a function of processing time predicted with SEP of 1.72%

$$CM_t = CM_\infty + (CM_0 - CM_\infty)e^{-k_{CM}t}$$

$$CM_\infty = (\beta_0 + \beta_1 T + \beta_2 t_{\max} + \beta_3 F_m + \beta_4 FP_m)$$

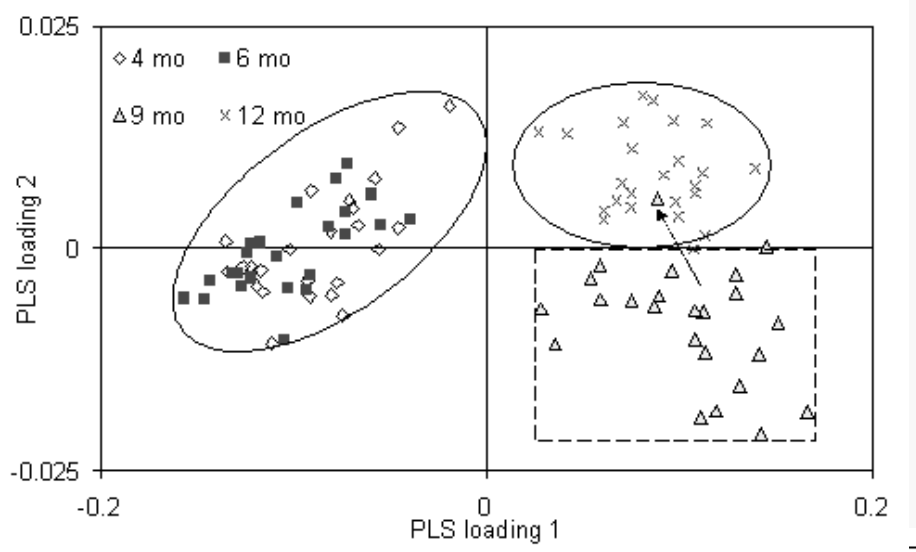
$$k_{CM} = \beta_5 T^2 + \beta_6 t_{\max} + \beta_7 k_{LFV15}$$


y = 0.9994x
R2 = 0.95
n = 540
Model XV
Predicted curd moisture content (%)
Measured curd moisture content (%)
50
60
70
80
90

# Cheese Ripening

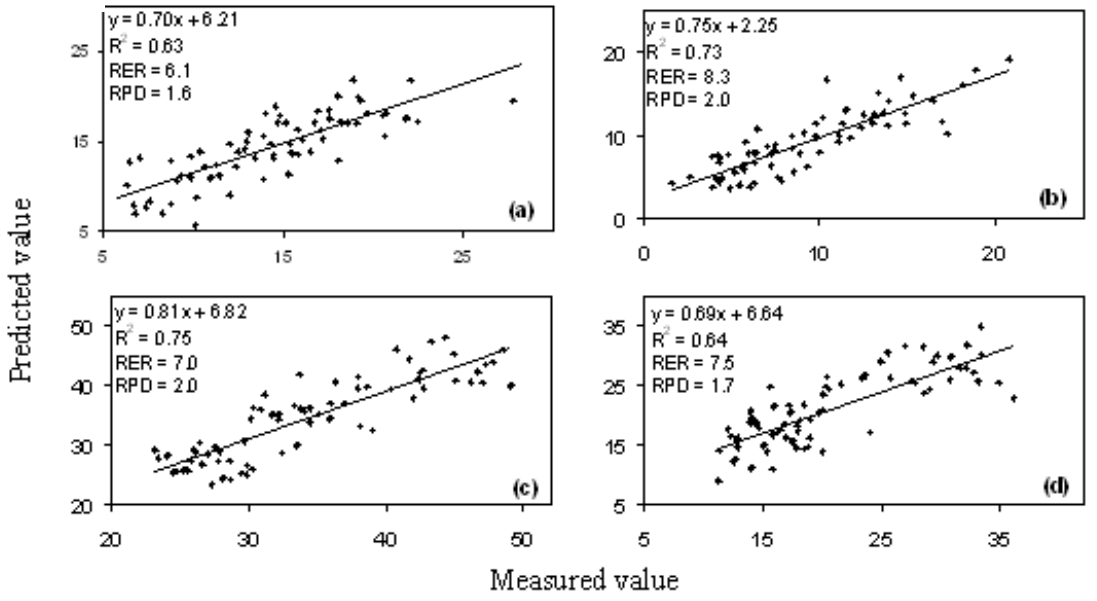
- Cheddar Cheese
- Grading performed after one month
- 3 month to assign each batch to a category.
  - Mild sold 3 to 5 months
  - Medium sold 6 to 8 months
  - Mature sold 9 to 12 months
  - Vintage 12 to 18 months.

# NIR / FTIR spectroscopy: monitoring cheese ripening




Age

(a) rubbery (b) crumbly
(c) chewy (d) massforming



NDC Infrared Engineering
InfraLab e-Series At-Line Analyzer

www.ndcinfrared.com

FoodScan Dairy Analyzer

Foss

http://www.foss.us

DA 7250 NIR Analyser
Perten

http://www.perten.com/

# Hyperspectral Imaging (HSI)

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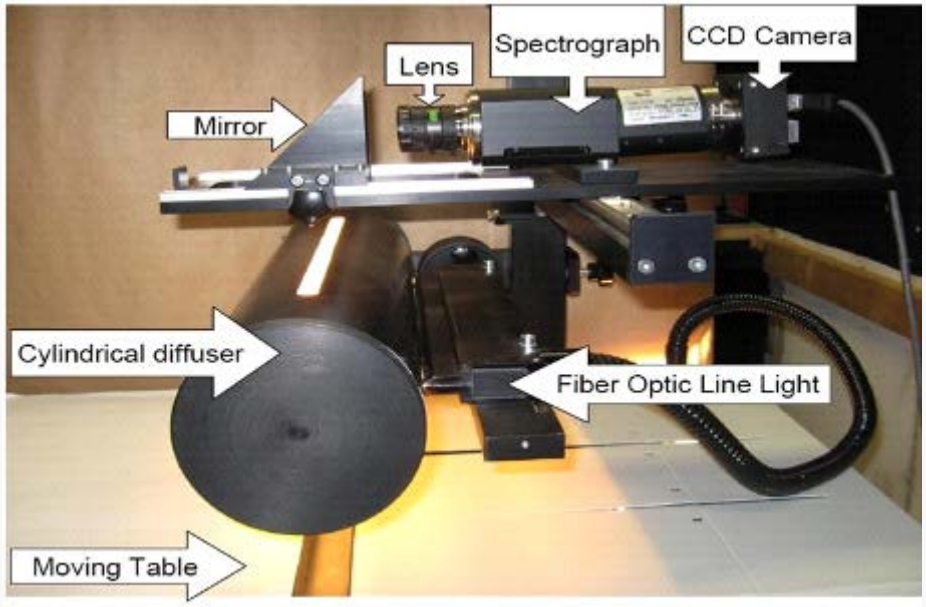
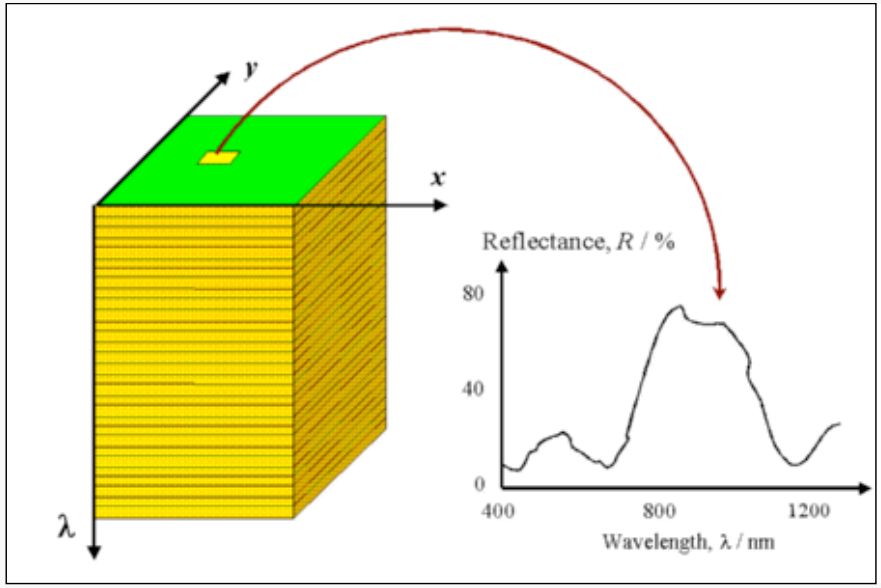
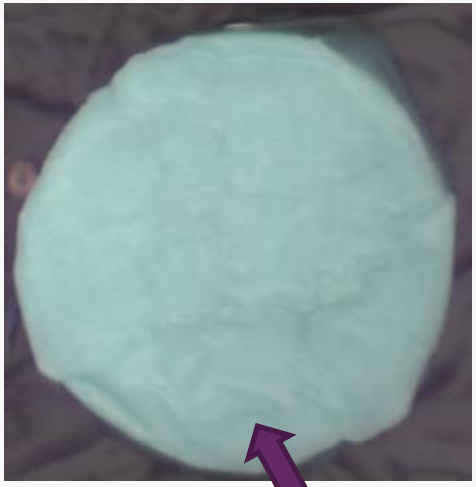


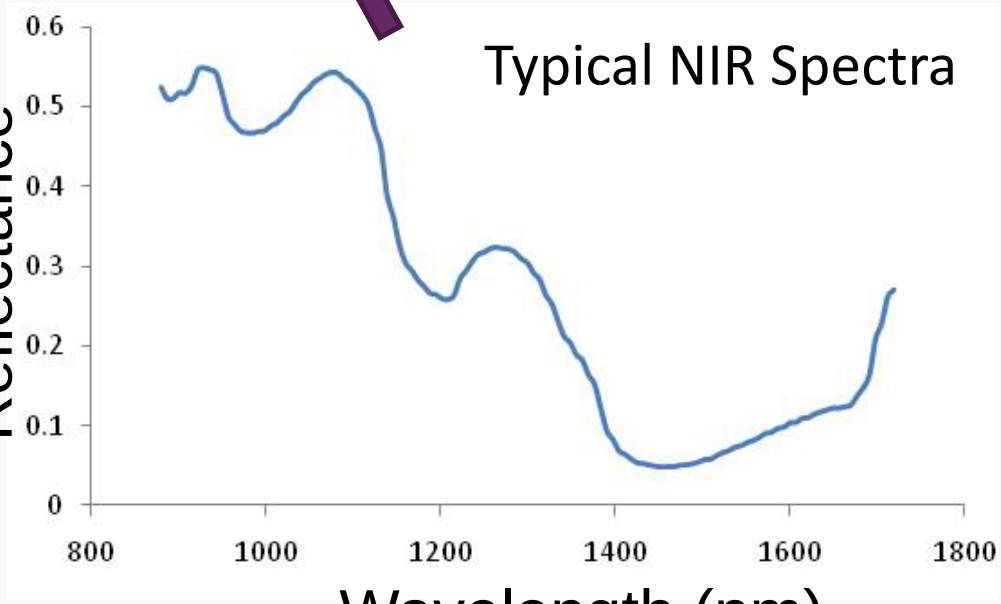




HSI emerging platform technology that integrates conventional computer vision and spectroscopy. It combines the advantages of both technologies by providing spatial, spectral, and multi-constituent information, while also being sensitive to minor constituents.

# NIR-HSI Image of cheese


RGB Image of cheese





# The Potential Of Hyperspectral Imaging To Map Variations In Cheese Composition

# Materials & Methods

- ***Cheese Manufacture and Analysis***
- Cheeses produced in triplicate (10 L milk)

- Recombined milk
  - 3 milk fat levels (0, 2.5 & 5.0 g/100 g)
  - constant protein level (3.3 g/100 g)

- Gel cut when the storage modulus (G') = 35 Pa

# Materials & Methods

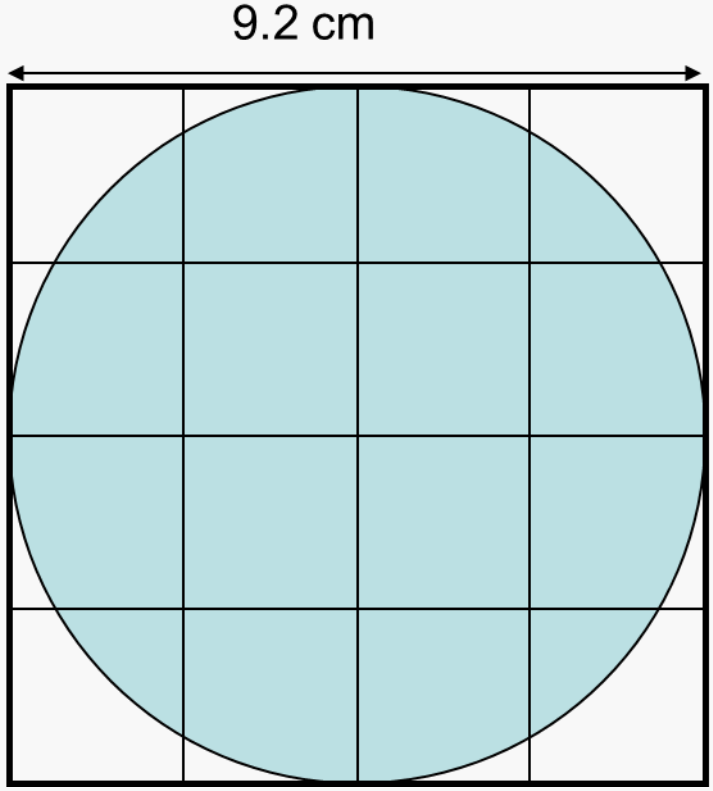
- ***Hyperspectral Imaging***

- Hyperspectral images obtained

- Pushbroom line-scanning HSI instruments (DV Optics Ltd., Padua)
  - NIR system 880-1720 nm, resolution: 7 nm, 320 × 280 pixels
  - Spectral Scanner software: image acquisition
  - Internal & external

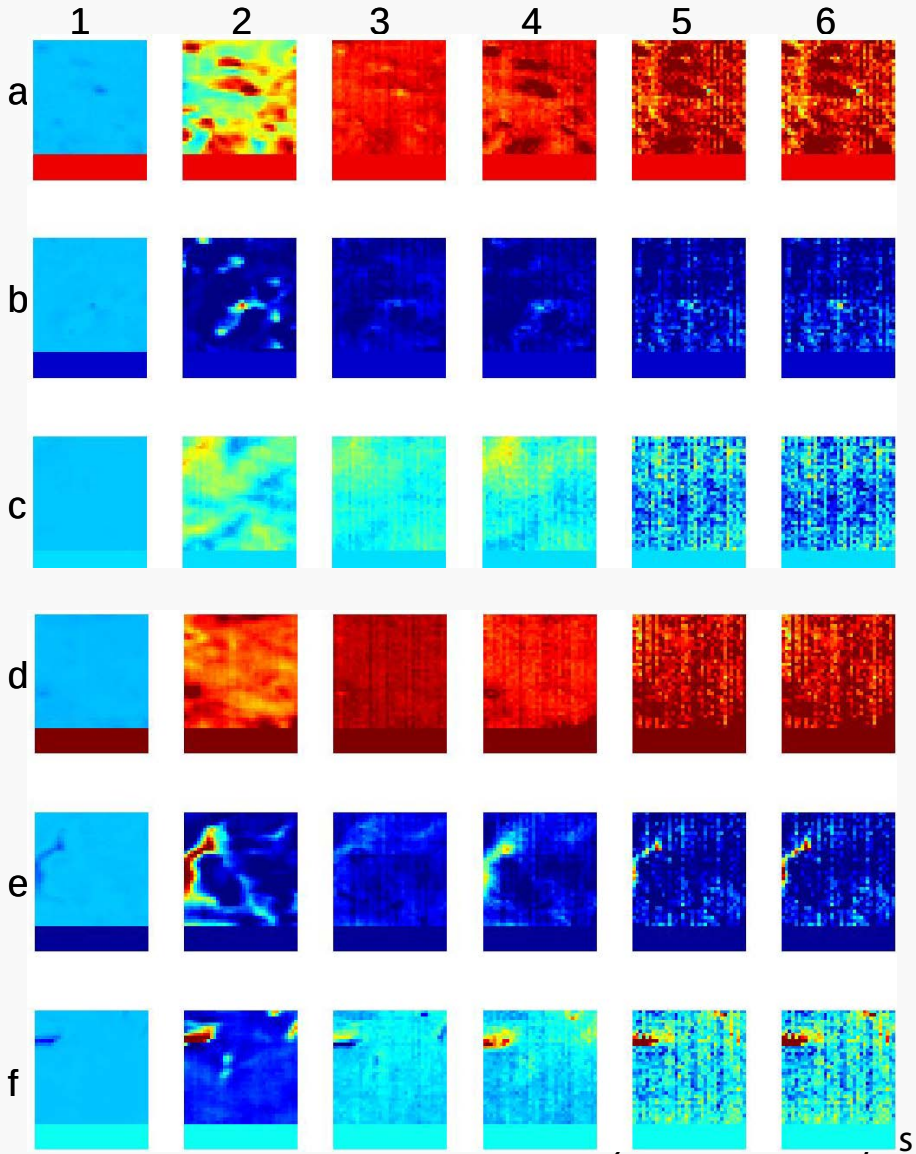
# Materials & Methods

- ***Analysis***
- Four subsamples of each cheese extracted using a cheese borer
  - moisture (2 subsamples)
  - fat content (2 subsamples)



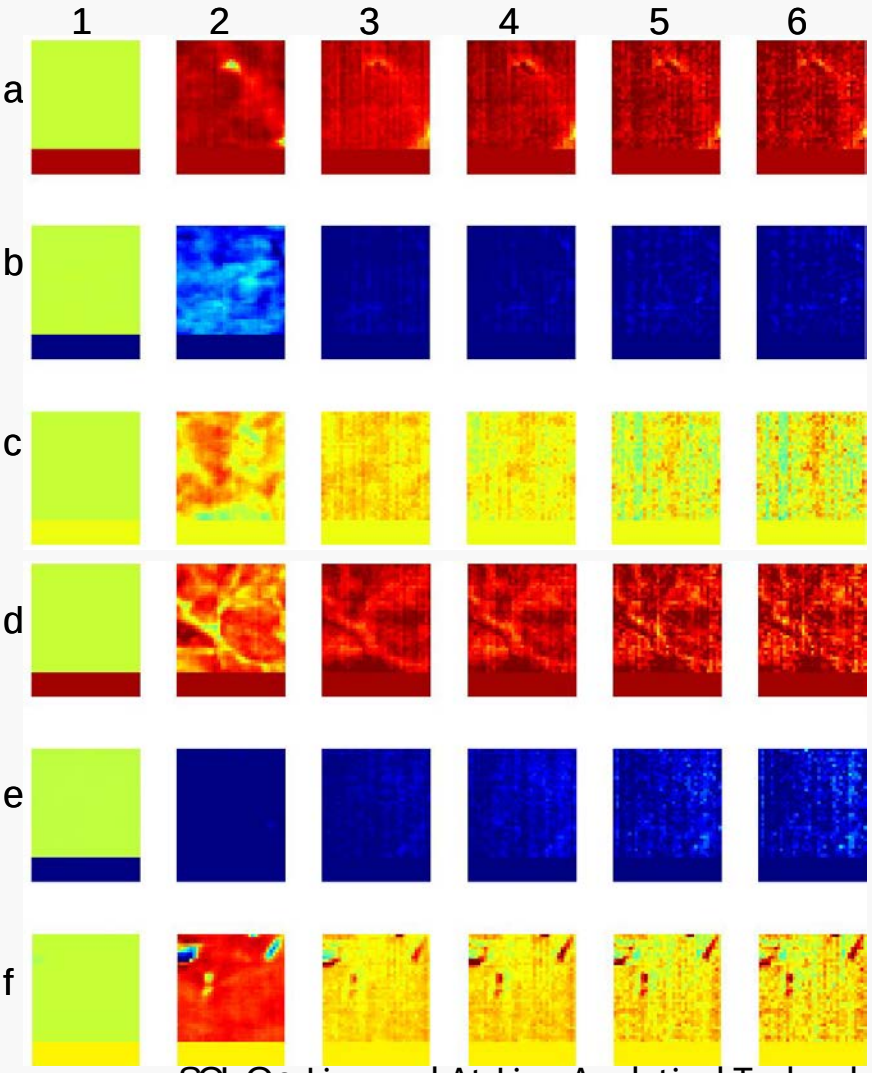

- average spectrum corresponding to each subsample was extracted, pretreated by standard normal variate, & subjected to PLS regression using full cross validation (n = 36).

# Moisture prediction maps



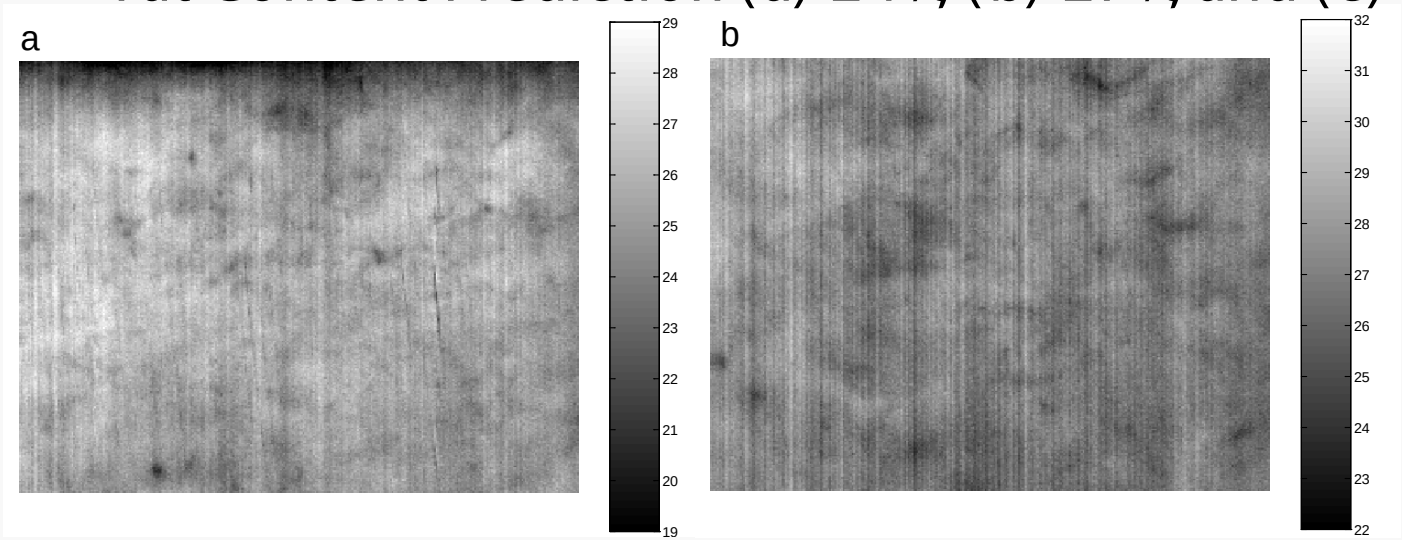

NIR SNV data.1 – 6 indicates the number of LV in the model applied to the image, colour bars below images represents the average moisture content (a: 59.6 % b: 45.9 % c: 50.4 % d: 61.5 % e: 45.0, f: 51.1 ) for that cheese subsample, (a-c: calibration set images; d-f: test set images).

# Fat prediction maps




NIR SNV data. 1 – 6 indicates the number of LV in the model applied to the image, colour bars below images represents the average fat content (a: 31.1 % b: 0 % c: 19.8 % d: 31.4 % e: 0% f: 20.44%) for that cheese subsample, (a-c: calibration set images; d-f: test set images)

# Fat Content Prediction (a) 24%, (b) 27% and (c) 38%



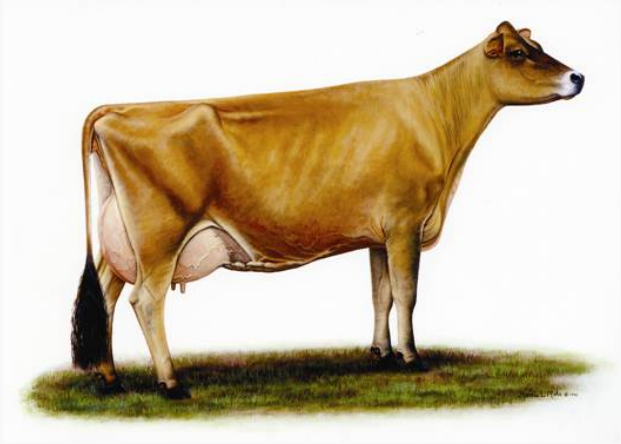

SCI: On-Line and At-Line A chnology Sector

# What is required

- Number of PAT tools

- the PAT strategy will require buy-in from personnel who will be operating the technology

- Process Development/Research
- Process understanding
- Process improvement



Effect of including Jersey milk in Holstein-Friesian milk supplies on Cheddar cheese yield and quality

# APPLICATION OF PAT TOOLS

# The project background

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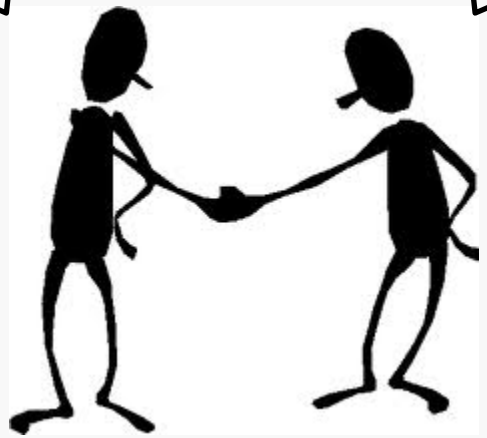
We want to find new markets for Jersey milk

We want to increase cheese-making efficiency

UK Jerseys

Pocock Memorial Trust

Dartington Cattle Breeding Trust



Lye Cross Farm – Alvis Family – Farmers and Cheesemakers

The Royal Bath & West of England Society – Patron Her Majesty The Queen

Wyke Farms – Somerset Farming Since 1861

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Dairy Science & Technology

PAT Tools

SCI: On-Line and At-Line Analytical Technologies in the Industrial Biotechnology Sector

# Conclusions

- PAT Framework
  - Not fully exploited in food industry
- Develop appropriate sensing technologies
    - Traditional, emerging , robust, cost
- Buy-in from all levels in industry
  - Product & Process understanding
  - Sustainability: environmental, economic
- Integrate food science, process engineering, statistic, photonics, data management

# Acknowledgments


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