WASTE PROCESSING

New near infrared technologies for material identification and selection.

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Outline

- What is waste, who produce it, the numbers
- Sorting techniques
- Spectroscopic technologies
- Data analysis methods
- NIR technology for material identification and selection
- Recycled aggregates from demolition waste selection
- PET and PVC separation
- List of some EU sorting companies

Waste classification:

Municipal solid wastes (MSW) residential and industrial (non-process wastes), commercial and institutional sources. Materials, which are organic or recyclable, are excluded from this definition.

Construction and demolition (C&D) waste consists of materials which are normally produced as a result of construction, demolition, or renovation projects. Includes, but is not limited to, soil, asphalt, brick, mortar.

Hazardous wastes are substances which are potentially hazardous to human health and/or the environment. Hazardous wastes are typically classified by product type.

Table 1: Waste streams classified by source (adopted from Tchobanoglous & Kreith, 2002)

Source	Facilities, activities, or locations where wastes are generated	Types of solid wastes
Residential	Single-family and multifamily dwellings; low-,medium, and high-density apartments. Can be included in IC&I sector	Food wastes, paper, cardboard, plastics, textiles, yard wastes, wood, ashes, street leaves, special wastes (including bulky items, consumer electronics, white goods, universal waste) and household hazardous waste.
Commercial	Stores, restaurants, markets, office buildings, hotels, motels, print shops, service stations, auto repair shops.	Paper, cardboard, plastics, wood, food wastes, glass, metal wastes, ashes, special wastes, hazardous wastes
Institutional	Schools, universities, hospitals, prisons, governmental centers	Same as commercial, plus biomedical
Industrial (non-process wastes)	Construction, fabrication, light and heavy manufacturing, refineries, chemical plants, power plants, demolition	Same as commercial
Municipal Solid waste	All of the preceding	All of the preceding
Construction and Demolition	New construction sites, road repair, renovation sites, razing of buildings, broken pavement	Wood, steel, concrete, asphalt paving, asphalt roofing, gypsum board, rocks and soils.
Industrial	Construction, fabrication, light and heavy manufacturing, refineries, chemical plants, power plants, demolition	Same as commercial, plus industrial process wastes, scrap materials
Agricultural	Field and row crops, orchards, vineyards, dairies, feedlots, farms	Spoiled food, agricultural waste, hazardous waste

Waste numbers:

1,3 billion tons per year of Municipal Solid Waste

⬇

2.2 billion tons per year by 2025

from 1.2 to 1.42 kg per person per day in the next ten years

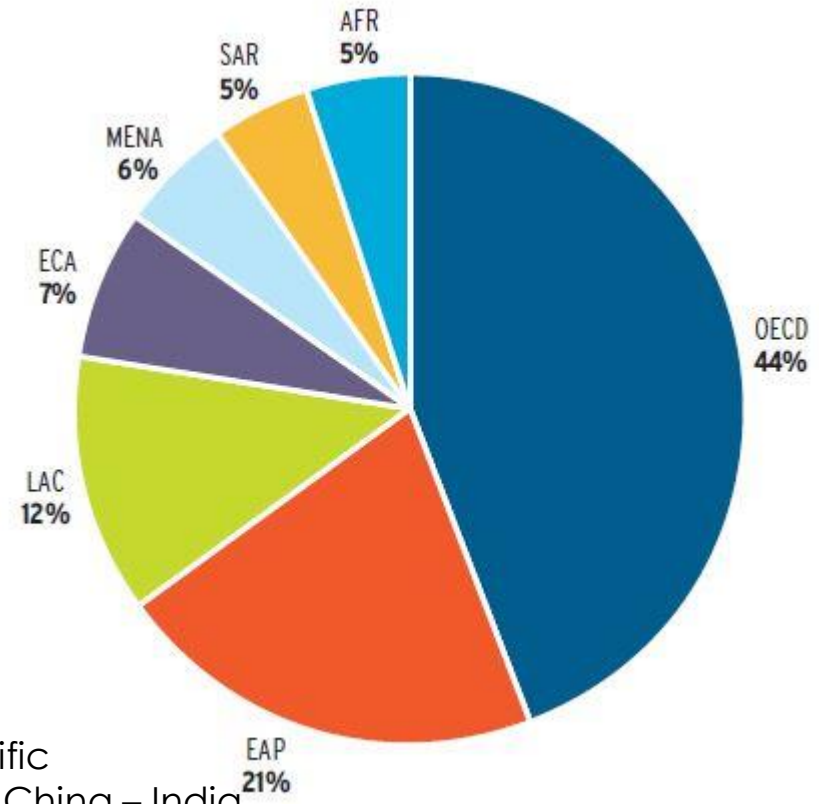
Source: What a waste 2012

Rates vary considerably by region, country, city, and even within cities.

MSW generation rates are influenced by economic development, the degree of industrialization, public habits, and local climate

Waste numbers:

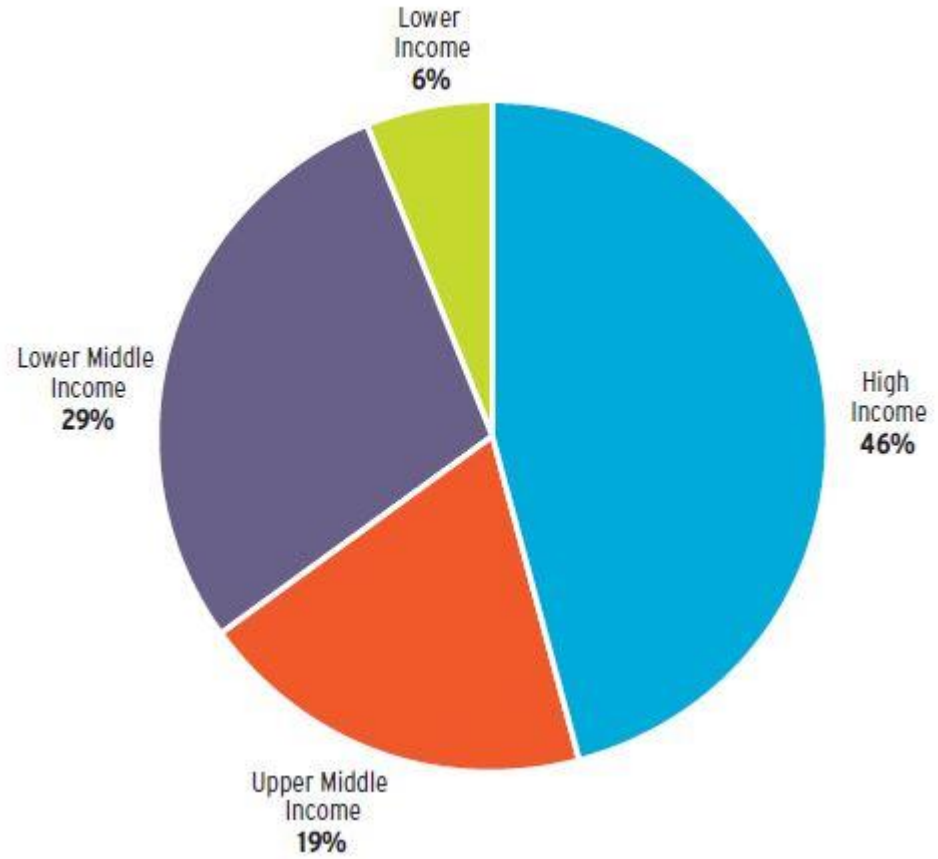
Waste generation by region



Africa
South Asia
Middle East
Europe
Latin America
Est Asia and Pacific
North America – China – India

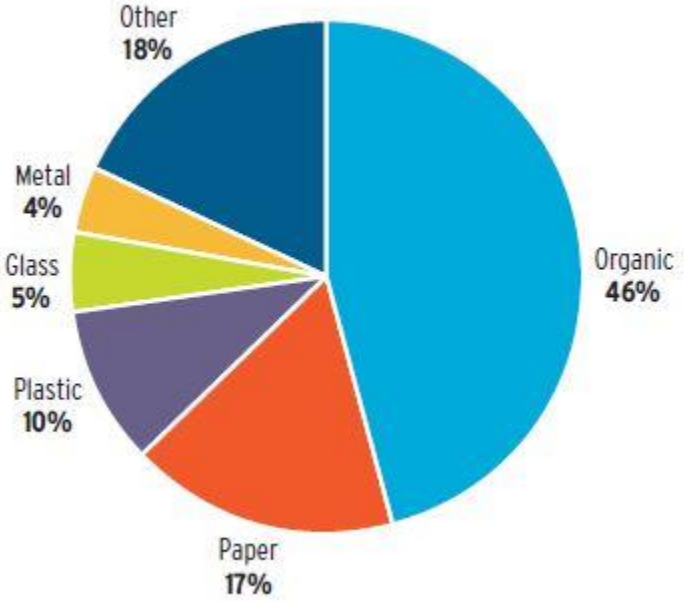
- OECD countries produce almost half of the world's waste, while Africa and South Asia regions produce the least waste.

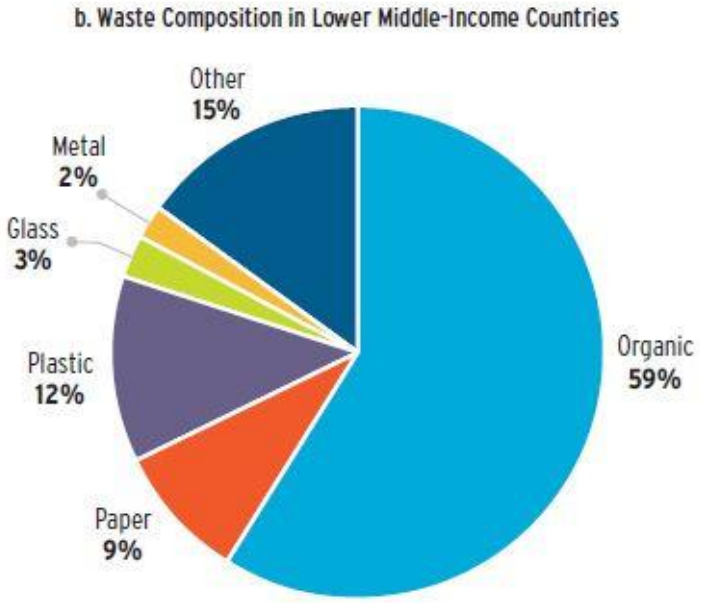
Waste generation by income

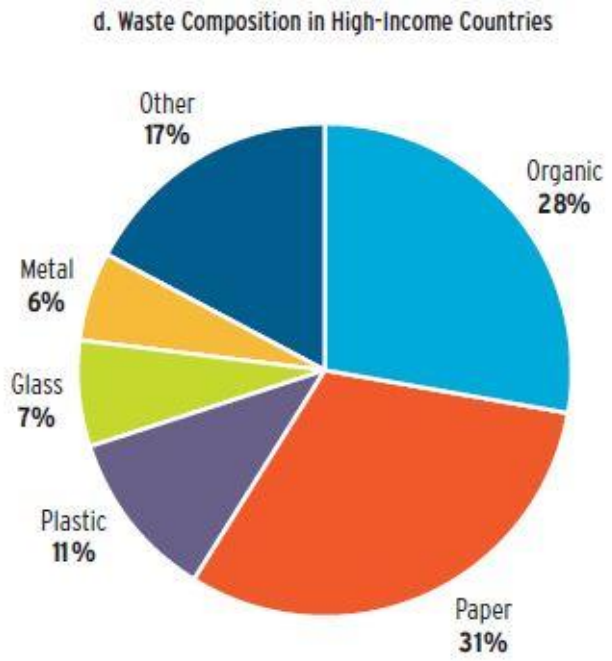


- The higher the income level and rate of urbanization, the greater the amount of solid waste produced.

Waste numbers:







- Low-income countries have the highest proportion of organic waste.
- Paper, plastics, and other inorganic materials make up the highest proportion of MSW in high income countries.

The EU contest:

Sorting of waste is becoming increasingly important

The EU countries differ how and which waste separate

The trend will be to separate as much useful waste as possible and deal with it in the most appropriate manner.

EU Legislation:
50% of all household waste
70% of all construction waste
re-used or recycled by the year 2020

⬇

Need of effective and economical sorting processes

Industry requirements:

- Pure, high quality production
- Efficient work
- Low cost

Competitiveness against developing countries → Low labor cost

Industry demand:

Raw material sorters, conveyors and processing systems

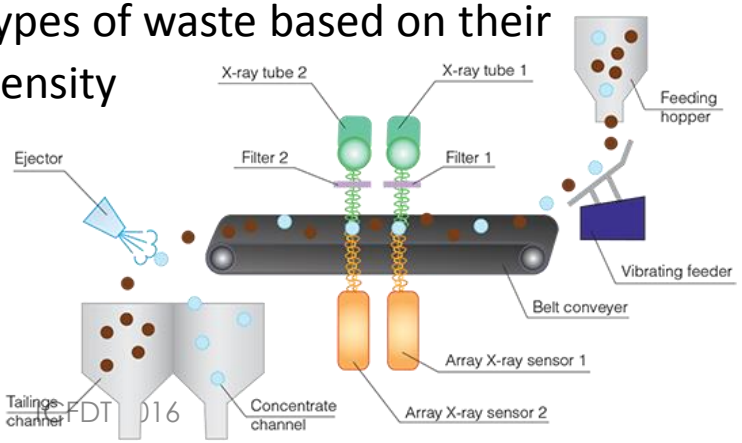
- ✓ easy to install
- ✓ energy efficient
- ✓ reliable
- ✓ low-maintenance
- ✓ simple to adjust and control
- ✓ network connectivity capabilities for remote monitoring

Effective recycling relies on effective sorting

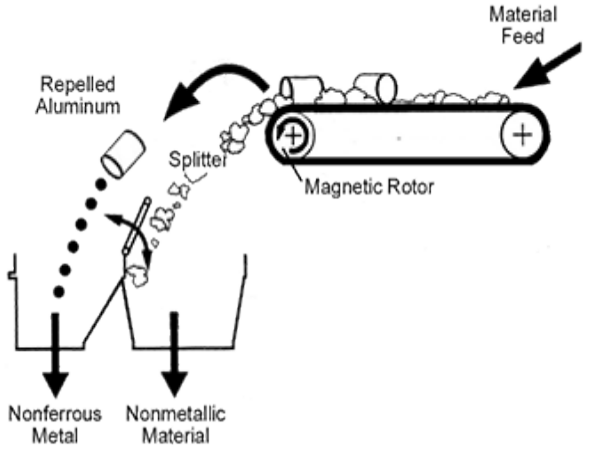
Sorting techniques

- **Trommel separators/drum screens** These separate materials according to their particle size.

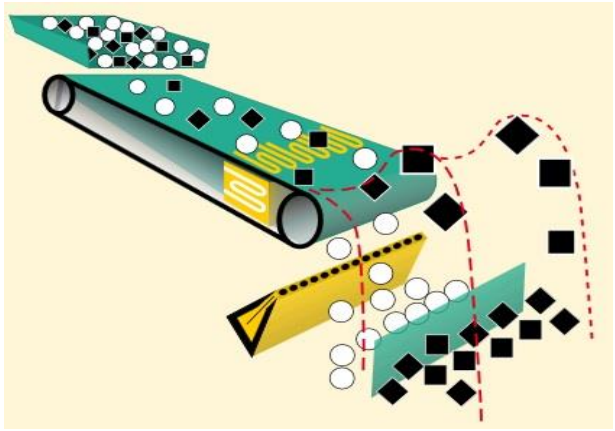
- **X-ray technology** can be used to distinguish between different types of waste based on their density



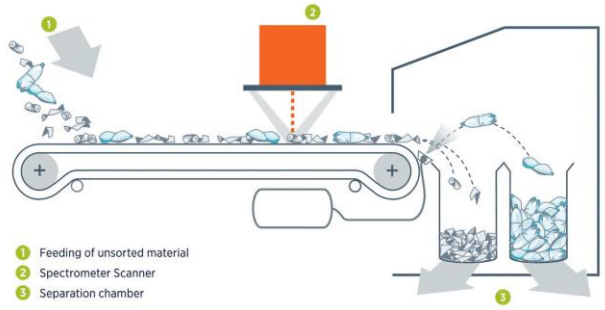
- **Magnetic and Eddy current separator** This methods are specifically for the separation of ferrous and nor ferrous metals.



- **Induction sorting** This method locate different types of metals and stainless steel from shredder residue



- **Light sensors** use the reflect light characteristics to distinguish between different materials



- **Manual sorting** is still very much a technique that is used in the world today

Technologies for quality evaluation:

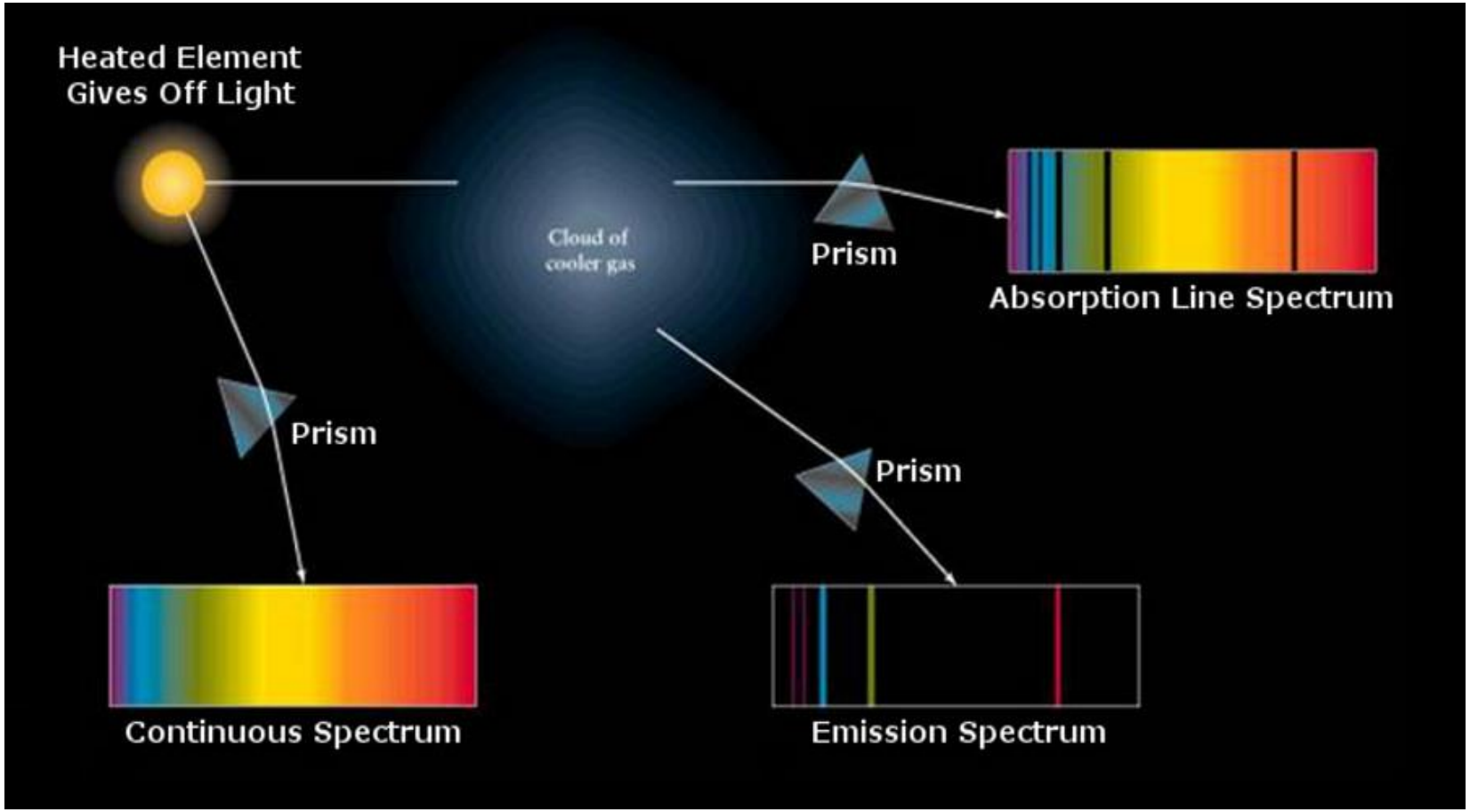
Detect physical properties → quality factors

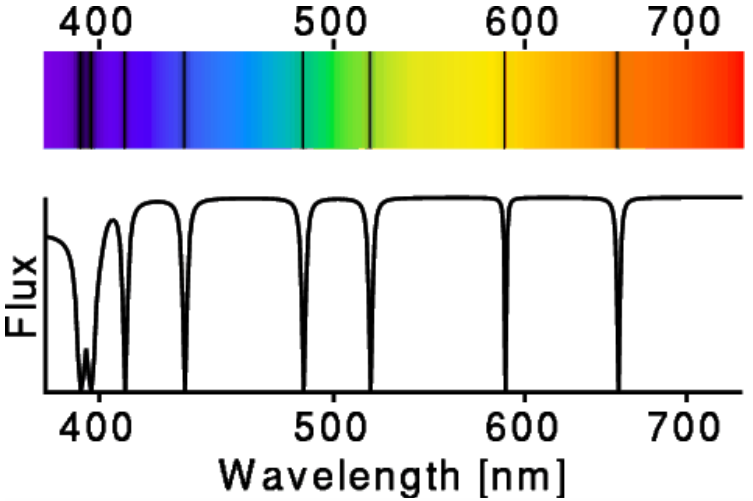
Electrical properties
Magnetic properties
Density
Vibrational characteristics
X-ray transmission
Optical reflectance and transmission
…

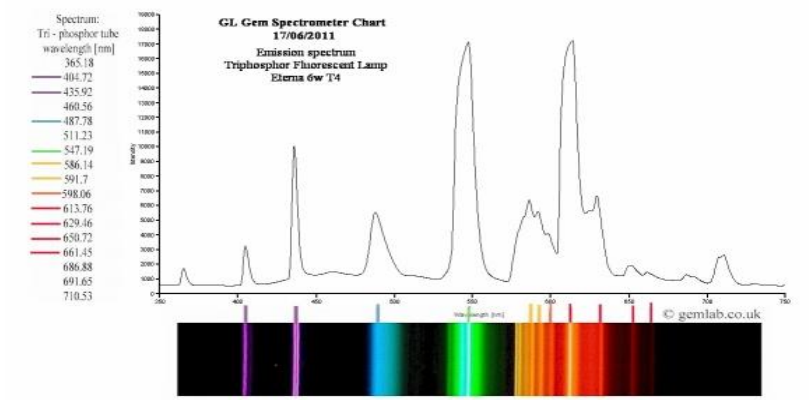
Advantages and limitations:

- image resolution
- imaging duration
- safe handling
- sample-specific requirements
- availability of details such as surface color, texture

Light spectra







Spectral technologies:

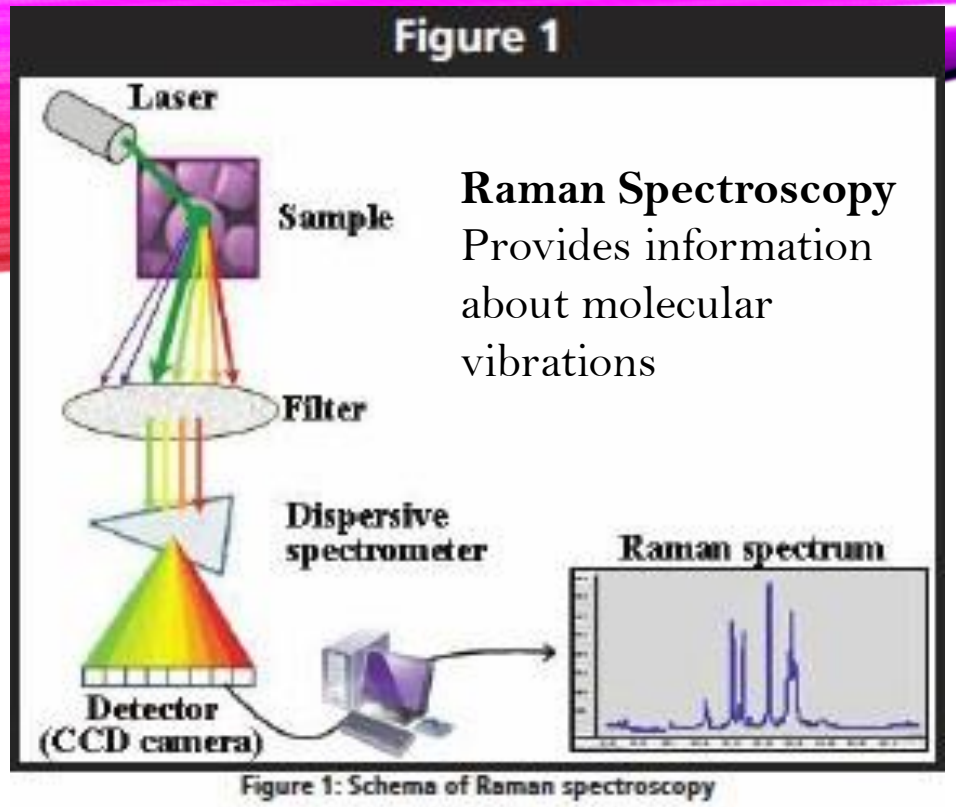
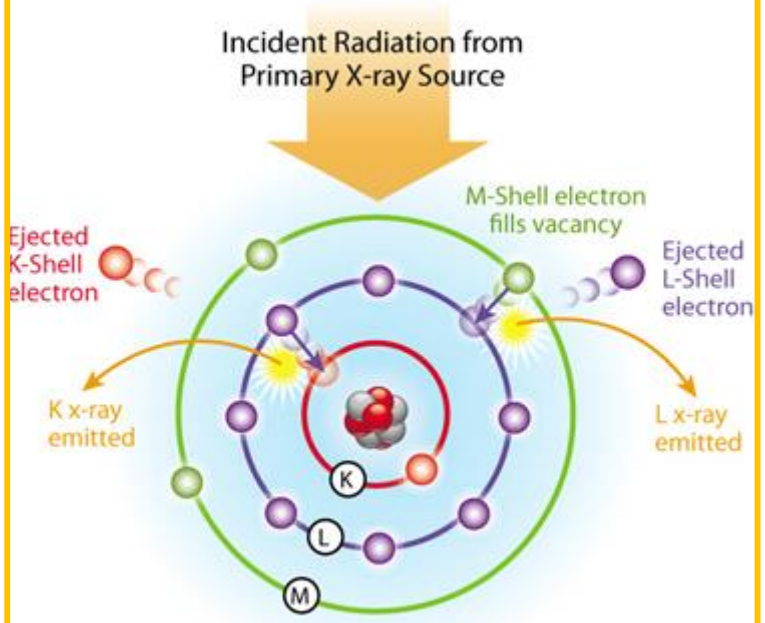


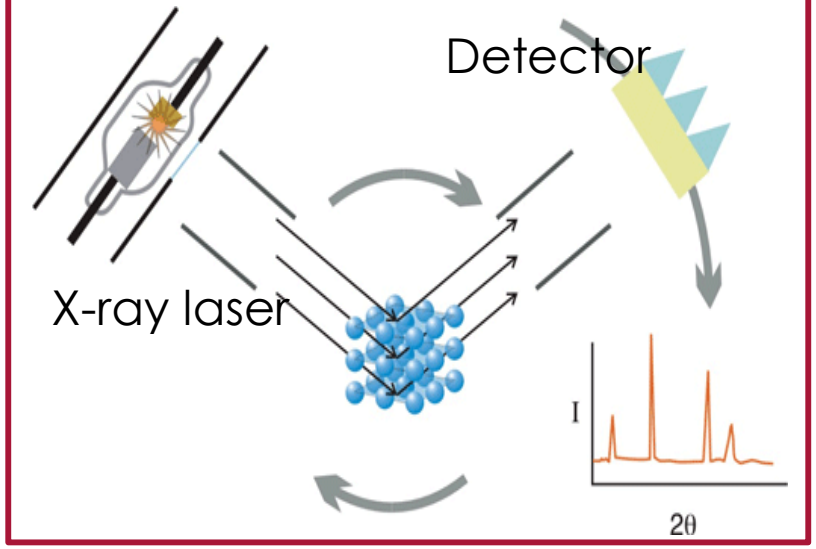
Figure 1: Schema of Raman spectroscopy

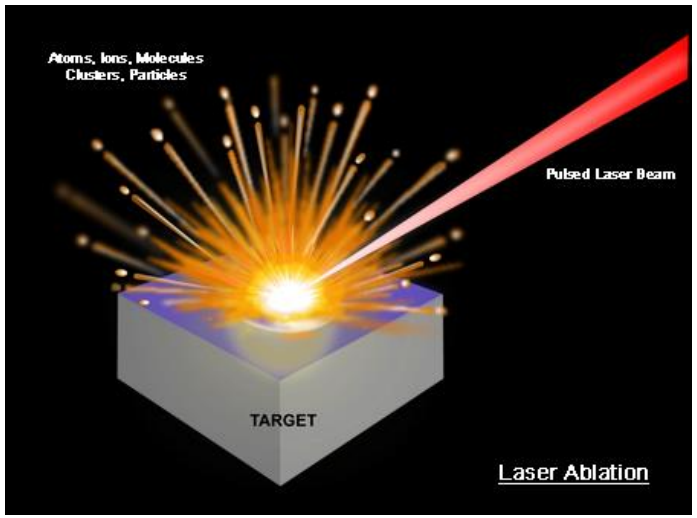
Raman Spectroscopy
Provides information about molecular vibrations

X-ray fluorescence XRF
Provides information about the component atoms



X-ray diffraction XRD
identify the atomic and molecular structure of a crystal





LIBS (Laser Induced Breakdown Spectroscopy) determines the chemical composition of laser evaporated material on surfaces

Optical Techniques

recognize objects' color, size, shape, structural properties and chemical composition.

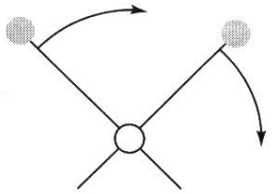
Visible light

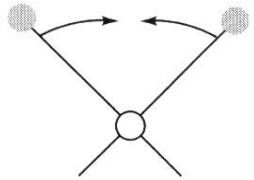
Monochromatic light to identify high contrast defects
Trichromatic or high color resolution camera to distinguish subtle color differences

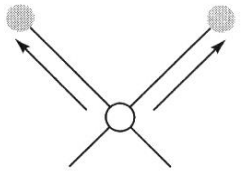
Near Infrared spectroscopy

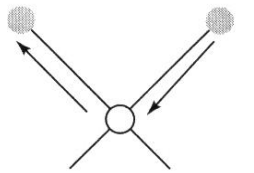
Bending - a change in bond angle or movement of a group of atoms with respect to the rest of the molecule.

Stretching - the rhythmic movement along a bond axis wit a subsequent increase and decrease in bond length.

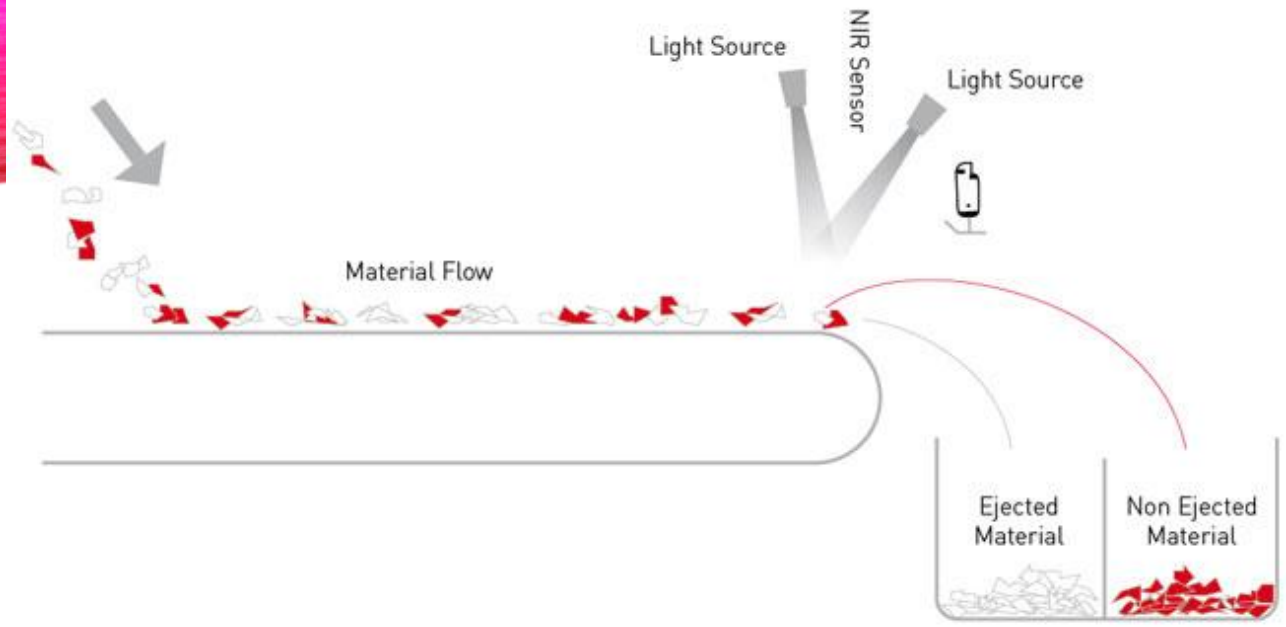

In-plane rocking


In-plane scissoring


Symmetric


Asymmetric

- O-H, N-H, C-H, S-H, R-H bonds etc., are NIR strong absorbers since they have the strongest overtones as the dipole moment is high
- Differences in spectra are usually very subtle. Instruments have a high signal to noise ratio.



Optical sorters:

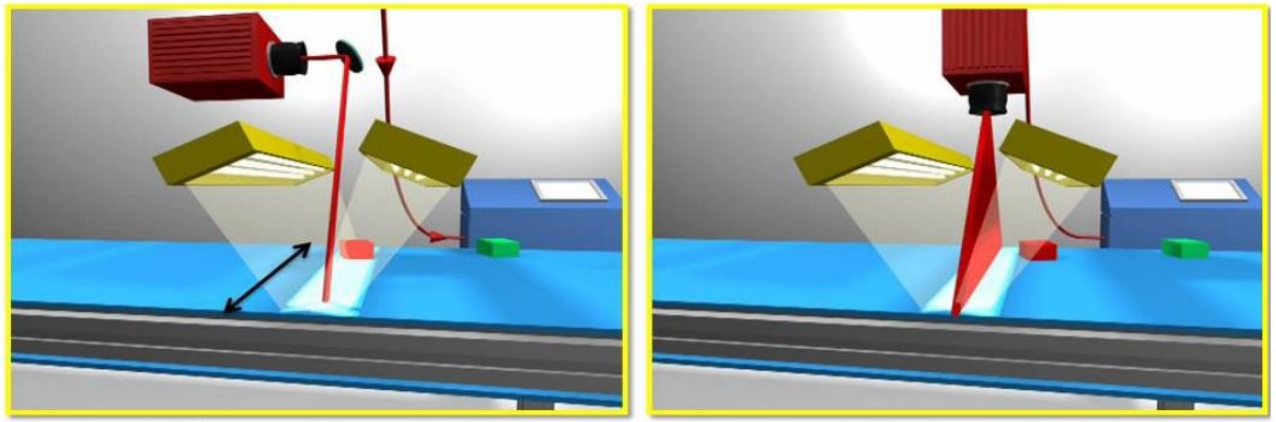
1. the feed system,
2. the optical system,
3. image processing software
4. separation system

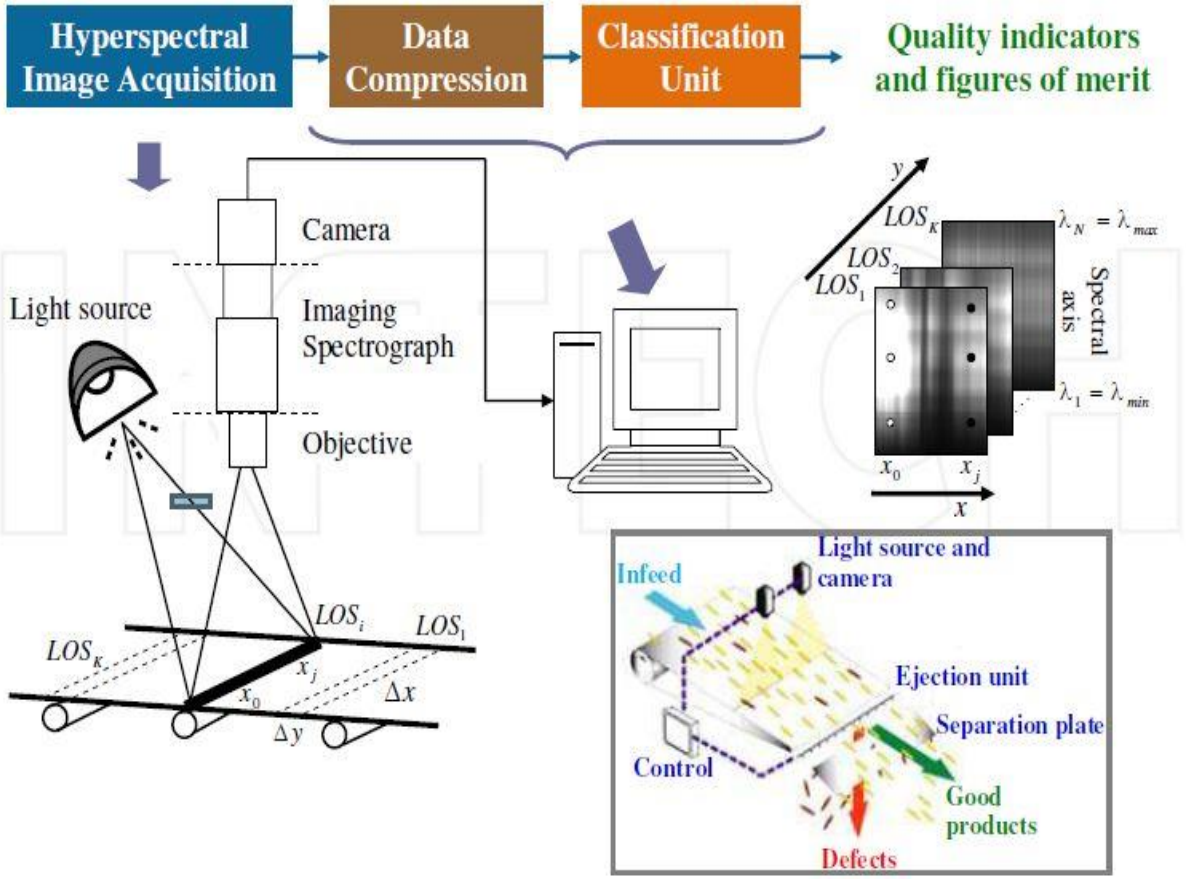
- Non-destructive
- Non-contact
- Real-time

Hyperspectral Imaging Spectroscopy:

In the last few years *Hyperspectral Imaging Spectroscopy* (HIS) that integrates conventional imaging and moderate resolution spectroscopy

- **Past**: NIR-sensors used rotation mirrors to scan the belt point by point.
- **Present:** "line scanning" technology such as HSI.





The standard camera chip uses a resolution of 320 x 256 pixels. This means the total working width of the belt is scanned with a resolution of 320 pixels the spectral resolution of this technology is also high. The reflected light from each of the 320 points on the belt is split into 256 segments.

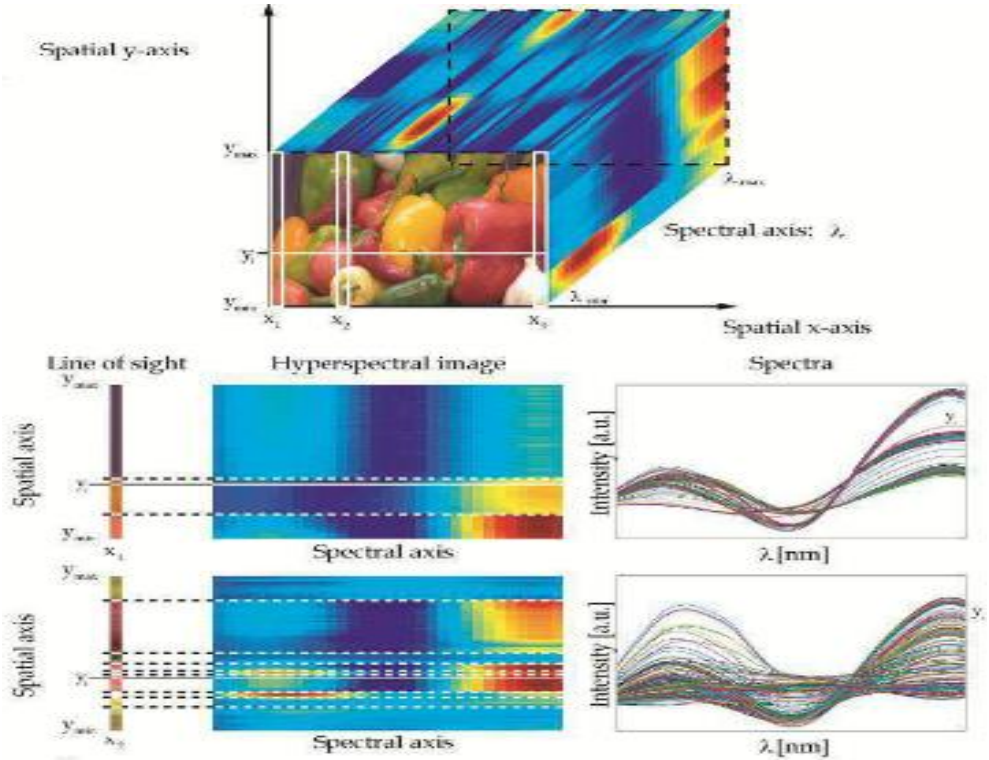
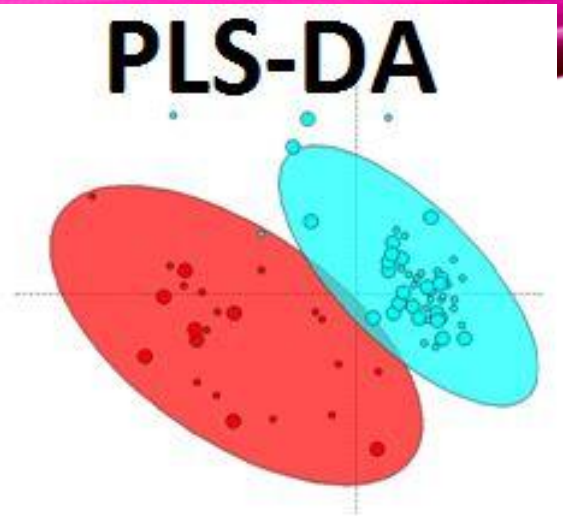
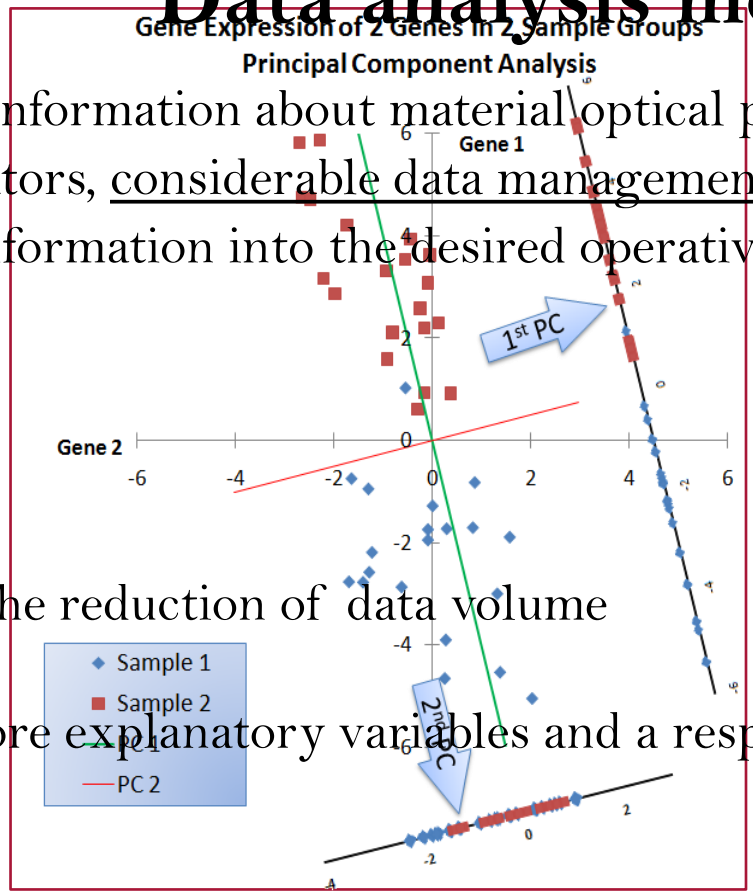


Image calibration: dark and white reference images.
offsets due to the detector dark current, the light source color drift, and the lighting spatial non-uniformity across the scene line.

Data analysis methods:



Imaging spectrometers collect information about material optical properties. Therefore, to obtain efficient quality indicators, considerable data management and analysis is required to convert this huge information into the desired operative indicators.



- "**data compression – feature extraction**" carries out the reduction of data volume
  - Multi linear regression (MLR)

    attempts to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to observed data.
  - Partial Last Square discriminant analysis (PLS)

    finds a linear regression model by projecting the predicted variables and the observable variables to a new space.
  - Principal Component Analysis (PCA)

    is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components.

Data analysis methods:

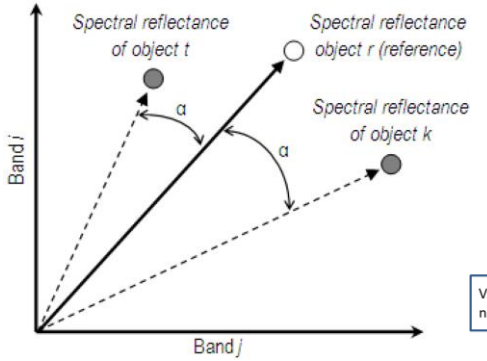
- "**feature selection**" methods that identify and ignore those variables that do not contribute to the classification.
  - ➢ Spectral Angle Mapper (SAM)

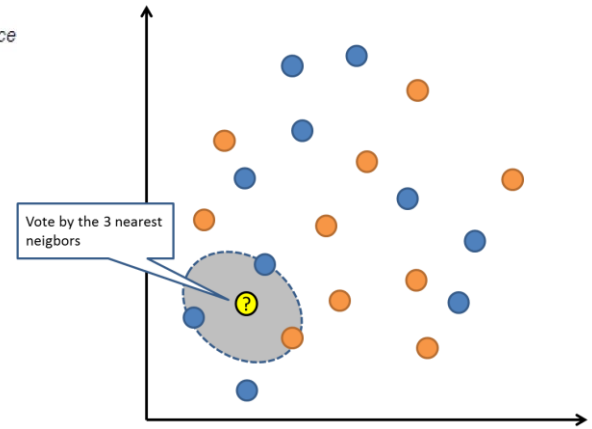
  measurement of the spectral similarity between two spectra.
  - ➢ K-Nearest Neighbors (KNN)

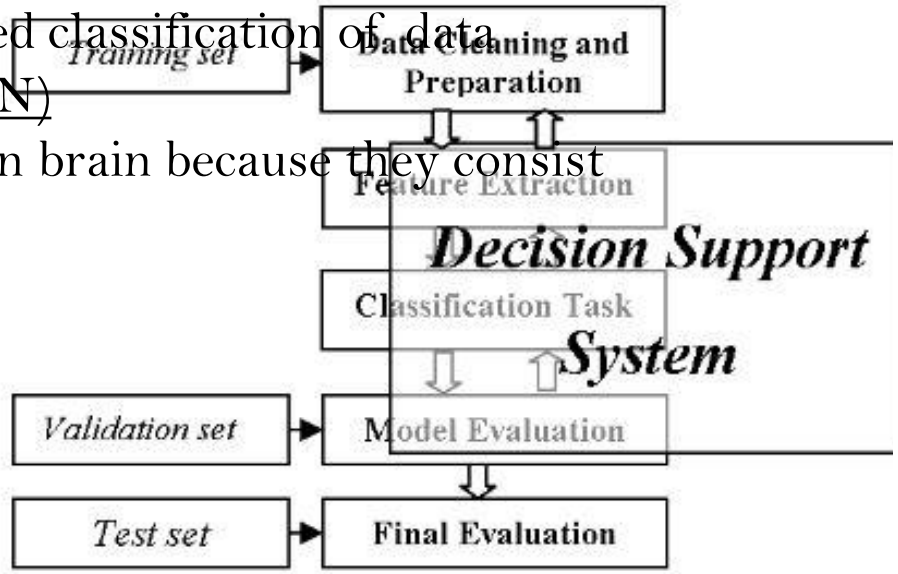
  An object is classified by a majority vote of its neighbors, with the object being assigned to the class most common among its k nearest neighbors
  - ➢ Soft independent modelling by class analogy (SIMCA)

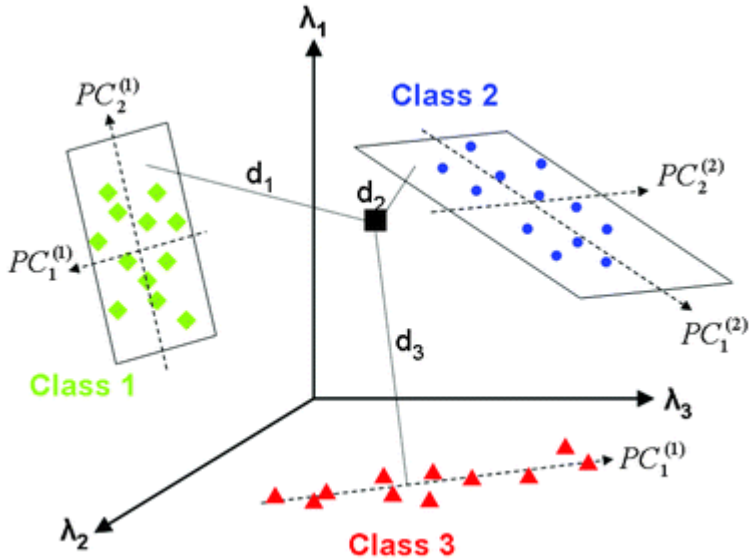
  is a statistical method for supervised classification of data
  - ➢ Artificial Neural Networks (ANN)

  Neural networks emulate the human brain because they consist of layers of interconnected nodes









PLASTIC KILLER

Life

Near Infrared technology for material identification and selection

PHOENIX s.r.l.

PAL IMAL PAL GROUP

Background and Objectives

- Industrial growing need of wood
- Waste wood can be used as building material, furniture and biomass
  - A cleaning process is necessary to comply with the ley specifications

  BUT

  - no systems in the market capable of achieving a good removal of impurities

We focused on the waste identification and selection

- **MDF panel production**, now only virgin wood is used to comply with the standards
- Power generation, **biomass for clean energy** generation

Goal: Bridge the gap between research and market

One promising technology ⇨ NIR spectroscopy
Fast, robust, high resolution, not destructive

Material identification ⇨ study of new techniques
Fast, robust, flexible

Develop an innovative system able to **remove up to 95% of impurities from post-consumer wood**.

Use of post-consumer wood ➡ **Environmental impact**
less wood waste, less virgin wood used, less CO^2, less water consumption.

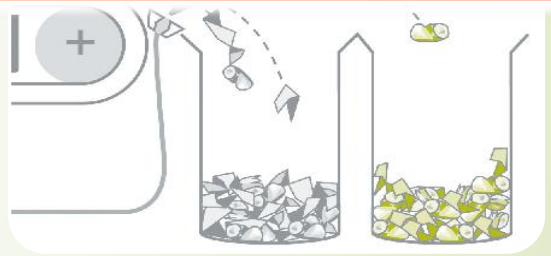
The project

Objective: set up and demonstrate the viability of a pilot plant able to finely separate post-consumer recycled wood from impurities

1. The conveyor belt moves the material to the detection system.
2. The optical system scans the material. **A new method that takes advantages of the NIR spectral images is used to identify different classes of materials.**
3. All the material is identified and a system of air compressed nozzle direct the material to the specific case.

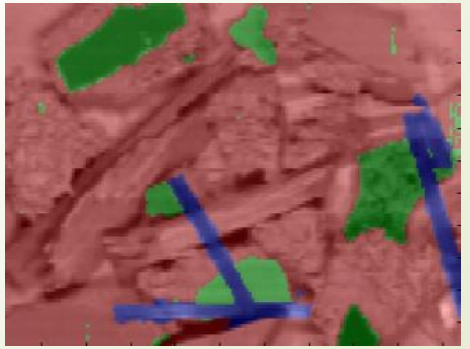
Velocity 8 m/s **Duration < 0,001s** **Duration ~ 0,001s**

Conveyor belt



Capacity > 40 m³/h

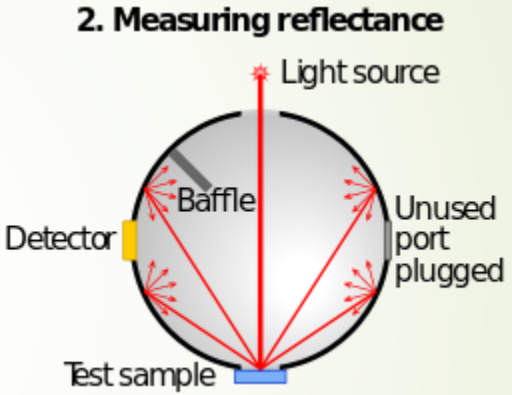
Vision and selection system



Separation system

The laboratory system

Varian Cary 5000
UV-VIS-NIR Spectrophotometers



Diffuse Reflectance Accessory: 110mm diameter integrating sphere

- Spectral range 250nm – 2500nm
- Spectral resolution 1nm
- 2D detector array in the NIR InGaAs (Indium Gallium Arsenide) and PbS (Lead Sulphide) - 2041 spectral points
- Frame frequency 64Hz

Sample

Wood Sample materials:

- Wood
- Micro chips clear (various essence)
- Micro chips dark (various essence)
- PB with laminate
- MDF with laminate

Contaminants Sample materials:

- Panel borders
- Plastic
- Red brick
- Ceramic
- Tile
- Glass
- Mirror
- Concrete
- Heavy polluting

1. Acquisition of the radiation for the whole range of wavelength to investigate the largest part of the spectrum available.
2. Acquisition of the reflected, both specular and diffuse, radiation of each sample.
3. Study of the spectrum features for the different materials.

Spectra

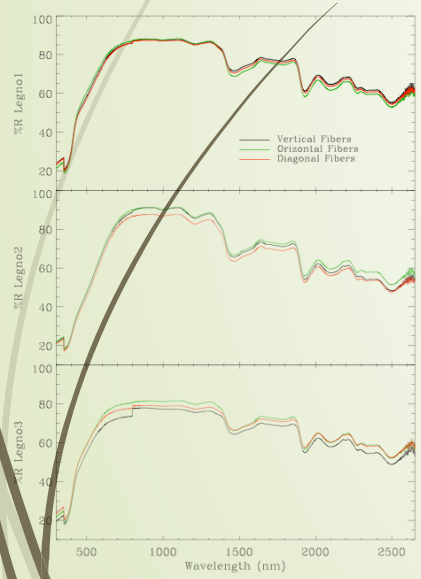

LEGNO 1
LEGNO 2
LEGNO 3

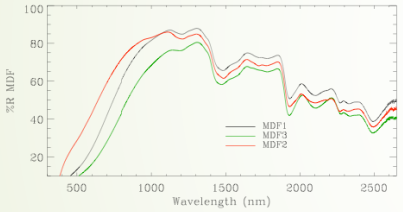

MDF 1
MDF 2
MDF3

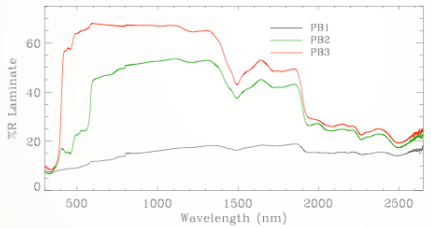

PB1 laminato Scuro
PB2 laminato chiaro
PB3 laminato Bianco

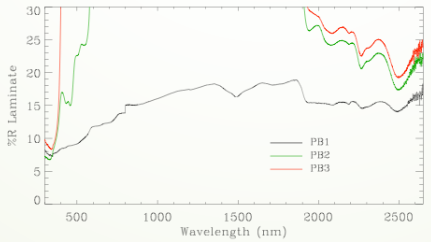

Plastica 1
Plastica 2
Plastica 3

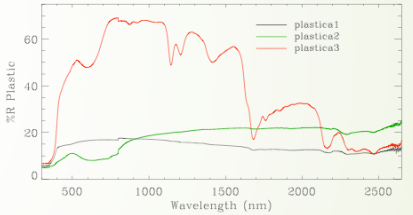

COTTO
MARMO
GRANITO

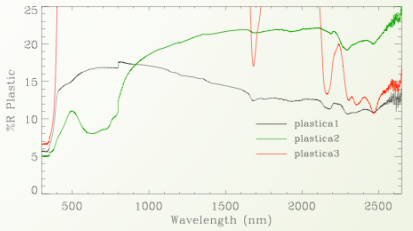

%R Legno1
%R Legno2
%R Legno3
Vertical Fibers
Orizontal Fibers
Diagonal Fibers
Wavelength (nm)

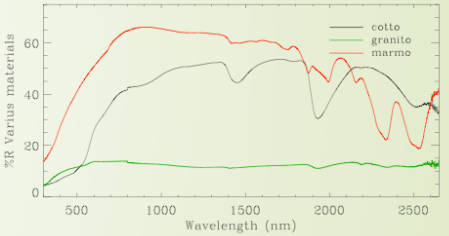

%R MDF
MDF1
MDF3
MDF2
Wavelength (nm)

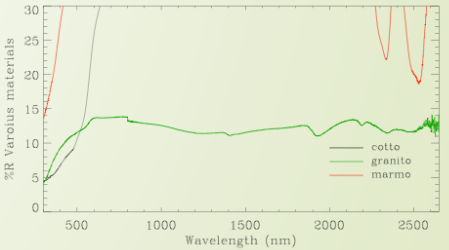

%R Laminate
PB1
PB2
PB3
Wavelength (nm)


%R Laminate
PB1
PB2
PB3
Wavelength (nm)


%R Plastic
plastica1
plastica2
plastica3
Wavelength (nm)


%R Plastic
plastica1
plastica2
plastica3
Wavelength (nm)

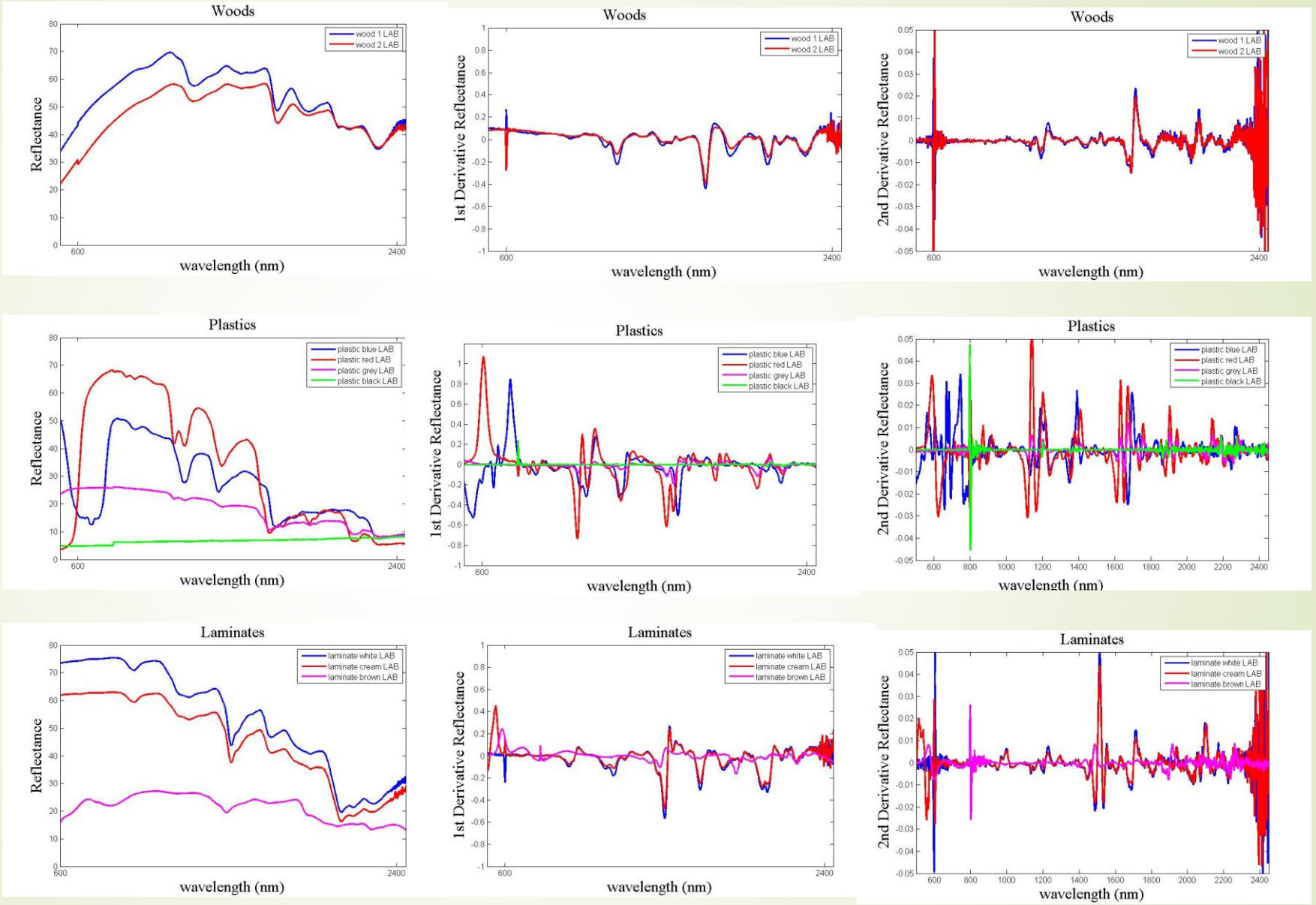

%R Varius materials
cotto
granito
marmo
Wavelength (nm)


%R Varius materials
cotto
granito
marmo
Wavelength (nm)

Data analysis

Samples examination

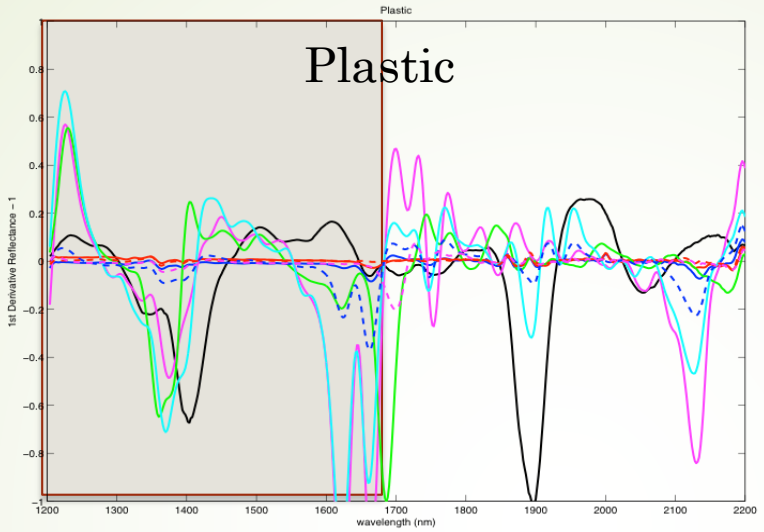
Pre-processing:
Noise suppression
Intensity fluctuation
Geometry effect

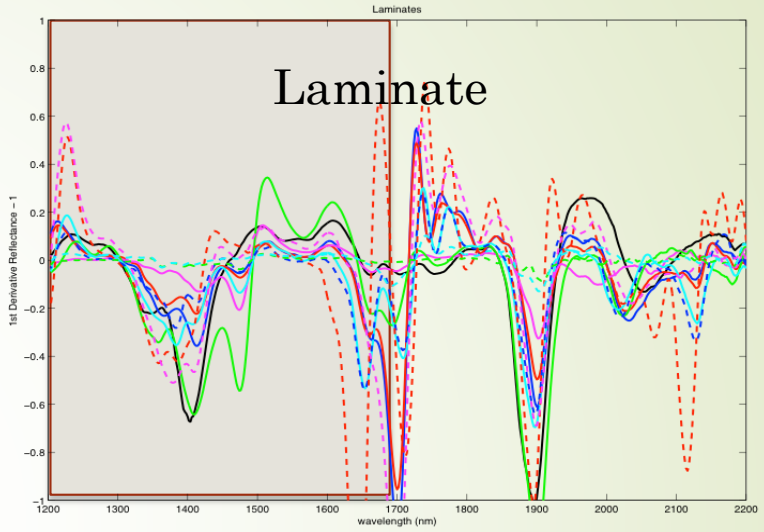


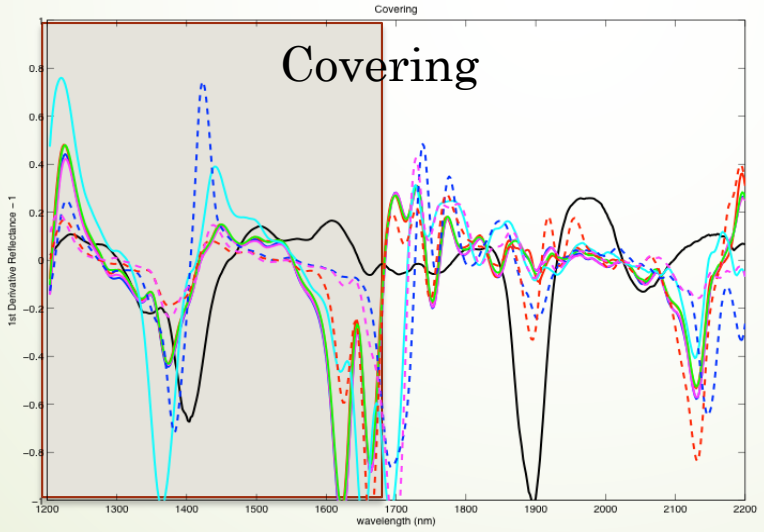
Spectra **1st Derivative** **2nd Derivative**

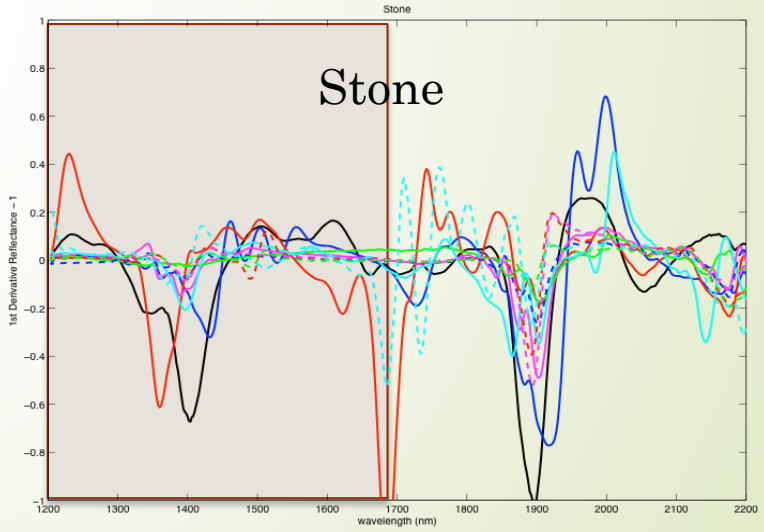
Data analysis

Wavelength range selection









Data analysis

Band definition

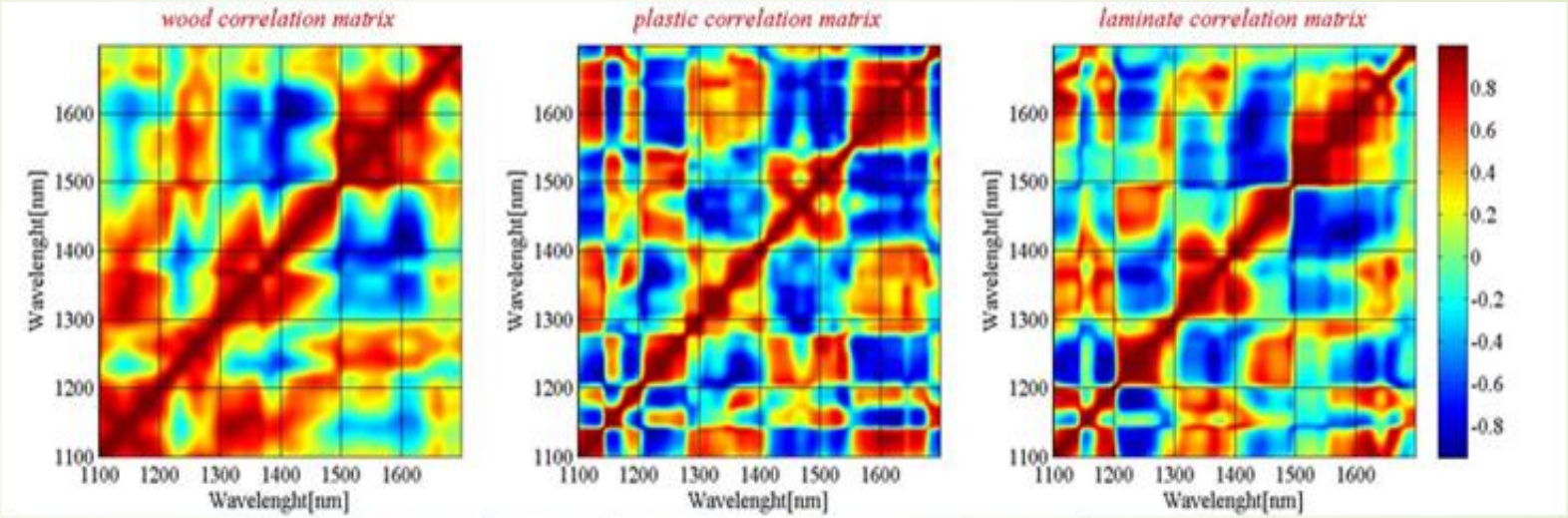


Figure 3. Correlation matrices for three classes of materials, wood, plastic and laminate.

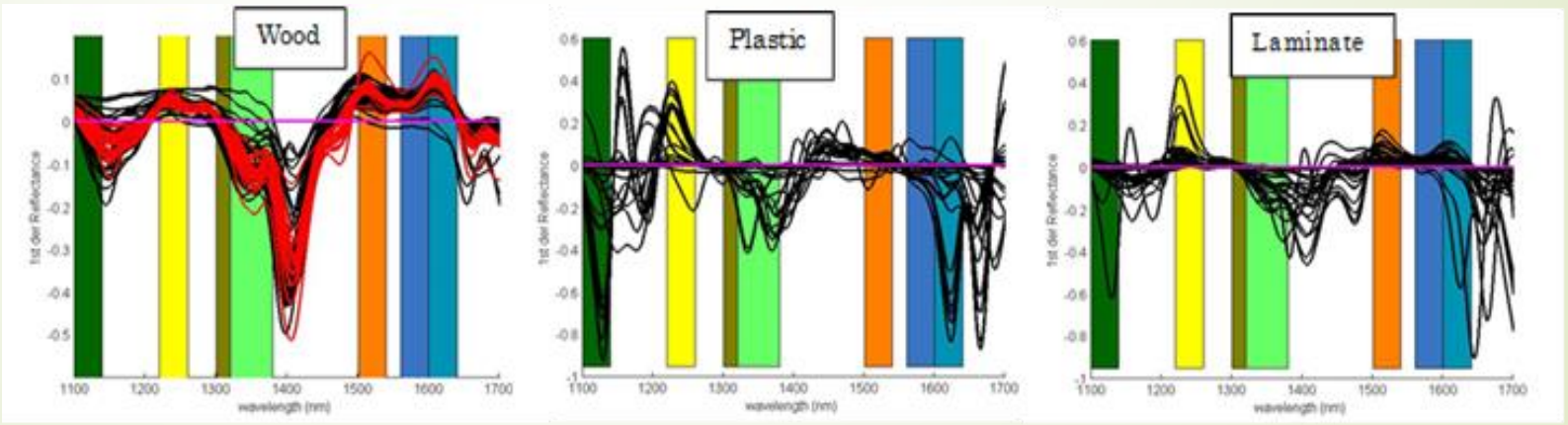


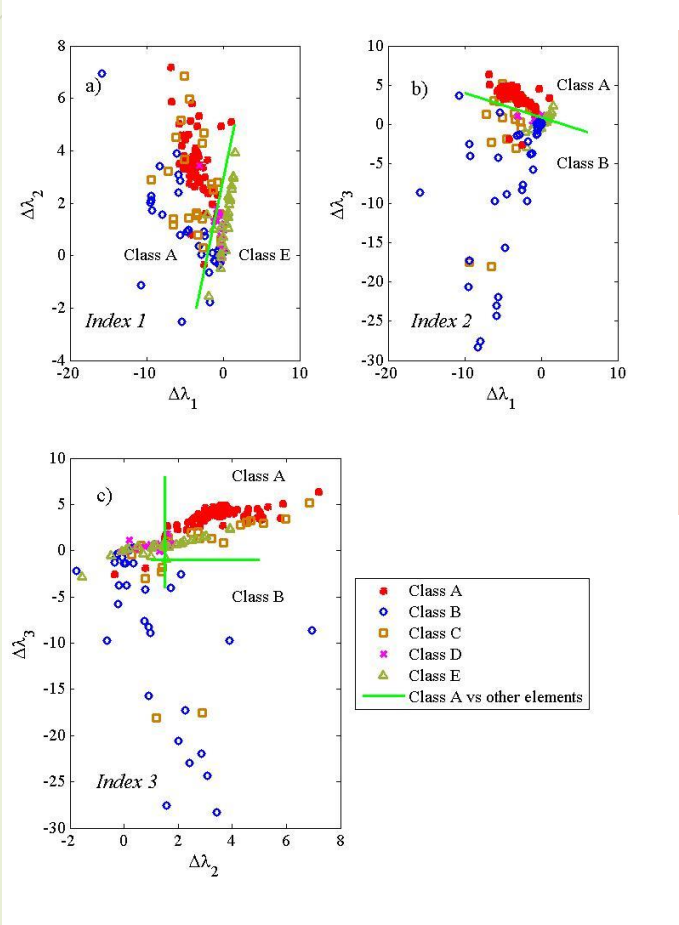
Figure 4. Behavior of reflectance first derivative in the selected regions for different classes of materials.

Data analysis

Indices definition

1100 – 1700 nm

3 bands

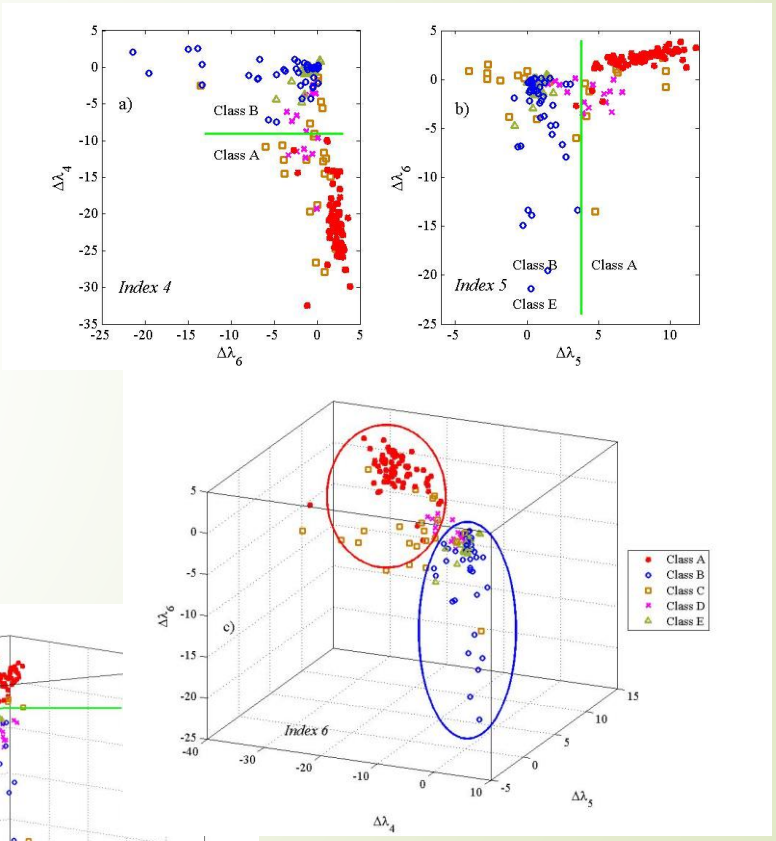


Sample

Class A	**wood**
Class B	**plastic**
Class C	**laminate**
Class D	**stone**
Class E	**glass & mirror**

1700 – 2500 nm

3 bands



Results

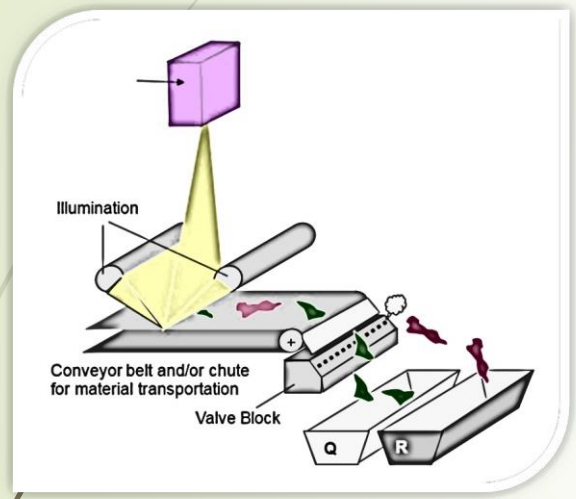
- We demonstrated that **new technologies** based on hyperspectral imaging are able to separate contaminants in waste wood with high accuracy.

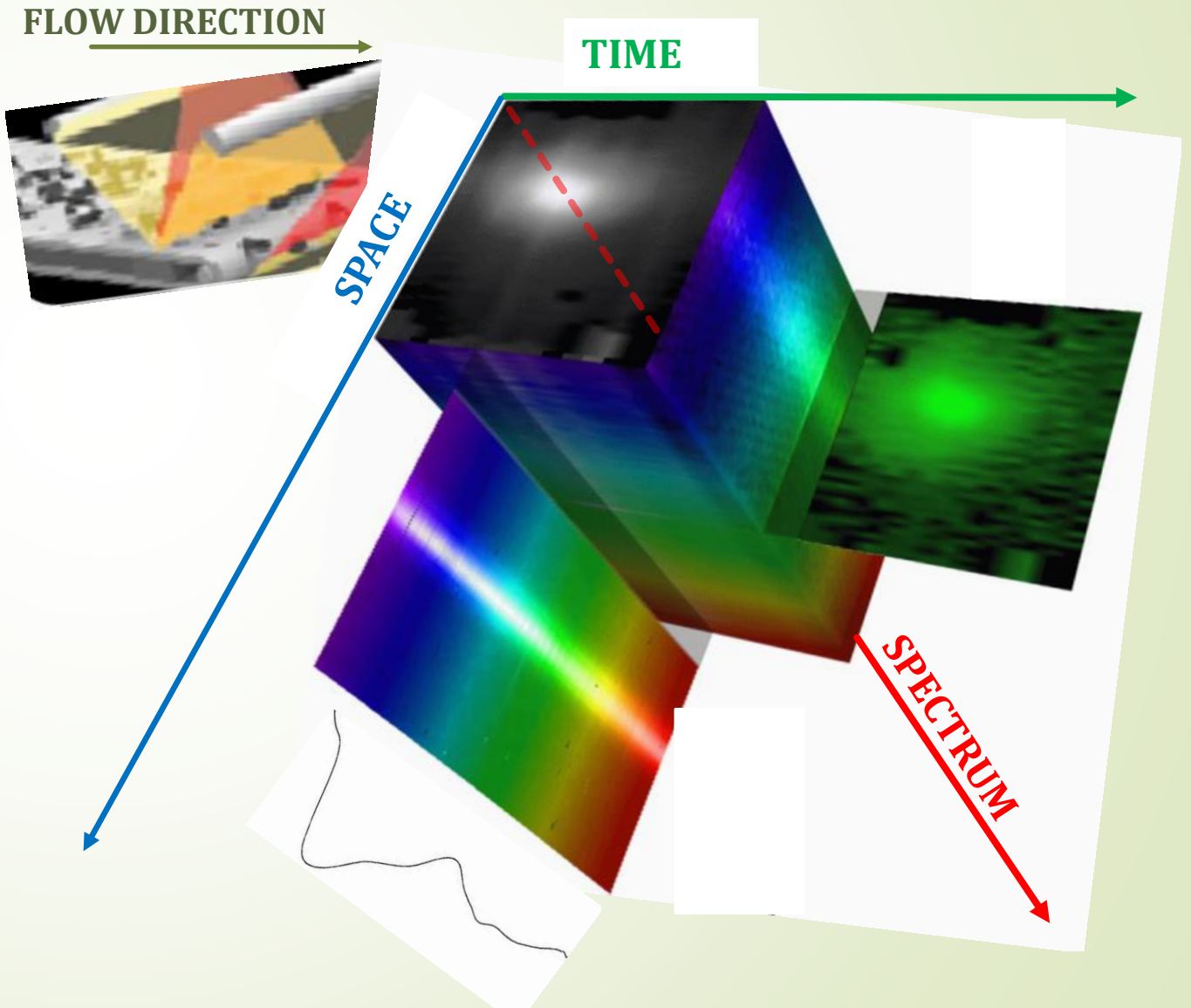
- We developed a **new classification method** able to detect and separate different classes of materials.
- We defined **six indices** and we showed their specific capability in the class identification and separation.
- We have been able to define an index, **Index 6, capable to select wood from other materials in a very efficient way.** A selection procedure that uses this index *can remove all the contaminants in a single step*.
- We also showed how the **combination of two indices** with a limited separation capacity can achieve an **optimal efficiency** in the three dimensional space as in the case of Index 6.

MOREOVER

- The classification algorithm can be further **expanded** by adding other classes of materials.
- The classification algorithm is really **flexible and can be optimized for different purposes**.

The real system

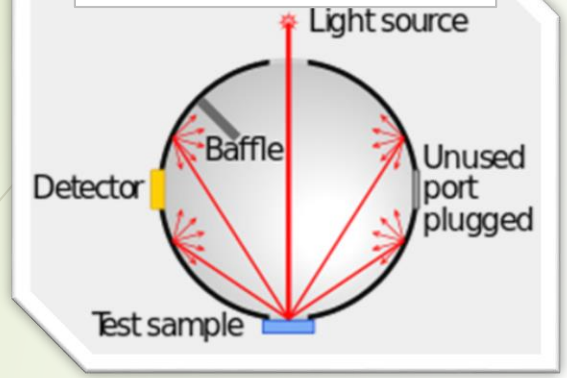




Hyperspectral imaging system

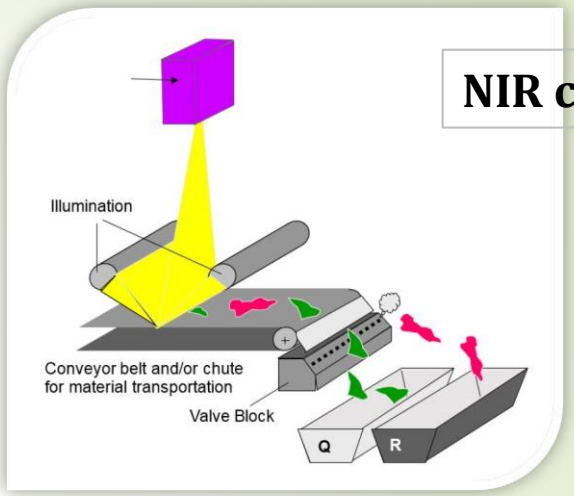
Systems differences

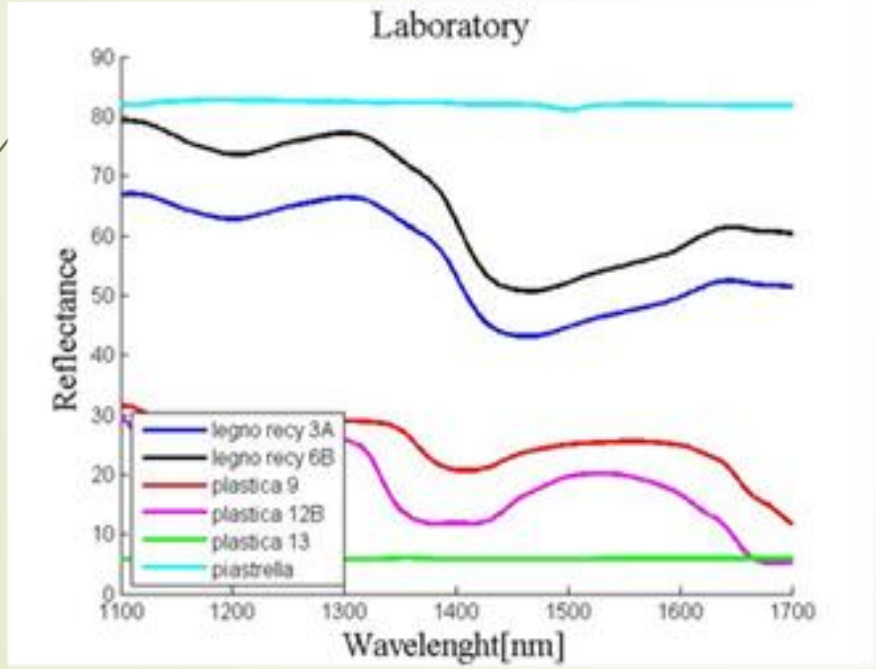
Integrating sphere

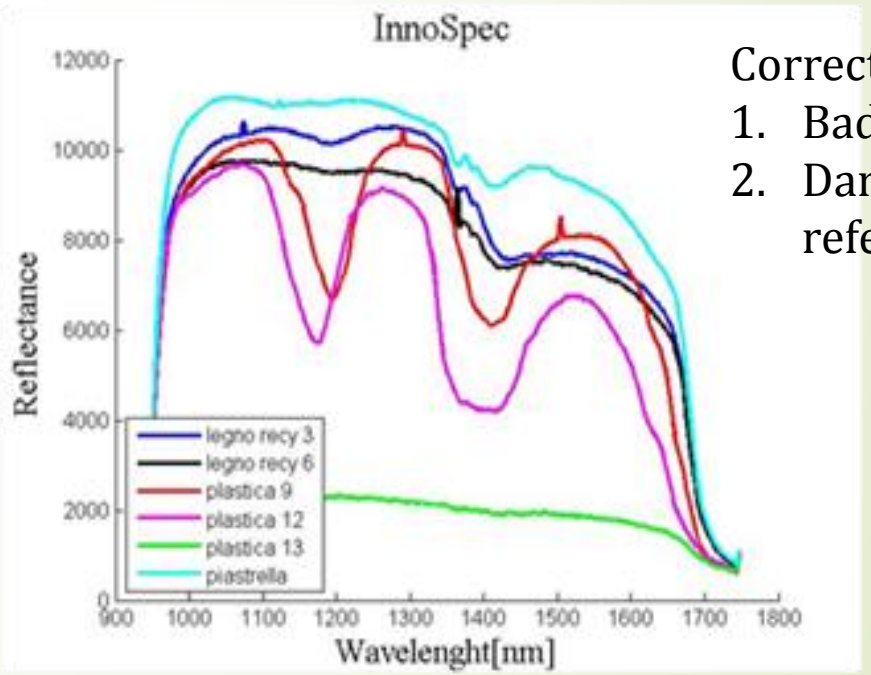


The background influenced the spectra features

NIR camera





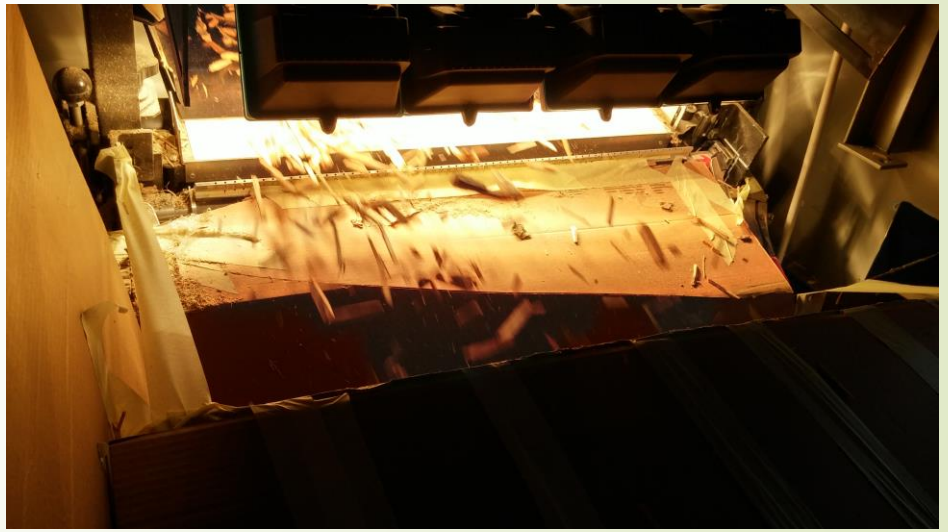


Corrections:

1. Bad pixel
2. Dark and white reference images

Figure 7. Reflectance spectra of different sample obtained with the Laboratory and the Inno-Spec systems.

The pilot system



Impact

Principal target: Identification and elimination of 95% of plastics impurities
Processing of 78 t/day of post-consumer, removal of 740-780 kg/day of plastics

Environmental impact:
New generation of **MDF panels** produced by up to 60% of post-consumer recycled wood
- Limit use of virgin wood, 9600 trees per year saved
- No water consumption, 693200 m^3 of water per year saved
- Reduction of the CO^2 emission, 21100 t CO^2 equivalent per year saved
  (0,9t of CO^2 is trapped in every cubic meter of wood)

Purified post-consumer wood to be used as **biomass** for energy production
- Reduction of dioxin, 135mg TEQ dioxin emission per year saved

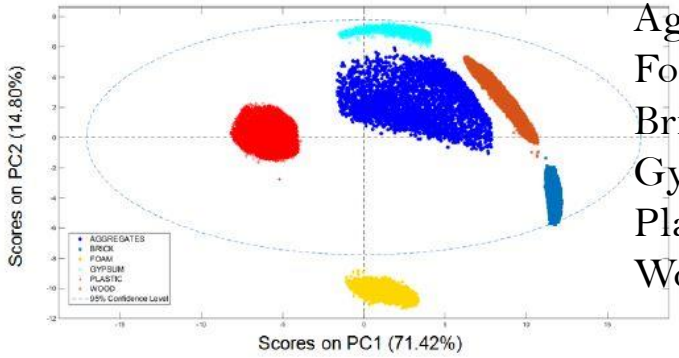
Social impact:
Social consciousness on the recycling capabilities and benefits
New job opportunities

THE SYSTEM CAN BE USED FOR THE IDENTIFICATION AND SELECTION OF MANY DIFFERENT TYPES OF MATERIALS … Think to the potential!!!!

Quality control of recycled **aggregates from demolition waste** by advanced sensing technology
S. Serranti, et al. 2015

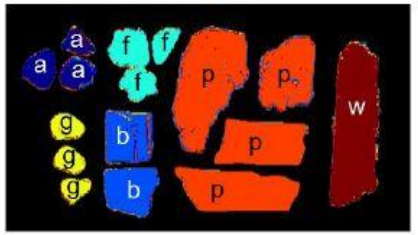
Reflectance spectra acquired by HSI for aggregates and contaminants classification were carried out in different steps:

- Spectra preprocessing: Useful to highlight the differences between the different classes of materials.
- Principal Component Analysis (PCA): Explorative analysis to evaluate the detection of the different classes of materials.
- Partial Least-Squares Discriminant Analysis (PLS-DA): Building of a classification model and its validation.

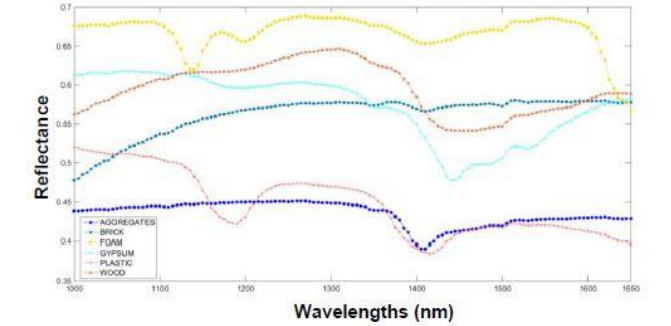


Aggregates
Foam
Brick
Gypsum
Plastic
Wood

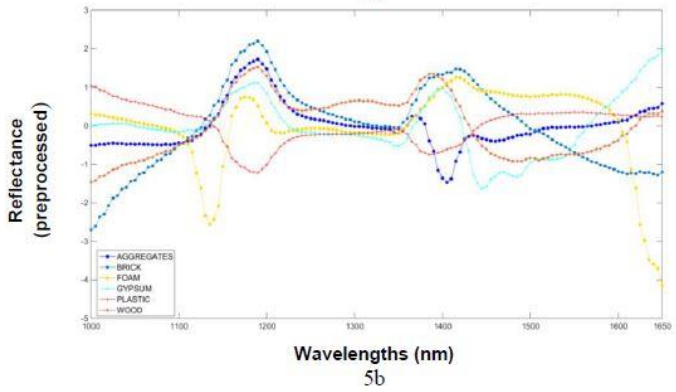
7a



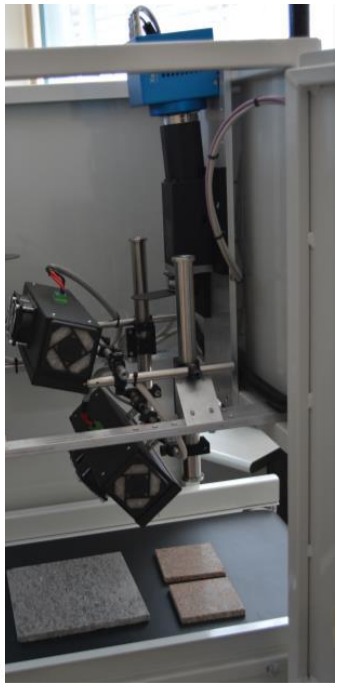
The results in terms of "class most probable" predictions



5a



5b



1000 nm – 1700 nm

Data correction:

1. Detrend: remove linear, curve offset
2. SNV: weighted normalization remove gain, scattering effects and source variation
3. Mean centering: remove the mean value from the data

PET and PVC Separation with Hyperspectral Imagery
Moroni et al. 2015

- Density

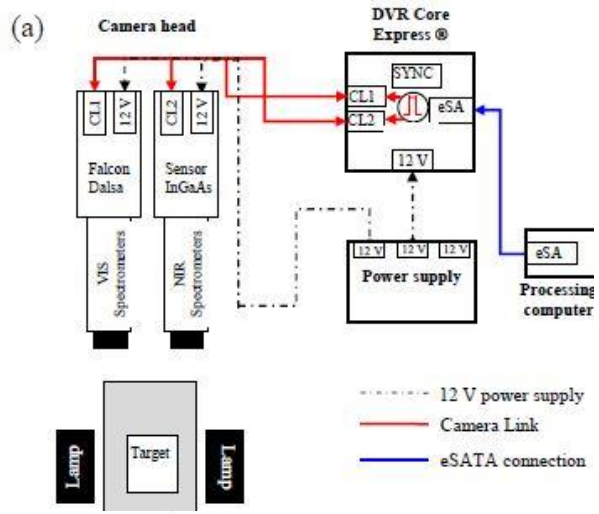
>1 g/cm3 for PVC and PET within a small interval.

Separation challenging with traditional methods.

- Melting temperature

PET(250–260 °C) and PVC (140–160 °C)

Degradation and not plasticization in mix materials



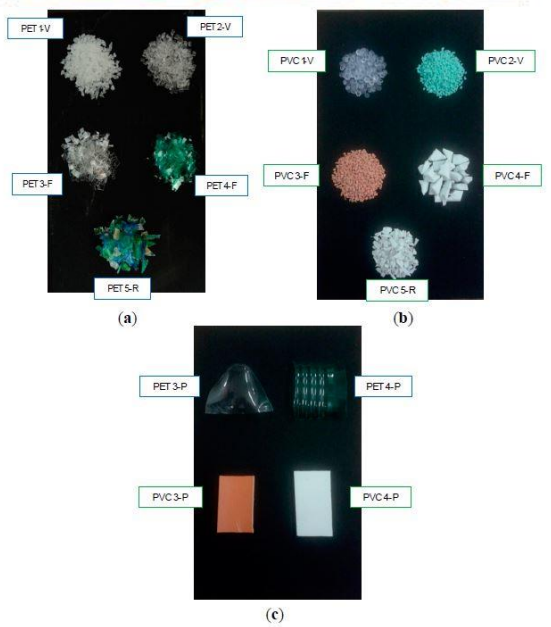


Figure 1. Images of (**a**) virgin, waste and regenerated PET samples; (**b**) virgin, waste and regenerated PVC samples; (**c**) PET and PVC samples in pieces (for the nomenclature refer to Table 1).

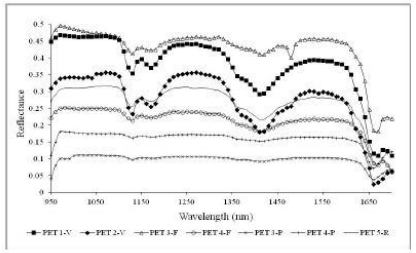


Figure 6. Representative NIR signatures of PET samples on conveyor belt.

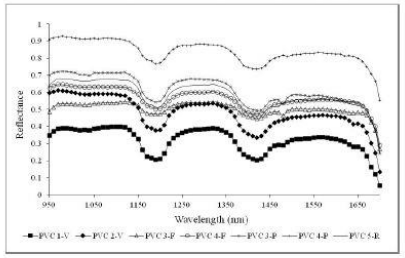


Figure 7. Representative NIR signatures of PVC samples on conveyor belt.

continuum-removed spectra: original reflectance values divided by the corresponding values of the continuum line.

The peak reflectance points standardized to a value of one

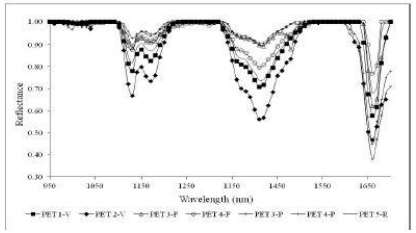


Figure 8. NIR signatures after continuum removal of PET samples on conveyor belt.

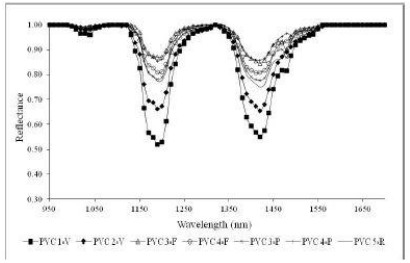


Figure 9. NIR signatures after continuum removal of PVC samples on conveyor belt.

900 nm – 1700 nm

Spectral absorption peaks:

PVC: 1200nm, 1420 nm, 1480 nm

PET: 1130 nm, 1170 nm, 1420 nm, 1660 nm

Spectral indices for PET and PVC differentiation:

1200 nm/1130 nm and 1200 nm – 1130 nm

COMPANIES SORTING examples

One of the key features of companies leading the way in today's market is the ability to sort the increasingly diverse range of materials coming through, and deal with them appropriately.

Titech, a global Norway company Steinert, a global German company	from plastic bottles and WEEE to construction and industrial waste The sensor technologies applied include: NIR (near infrared), which recognizes different materials based on their spectral properties of reflected light; CMYK (cyan, magenta, yellow, key) sorts paper or carton that has been printed using CMYK; VIS (visual spectrometry) recognizes all colors that are visible
RTT, a German company	salvages circuit boards from WEEE, a wide range of polymers, papers and more using NIR technology.
Sesotech, a Bavarian company	detection and separation of contaminants from material streams with the combination of different technologies in one machine
Pellenc ST, a French company	emerging technology MIR (mid infrared) a more efficient way to separate paper and cardboard
ZenRobotics, a Finnish company	The system features and grab for picking the waste and an electronic 'brain', or artificial intelligence to tell it what to pick and where to put it.

Thank you for to the attention

and

good recycling!