DEVELOPMENT OF ADVANCED IMAGING TECHNIQUES

FOR

REAL TIME PARTICLE SENSING

IN

MINERAL PROCESSING & RECYCLING

Pirard, E.

Leroy, S., Barnabé P., Dislaire G., Decamp X., Singh Parmar A.

About GeMMe@ULiege

Connecting particles and processes

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Resourceful Engineers

GeMMe

- 30+ Research Staff
- 3 M€ annual turnover
  - *2/3 Pubic – 1/3 Private*

- *Resource*
  - Particular attention given to **MINERAL** and **METALLIC RESOURCES**
  - Interest for both **MINING** and **URBAN MINING**
- *Efficiency*
  - Contribute to developing a more **CIRCULAR ECONOMY**
  - Privilege a **HOLISTIC** approach of the material cycle
  - Put engineering to the service of a more **SUSTAINABLE** societal project
- *Engineering*
  - Contribute to the **EDUCATION** of creative and open-minded engineers
  - Be a source of **TECHNOLOGICAL INNOVATION** for increased recovery of valuable metals

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Research Themes

SMART SORTING

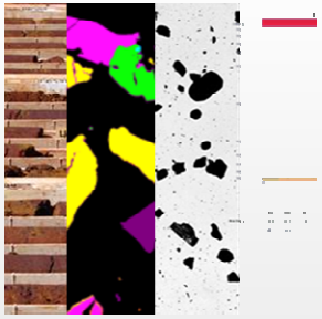
Advanced 3D imaging and hyperspectral sorting

PHYSICAL PRE-PROCESSING

Energy-Efficient fragmentation and conditioning

GEOMETALLURGICAL CHARACTERIZATION

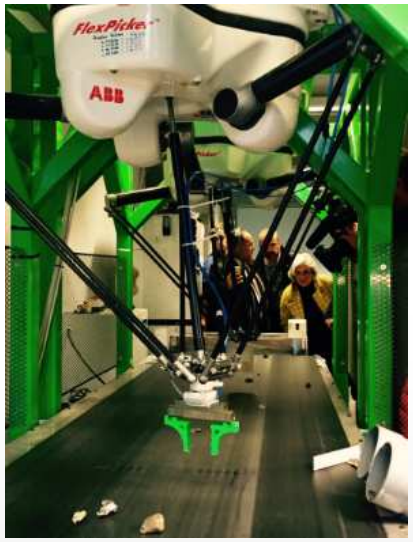
Process oriented "mineralogical" mapping



BIO - HYDROMETALLURGY

Resource efficient processes for end-of-life goods

Smart Sorting Bench



Multisensor
3D – VNIR- XRT – LIBS

MultiBin
Delta Robots

Hydrometallurgical Platform

- 5 kg REE/day from EoL Vehicles

- Cu-Sn-Au from low-grade WEEE's

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Monitoring of unit processes

Process vs. Product

Process monitoring

- Controlling Operational Parameters of a Ball Mill
  - Power Draw
  - Mill Speed
  - Ball Filling Degree
  - Pulp (solid %)
  - …
- Getting more insight with Real Time Sensors
  - SensoMag®
    - Ball foot
    - Pulp foot
    - etc

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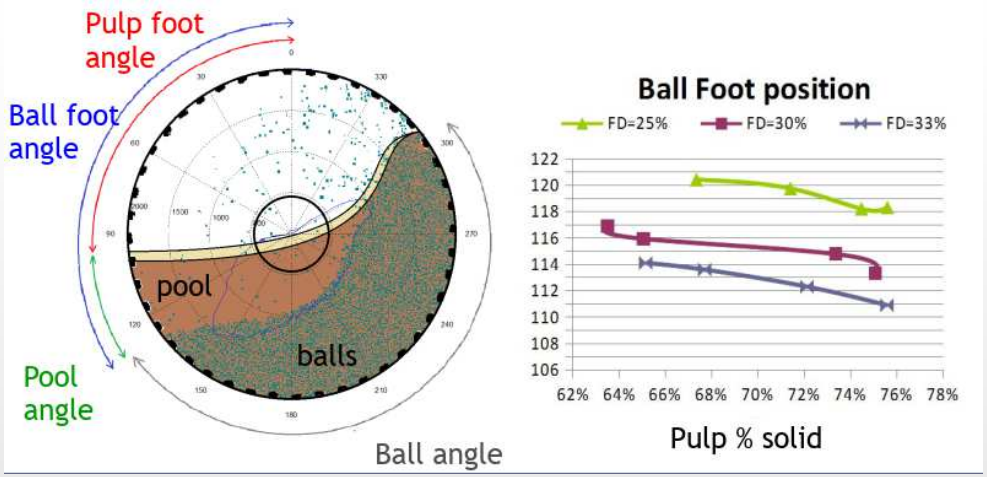
Fast decision-making
Cost optimization
Wear reduction
…



Köttgen et al., 2012, Online monitoring of the interaction of balls and slurry with the Sensomag ®, Int. Conf. Sust. Min. Proc., Oulu

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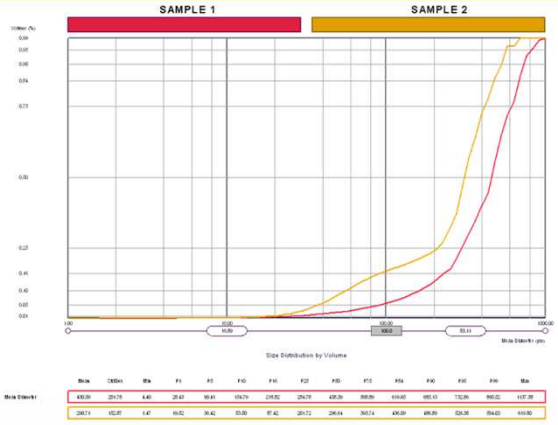
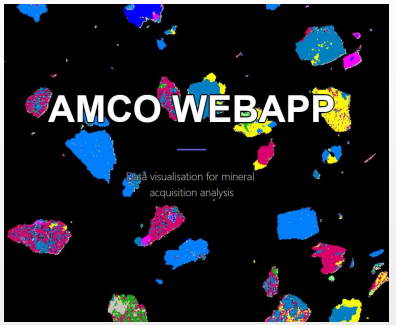
Product monitoring

- Controlling Particle Populations
  - D_{80}
  - Full Particle Size Distribution (PSD)
  - Particle Shape



- Getting more insight with Quantitative Microscopy
  - Mineralogy
  - Liberation
  - Textural indices

Accurate quality control
Process performance
Understanding / Simulating
…



Open Web App for Liberation and Texture Analysis

RawMaterials
Connecting matters

UPM Politecnica de Madrid
Université de Liège
TSI Labs
First Quantum (CLC)
KGHM

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Monitoring Particle Populations

The online challenge

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The Online Challenge

- Need for speed (“*close to real time*”)
  - NO MECHANICAL SAMPLING
    - Eventually automatic sampling without stopping the process
  - NO SAMPLE PREPARATION
    - Eventually a limited dilution / dispersion step
- Existing Bulk Particle Sensing (BPS) systems
  - XRF
    - ThermoFisher MSA-330 Multi-Stream Slurry XRF Analyzer
    - Outotec Courier® 5X/6X SL Analyzer
  - LIBS
    - Outotec Courier® 8 SL Analyzer
  - Laser Diffraction
    - Outotec PSI 500i Particle Size Analyzer (LD)
  - VNIR Spectroscopy
    - Bluecube slurry analyser
  - Time Resolved Raman
    - Timegate

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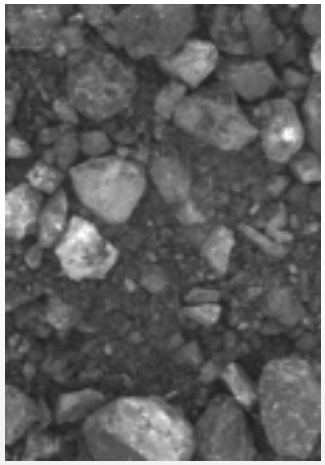
The Online Challenge

- Need for higher "accuracy"
  - Provide statistics on particle distributions

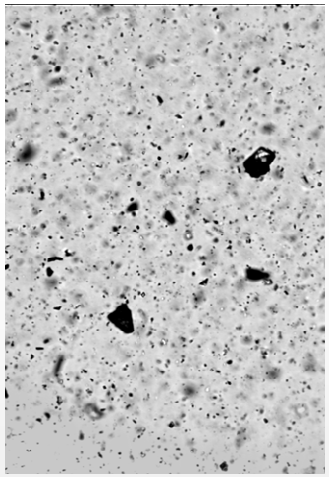
BULK PARTICLE SENSING

SINGLE PARTICLE SENSING



SEGMENTED

« ***STATIC*** »
RESTING PLANE



« ***DYNAMIC*** »
RANDOM (?) ORIENTATION

HIGHER THROUGHPUT

LOWER THROUGHPUT

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Single Particle Sensing Technologies

For Online Applications

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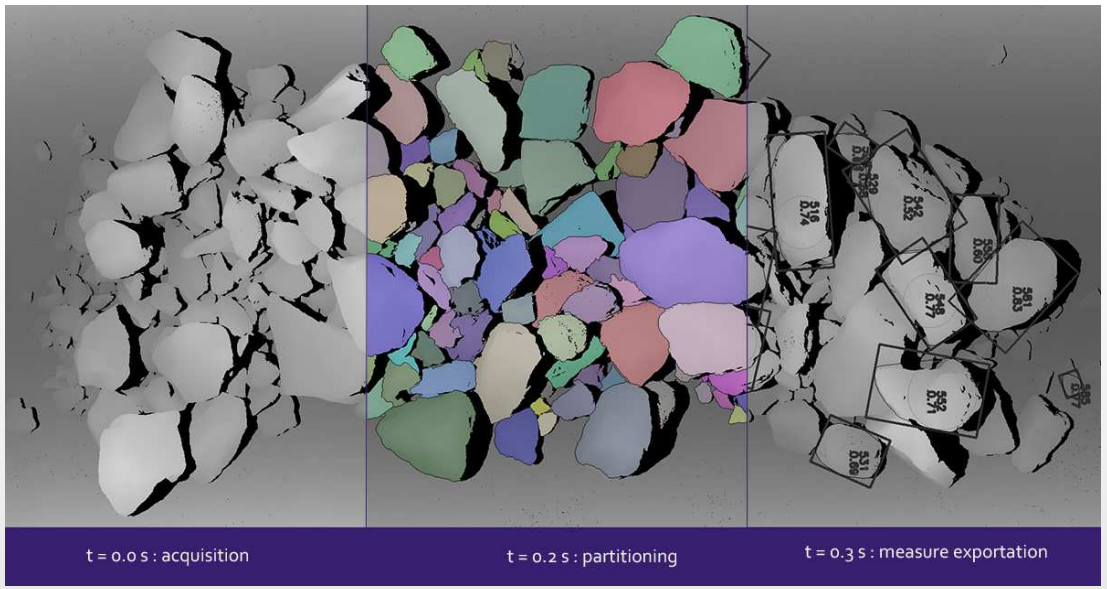
LASERSIEVE

METEORE
A MATTER OF VISION

- Imaging Principle
  - Surfometric Imaging
    - Laser Triangulation
  - Particle segmentation
- Particle Size Range
  - 5 mm – 10 cm
- Measurable Properties
  - Apparent Volume
    - continuous throughput
  - 3D Size
  - 3D Shape
    - Elongation
    - Flatness



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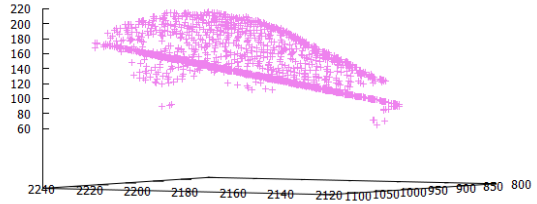
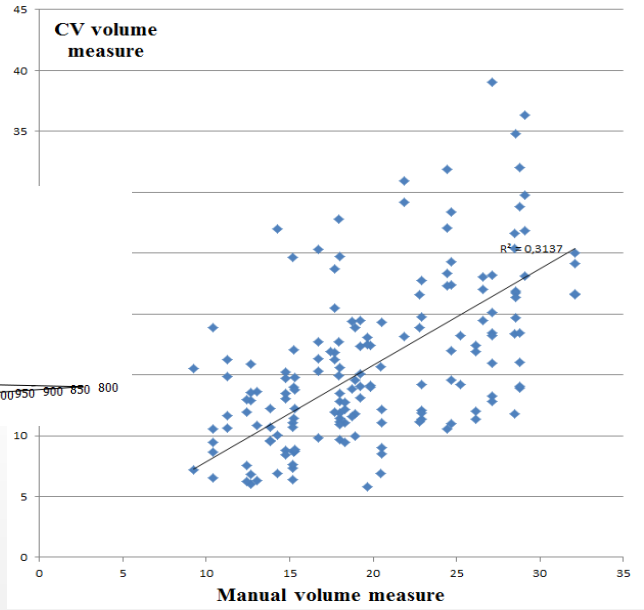
LASERSIEVE

- Single Particle Measurement Validation
  - Manual measurement of selected particles
  - Random positioning on heap
  - Volume estimation from visible cap



visible cap



Correlation between manual and digital volume estimates for randomly positioned particles *(narrow range!)*

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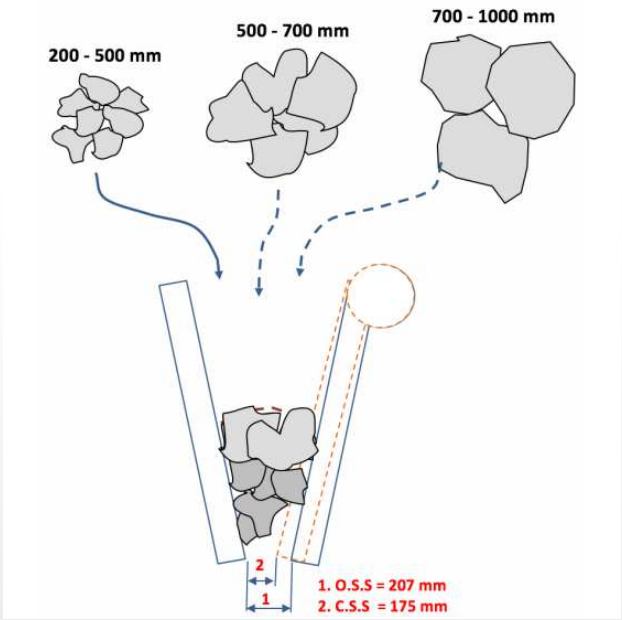
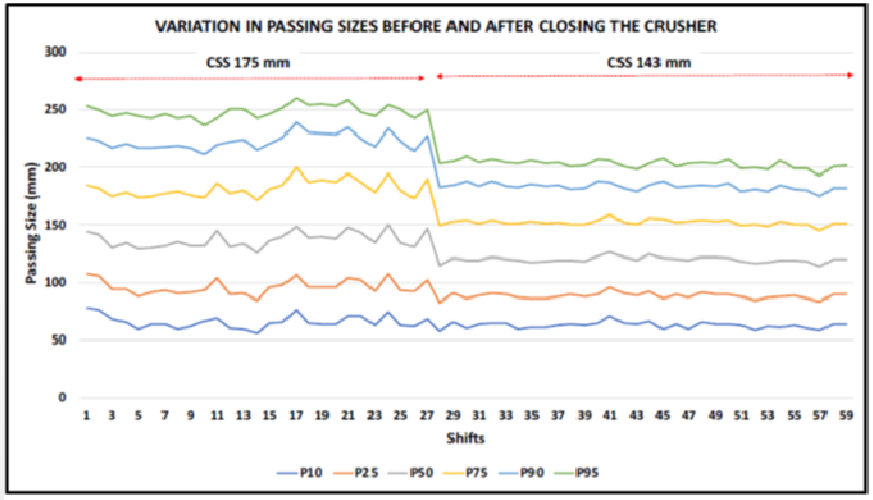
LASERSIEVE

- Output of Primary Crusher
  - Surface Distribution Analysis
    - Full PSD using Rosin-Rammler model





Real-time monitoring of the impact of operational conditions (changing the closed side setting from 175 mm down to 143 mm) on the output of a primary crusher with the LaserSieve system.

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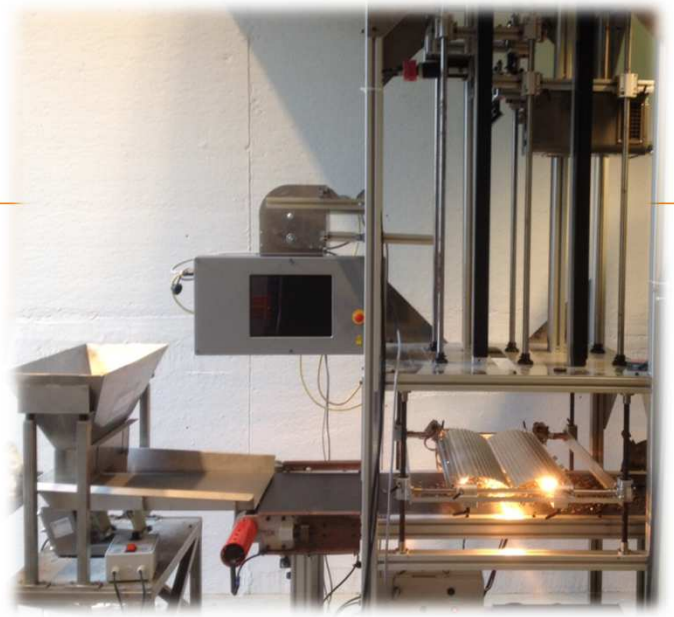
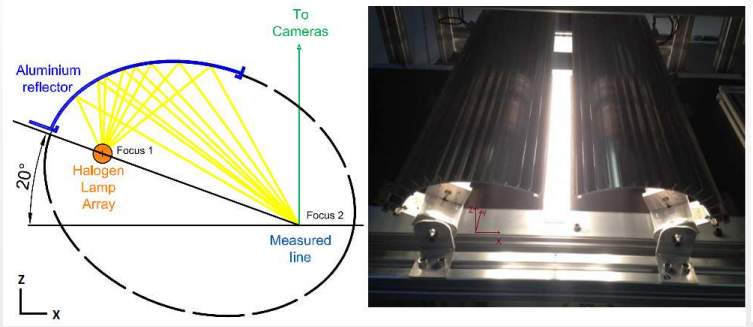
Parmar, A. 2018, M Sc Thesis (unpublished)

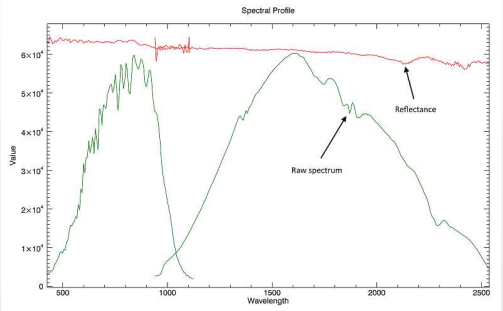
ILIADE

- Imaging Principle
  - Hyperspectral Diffuse Reflectance Imaging
  - Mechanical Dispersion (dry)
  - Static Image Analaysis
- Particle Size Range
  - 100 µm – 5 mm
- Measurable Properties
  - 2D Size
    - True sieving diameter
  - 2D Shape
    - True elongation
  - Mineralogy
    - Spectral class



Coaxial imaging system combining a SWIR (Specim Oy) and a VNIR (PhotonfocusMV1+ImSpector V10E) linescan camera.



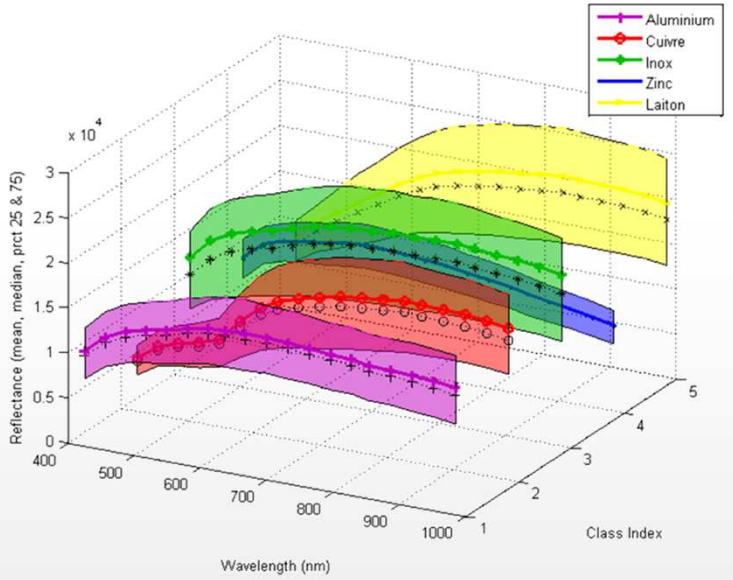


Propietary illumination and image calibration

Barnabé et al., 2015, J. Electronic Imaging Vol. 24.

ILIADE

- Automatic identification of metallic scraps
  - Training phase



Spectral distribution (Q1-Q3 interquartile) of the different scrap types in the VNIR range

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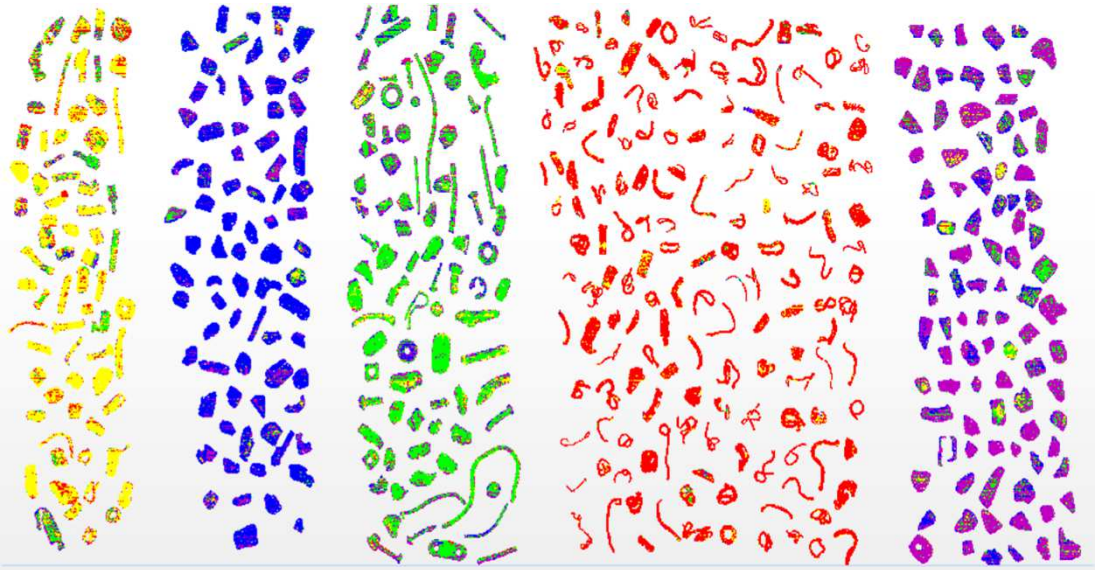
ILIADE

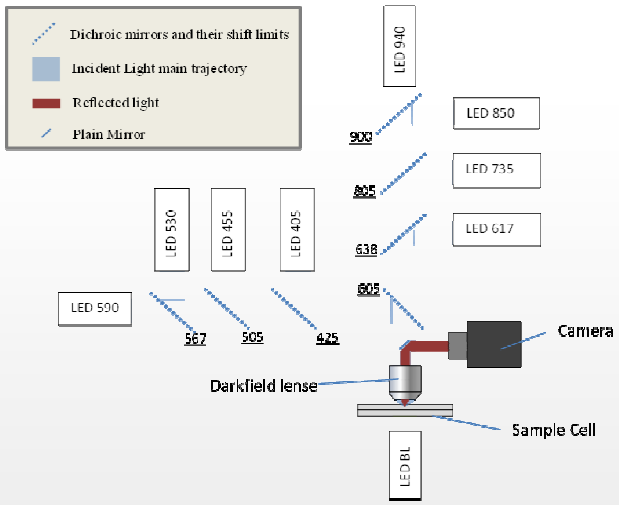
- Automatic identification of metallic scraps
  - Classification (SVM)
    - Decision making based on dominant class



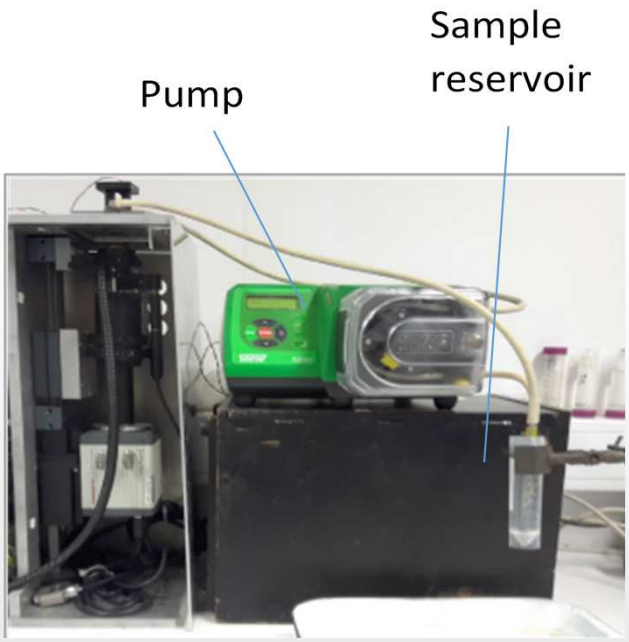
	Decisions					
	Zinc	Stain. Steel	Copper	Aluminium	Brass	
Zinc	100.0%	0%	0%	0%	0%	100%
St. Steel	0%	100.0%	0%	0%	0%	100%
Copper	5.3%	0%	94.7%	0%	0%	100%
Alu.	0%	5%	0%	95.0%	0%	100%
Brass	0%	9.52%	0%	0%	90.5%	100%

PULPMIN

- Imaging Principle
  - Multispectral Diffuse Reflectance Imaging + Backlight Imaging
  - Mechanical Dispersion (wet) / Pulp Dilution
  - "Dynamic" Image Analysis
- Particle Size Range
  - 1 µm – 100 µm
- Measurable Properties
  - 2D Size
  - 2D Shape
  - Indicative Mineralogy
    - Spectral class



Propietary multispectral illumination



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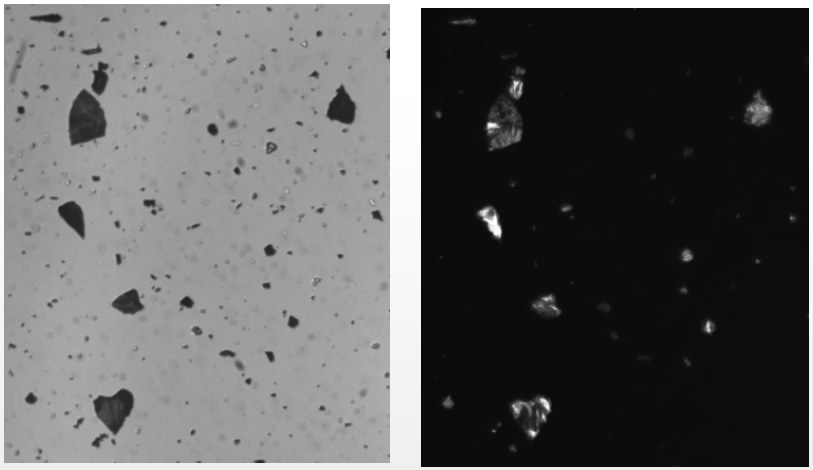
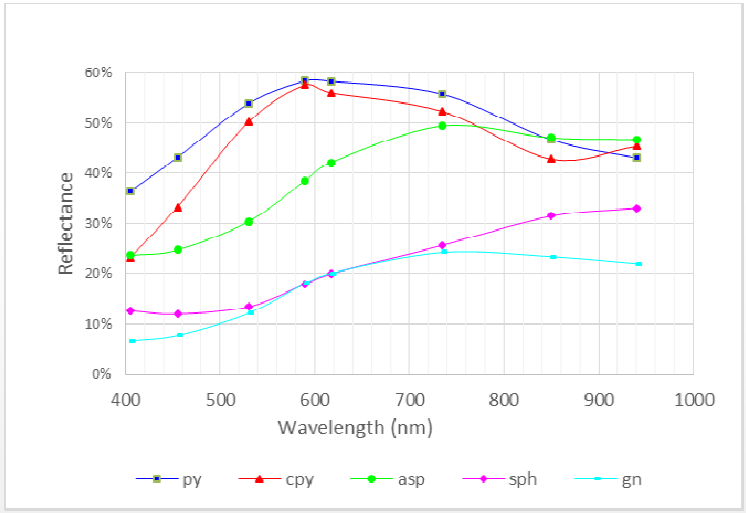
PULPMIN

- Multispectral Imaging
  - 1,6 µm / pixel
- of ground base metal sulphide particles
  - D_{95} = 150µm



Diascopic (transmission) and Episcopic (reflected@405nm) image of the same scene



Spectra of median reflectance values for five major sulphide species in real time pulp imaging conditions : Pyrite (Py); Chalcopyrite (Cpy); Arsenopyrite (Asp); Sphalerite (Sph) and Galena (Gn).

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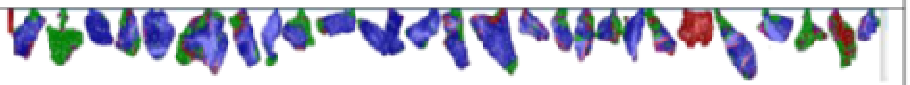
PULPMIN

- Neural Network Classification of BSM populations

	Py – C	Cpy – D	Asp - E	Sph – F	Results visualisation
Py – C	0.61	0.13	0.22	0.03	
Cpy – D	0.03	0.89	0.07	0.01	
Asp - E	0.06	0.01	0.87	0.06	
Sph – F	0.17	0.02	0.08	0.88	

Matrix of confusion resulting from neural network classification of a mix of pyrite (Py - blue); Chalcopyrite (Cpy - red); Arsenopyrite (Asp - green) and Sphalerite (Sph - purple) particles (~=100 µm)

Leroy, S. and Pirard, E., 2019, Minerals Engng, V.132, 228-237 (in press)

Conclusions

- Potential of low cost imaging technologies
  - ex. VNIR imaging
- Importance of particle tracking
  - Improve simulation tools
  - Provide feed-forward process control
- Do more less well
  - Compromise between representative sample and accuracy of individual measurements
- Future developments in “smart tagging”
  - Go beyond intrinsic properties of particles