

Multispectral Imaging System based on Light-Emitting Diodes in the wavelength ranges of ultraviolet, visible and near infrared. Application to the study and preservation of artwork



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- **Motivation:**

- Explore the possibilities of an LED based multispectral system for art work study

Objectives:

- Use off-the-shelf elements to build the system
- Performance evaluation over pigments used in art work
- Application to paintings at the Royal Museum-Monastery of Pedralbes, Barcelona.

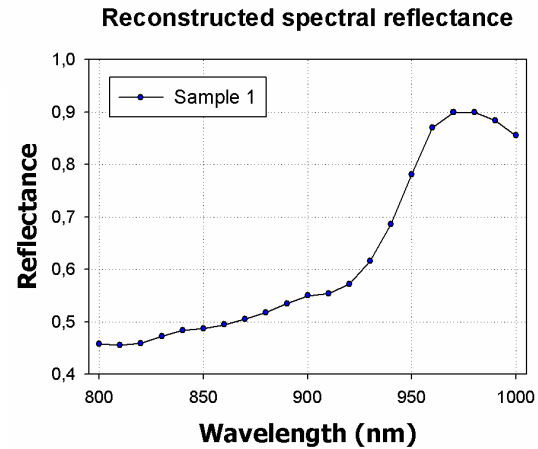
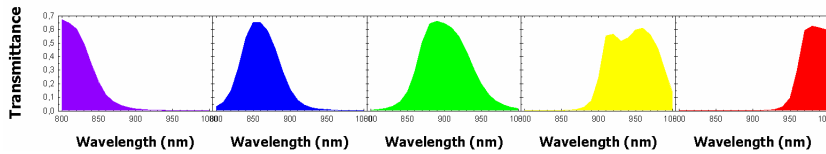
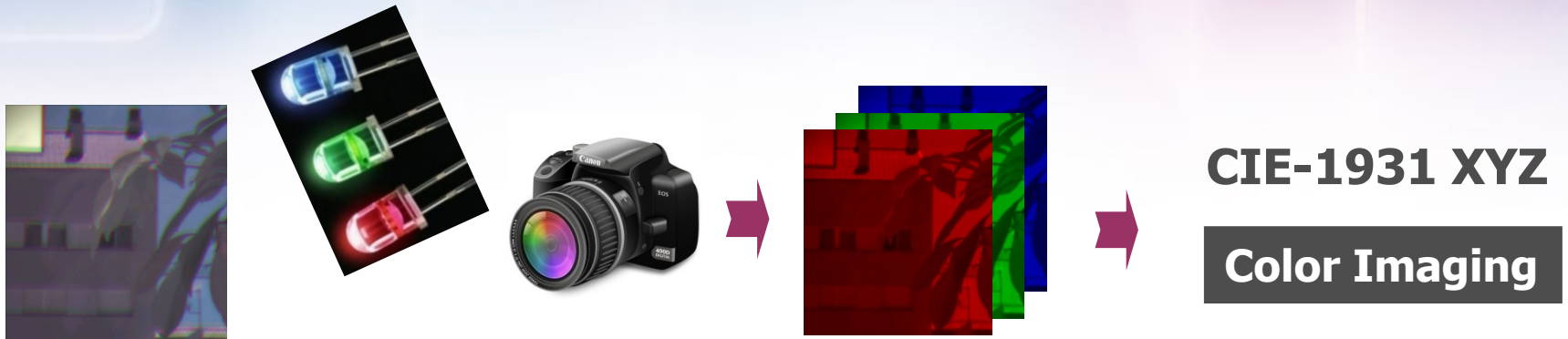


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Introduction



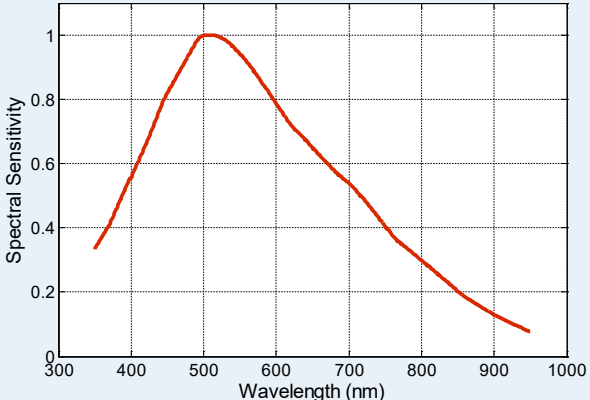
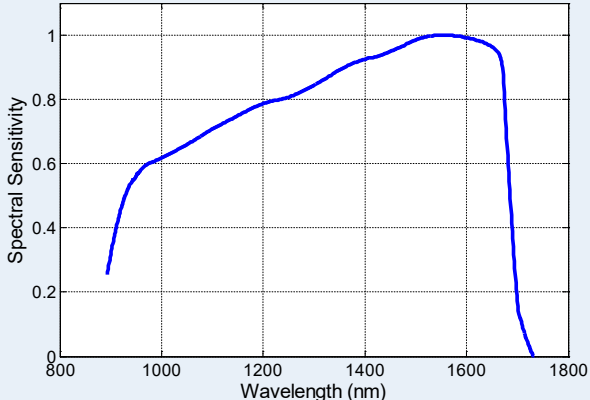
Multispectral systems

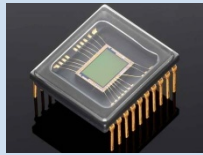


Multispectral Imaging



Imaging Sensors

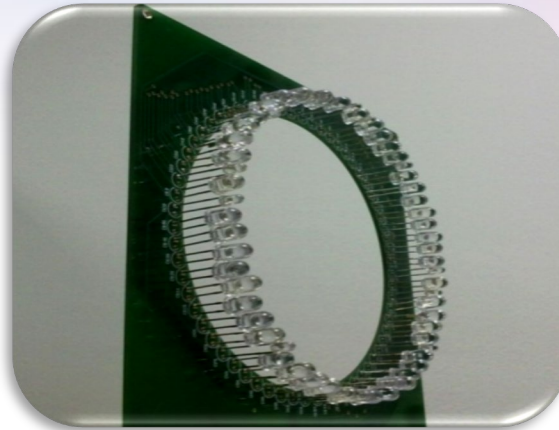
	Near UV-Vis-NIR (370-900nm)	IR (900-1600nm)																																																				
Imaging Sensors	<p>QICAM CCD</p> 	<p>HAMAMATSU InGaAs</p> 																																																				
Spectral sensitivity	 <p>The graph shows the spectral sensitivity of the QICAM CCD camera. The x-axis is Wavelength (nm) from 300 to 1000, and the y-axis is Spectral Sensitivity from 0 to 1. The curve peaks at approximately 0.95 at 500 nm and drops to near zero by 950 nm.</p> <table border="1"><caption>Approximate data for QICAM CCD spectral sensitivity</caption><thead><tr><th>Wavelength (nm)</th><th>Spectral Sensitivity</th></tr></thead><tbody><tr><td>350</td><td>0.35</td></tr><tr><td>400</td><td>0.55</td></tr><tr><td>450</td><td>0.80</td></tr><tr><td>500</td><td>1.00</td></tr><tr><td>550</td><td>0.90</td></tr><tr><td>600</td><td>0.75</td></tr><tr><td>650</td><td>0.65</td></tr><tr><td>700</td><td>0.55</td></tr><tr><td>750</td><td>0.45</td></tr><tr><td>800</td><td>0.35</td></tr><tr><td>850</td><td>0.25</td></tr><tr><td>900</td><td>0.15</td></tr><tr><td>950</td><td>0.05</td></tr></tbody></table>	Wavelength (nm)	Spectral Sensitivity	350	0.35	400	0.55	450	0.80	500	1.00	550	0.90	600	0.75	650	0.65	700	0.55	750	0.45	800	0.35	850	0.25	900	0.15	950	0.05	 <p>The graph shows the spectral sensitivity of the HAMAMATSU InGaAs camera. The x-axis is Wavelength (nm) from 800 to 1800, and the y-axis is Spectral Sensitivity from 0 to 1. The curve rises from 0.25 at 900 nm to a peak of 1.0 at 1550 nm, then drops sharply to zero by 1700 nm.</p> <table border="1"><caption>Approximate data for HAMAMATSU InGaAs spectral sensitivity</caption><thead><tr><th>Wavelength (nm)</th><th>Spectral Sensitivity</th></tr></thead><tbody><tr><td>900</td><td>0.25</td></tr><tr><td>1000</td><td>0.60</td></tr><tr><td>1100</td><td>0.75</td></tr><tr><td>1200</td><td>0.80</td></tr><tr><td>1300</td><td>0.85</td></tr><tr><td>1400</td><td>0.90</td></tr><tr><td>1500</td><td>0.95</td></tr><tr><td>1550</td><td>1.00</td></tr><tr><td>1600</td><td>0.95</td></tr><tr><td>1650</td><td>0.15</td></tr><tr><td>1700</td><td>0.00</td></tr></tbody></table>	Wavelength (nm)	Spectral Sensitivity	900	0.25	1000	0.60	1100	0.75	1200	0.80	1300	0.85	1400	0.90	1500	0.95	1550	1.00	1600	0.95	1650	0.15	1700	0.00
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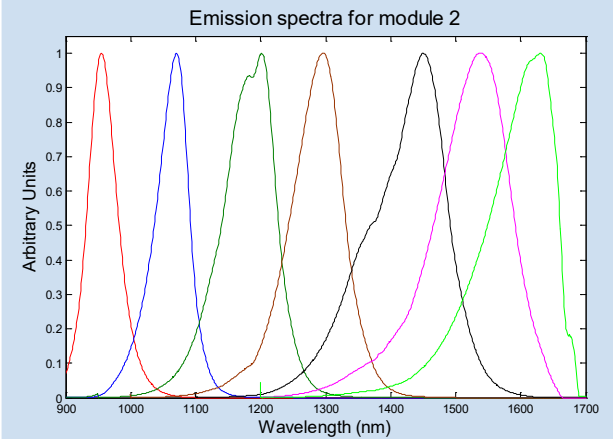
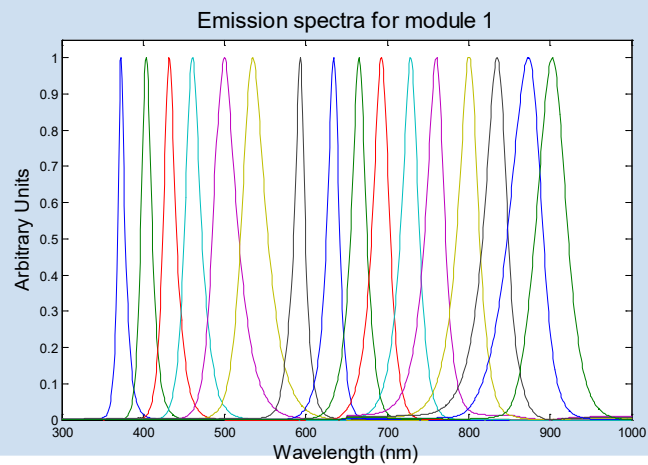
Illumination modules



Near UV-Vis-NIR (370-900nm)

IR (900-1600nm)

Spectral
emission

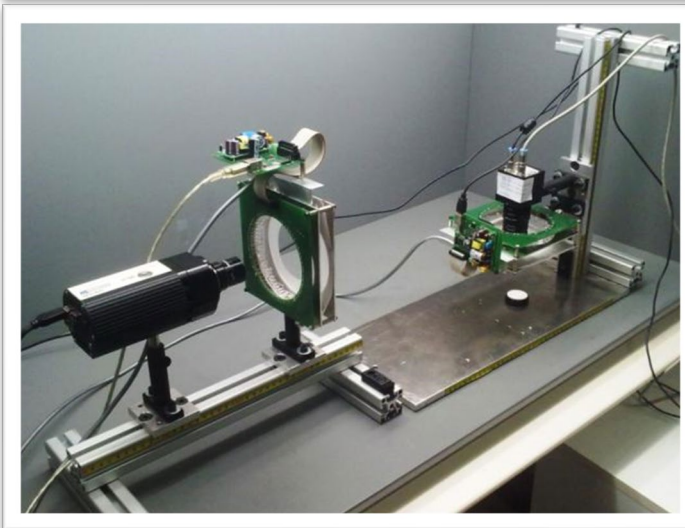
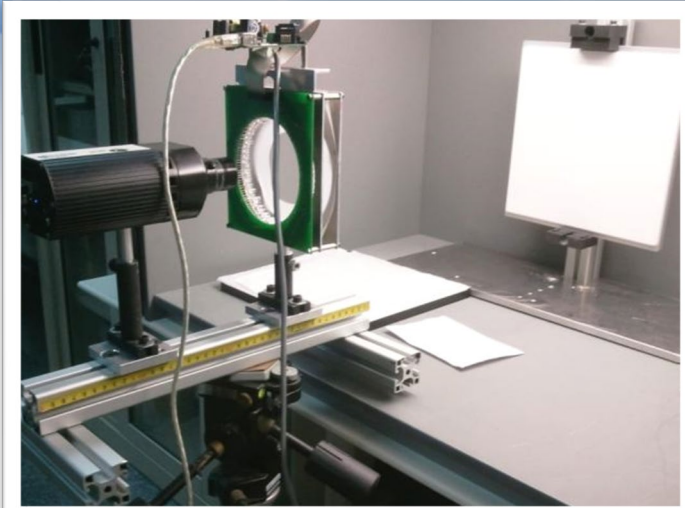


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Experimental system

Operative prototype



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Spectral reconstruction

- Pseudo-inverse method for spectral estimation

$$D = R_t X_t^T (X_t X_t^T)^{-1}; \quad r_e = Dx$$

- Interpolation using cubic splines.

Evaluation metrics

- Colorimetric evaluation → **CIEDE2000 formula** (*DE00*)

- Spectral evaluation → **RMSE**

$$GFC = \frac{\left| \sum_j r_o(\lambda_j) r_e(\lambda_j) \right|}{\sqrt{\sum_j [r_o(\lambda_j)]^2 \sum_j [r_e(\lambda_j)]^2}}$$

GFC ≥ 0.999 Good Match

GFC ≥ 0.9999 excellent match



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Training and evaluation set: Fresco paintings



- Indigo
- Venetian red
- Ivory black
- Yellow Ochre
- White lead
- Burnt brown
- Etc.



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Software interface

Pin3_Verde
Number of elements =8
[1,2,3,4,7,9,10,11]

Training Data

Get Training Spectra

Images

UV-Vis
 IR

Calculate PSE Transformation Ma...

Save Result

Name Sample Reconstructed

Reconstructed Reflectances

Refresh Plot Reconstruction

Training Set PSE UV-Vis

Reflectances (* Reconstructed, -- Real)

Reconstruction Method

Pseudo Inverse Estimati...

Interpolation Splines Linear

Run Reconstruction

Close Figures

EXIT

Results Evaluation

Sample List

Sample	Sample Name (File Name)	Image Number
1	InBaseWhiteRef	1
2	InDark	2
3	Leorio_1	3

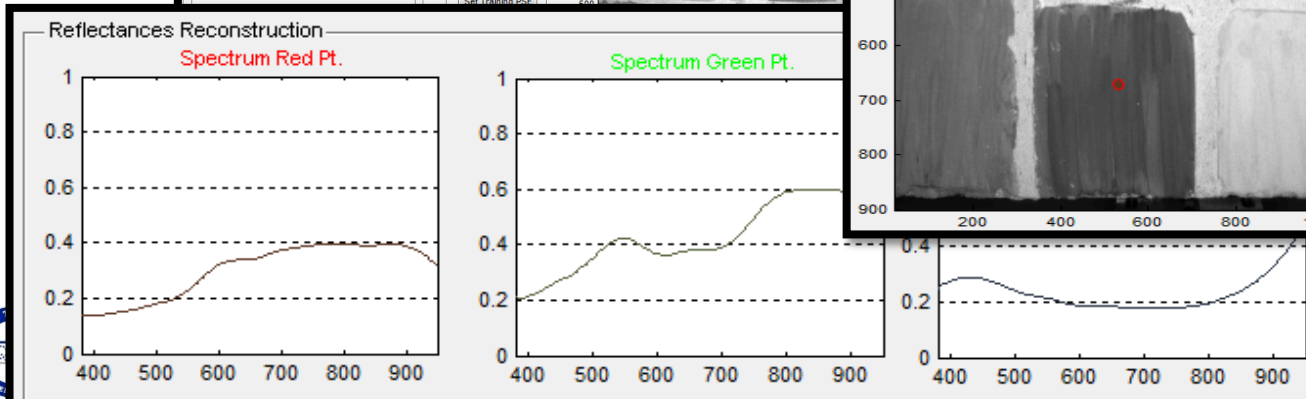
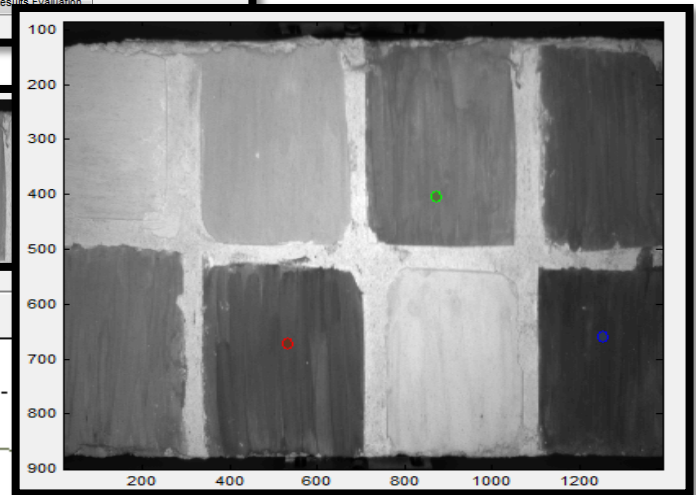
Right-click plots for larger view

Button Group

Load Images

UV-Vis
 IR

Set Training PSE



UNE-EN ISO 9001

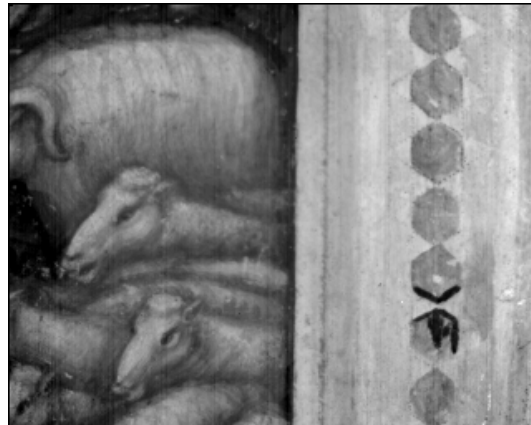
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Spectral Images



Wall painting images at 635 nm



Wall painting images at 1300nm

Art work: wall paintings in Saint Michel's cell at the Royal Monastery of Pedralbes.



Image stitching



Set of images



Stitched image



Stitched image (RGB)

**Art work: Diptych, Virgen de la leche
mhcb, mmp 115035**



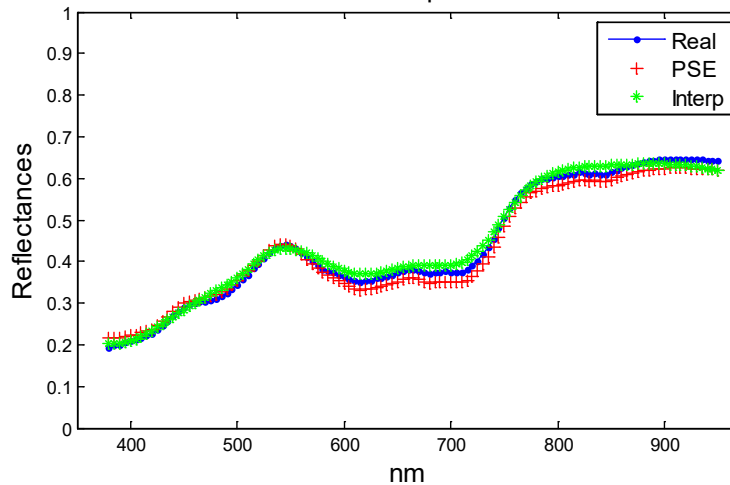
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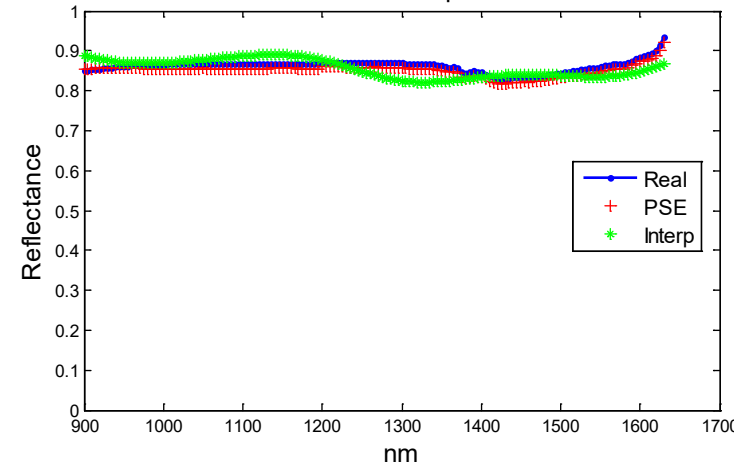
Metrics for Spectral reconstruction Samples: Fresco patches

	Module 1 (Interpolation)			Module 2 (Interpolation)	
	DE00	RMSE x 100	GFC	RMSE x 100	GFC
Mean	1.83	2.19	0.9994	5.57	0.9968
Min	1.29	0.61	0.9977	2.40	0.9922
Max	2.96	4.49	0.9999	9.56	0.9996

Reflectances comparison UV-Vis



Reflectances comparison IR



	Module 1 (PSE)			Module 2 (PSE)	
	DE00	RMSE x 100	GFC	RMSE x 100	GFC
Mean	0.99	1.09	0.9999	1.97	0.9996
Min	0.33	0.56	0.9996	0.41	0.9991
Max	1.89	2.55	1.0000	3.59	1.0000



Metrics for Spectral reconstruction Samples: points over the wall paintings

	<i>Module 1 (Interp)</i>			<i>Module 2 (Interp)</i>	
	DE00	RMSE x 100	GFC	RMSE x 100	GFC
Mean	2.00	1.93	0.9994	3.09	0.9977
Min	1.19	0.57	0.9990	1.75	0.9936
Max	2.84	4.11	0.9996	4.91	0.9999

	<i>Module 1 (PSE)</i>			<i>Module 2 (PSE)</i>	
	DE00	RMSE x 100	GFC	RMSE x 100	GFC
Mean	1.24	0.91	0.9997	2.04	0.9998
Min	0.07	0.09	0.9984	0.51	0.9993
Max	4.73	2.37	1.0000	2.04	1.0000



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Summary

- Implementation of a multispectral system based on LEDs
- Evaluation of performance through simulations
- Application to artwork
- Concordance between simulations and results over real samples.



Acknowledgments

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Generalitat de Catalunya
**Departament d'Innovació,
Universitats i Empresa**



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Thank you!



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