

# Multi-spectral-line imaging for forensics: recent developments

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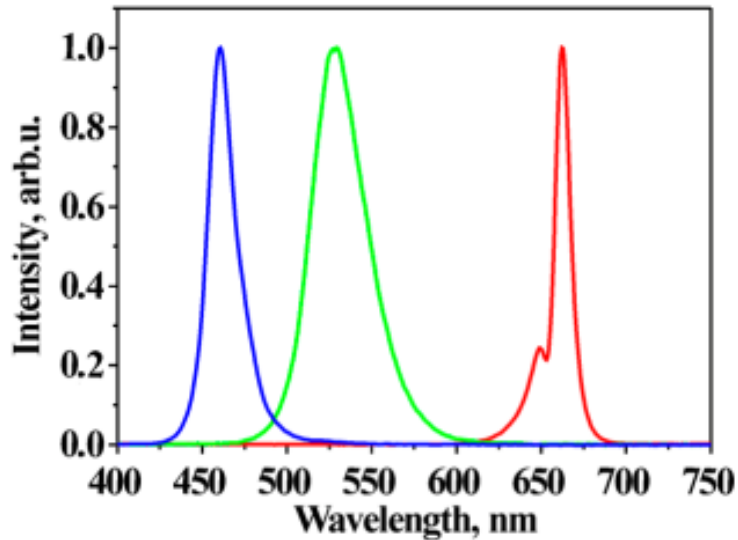
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University of Latvia, Riga

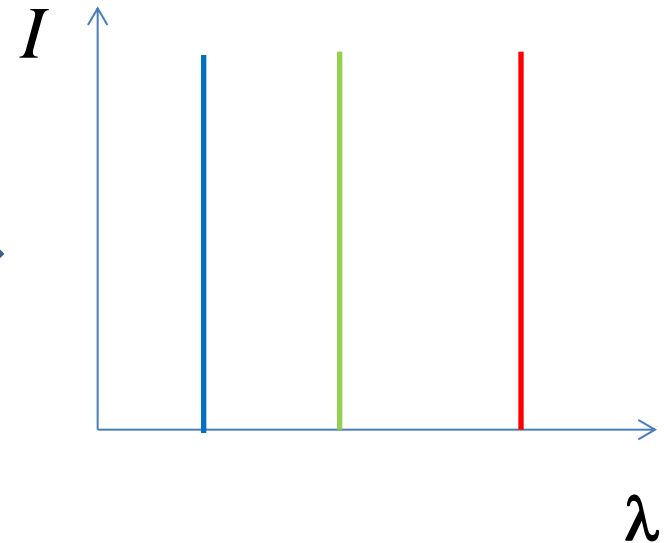
# The main concept: improved MSI

Conventional:  
Spectral **band** images



Sequential ( $t \gg 0$ )

Novel:  
Spectral **line** images



Single snapshot ( $t \rightarrow 0$ )

$$n = 3 \rightarrow n > 3$$

# Why? Advantages:

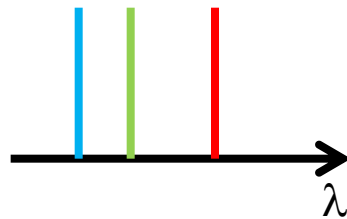
- Increased (ultimate) spectral selectivity
- Improved imaging quality (avoided motion artefacts – single snapshot)
- Simpler/faster image processing (numbers instead of integrals over wavelength bands)

# Triple spectral line imaging

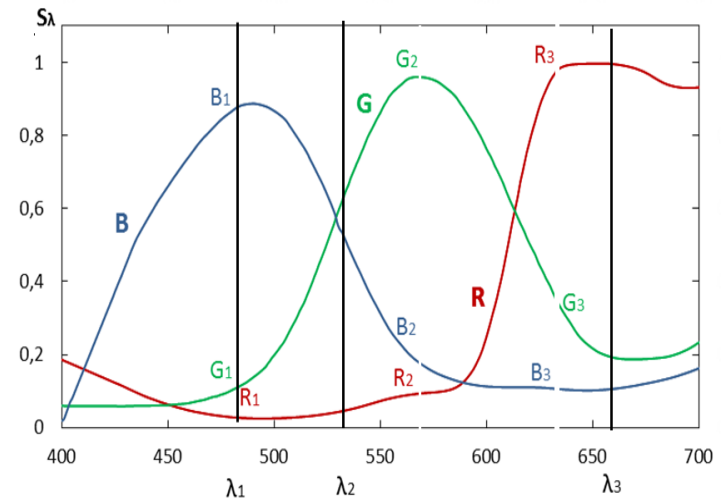
3 **monochromatic spectral images** from a **single-snapshot RGB image** data can be extracted if object is illuminated simultaneously at 3 laser wavelengths, and the RGB-band sensitivities of the image sensor are known  $\rightarrow$  corrected R-, G- and B-band images\*

## Illumination spectrum

Triple-wavelength



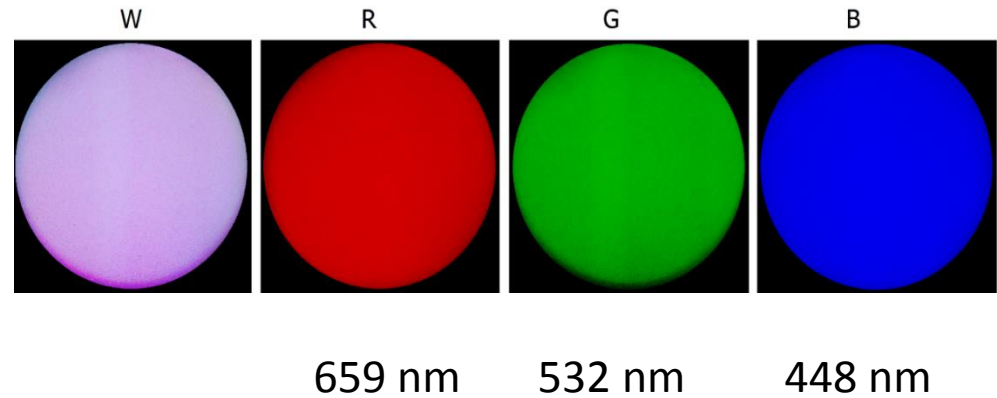
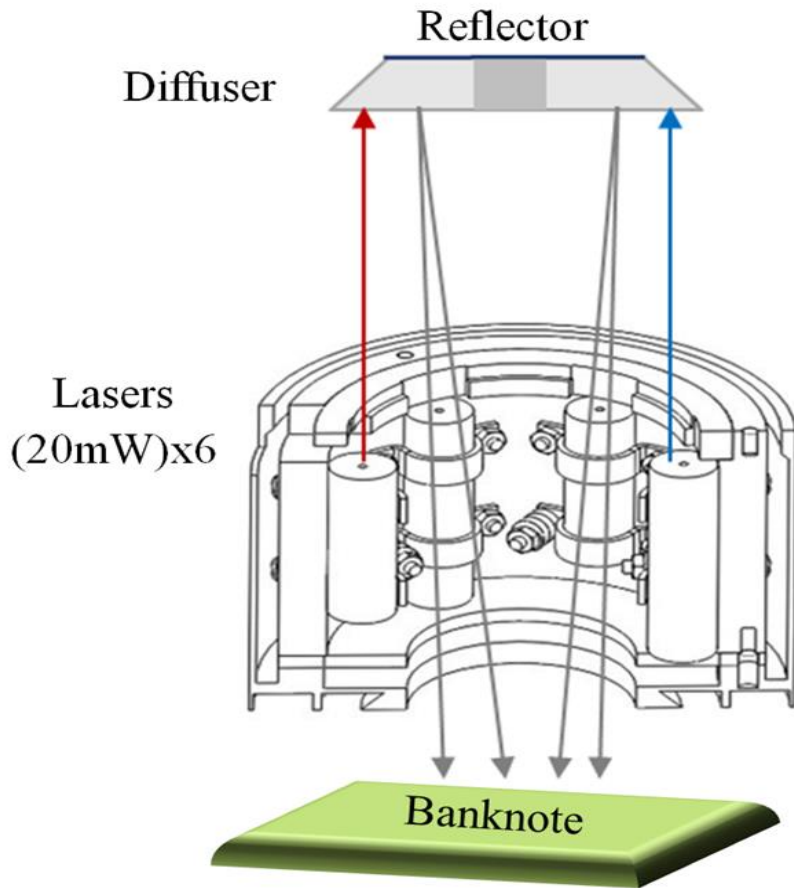
## RGB sensitivities of the image sensor :



\*) WO 2013135311 (A1), 2012. Method and device for imaging of spectral reflectance at several wavelength bands.

# How about uniformity of laser illumination?

## Flat ring-shaped diffusing reflector



# Proof of concept: color pigment differences in counterfeits

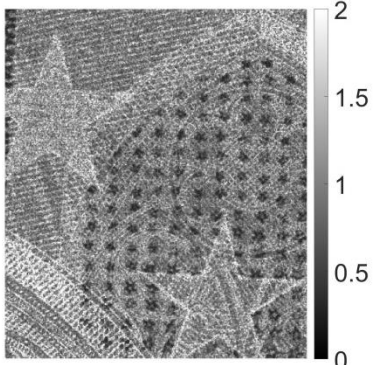
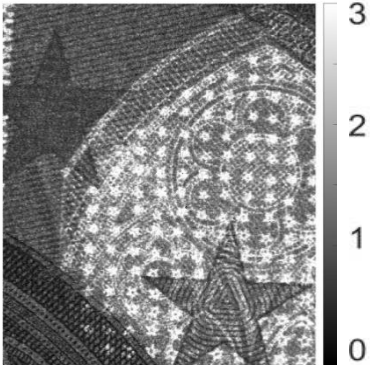




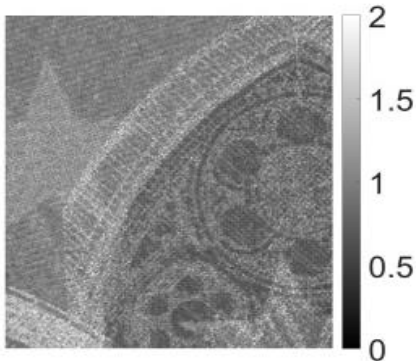
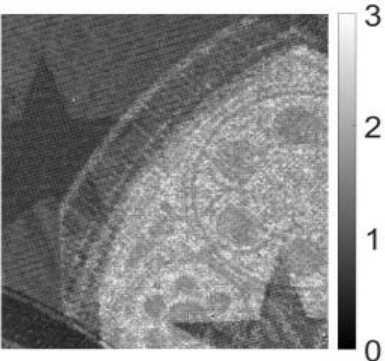
# Preliminary: increased sensitivity by ratios of spectral line images involving 448 nm



Authentic



Counterfeit

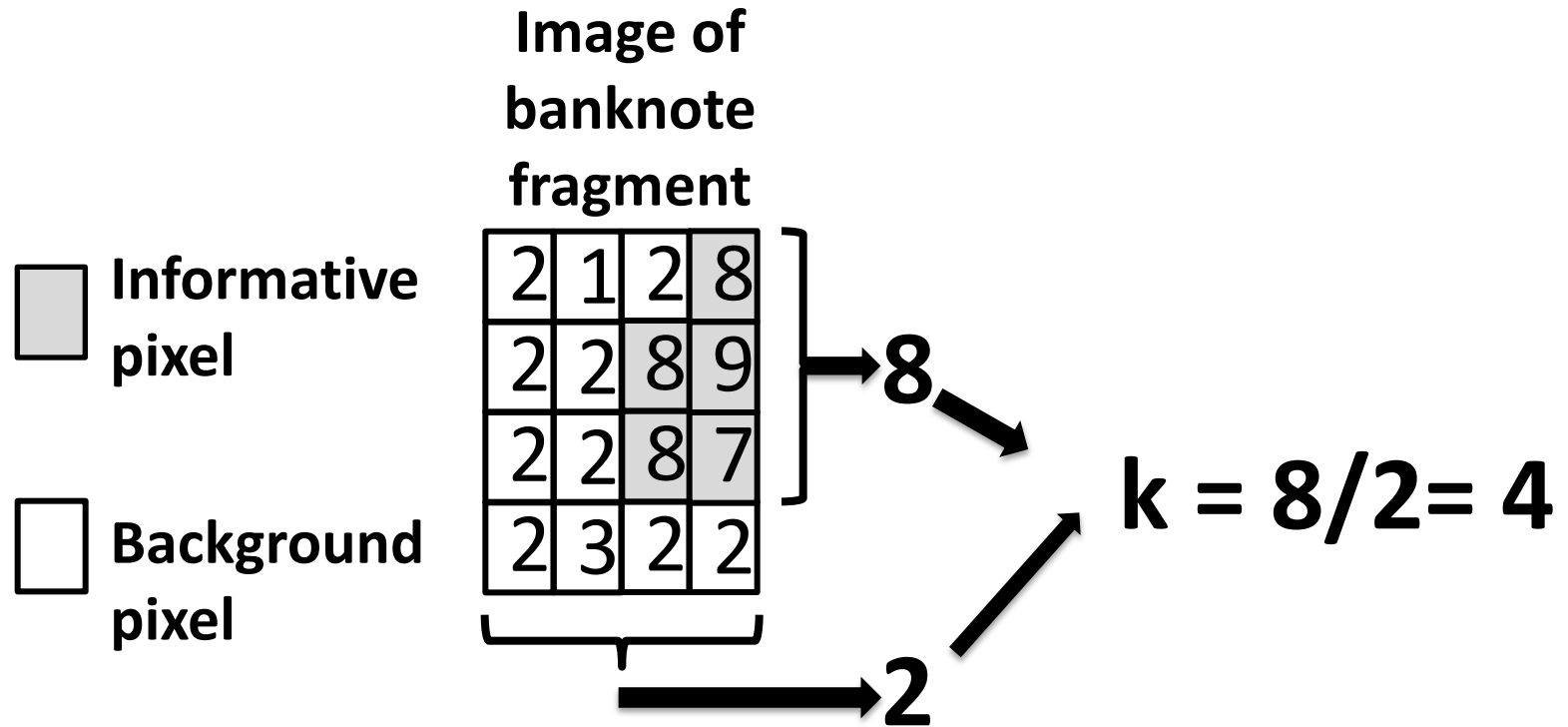


RGB

659/448nm

448/532nm

# Numerical comparison: k-factor (single-wavelength spectral image)



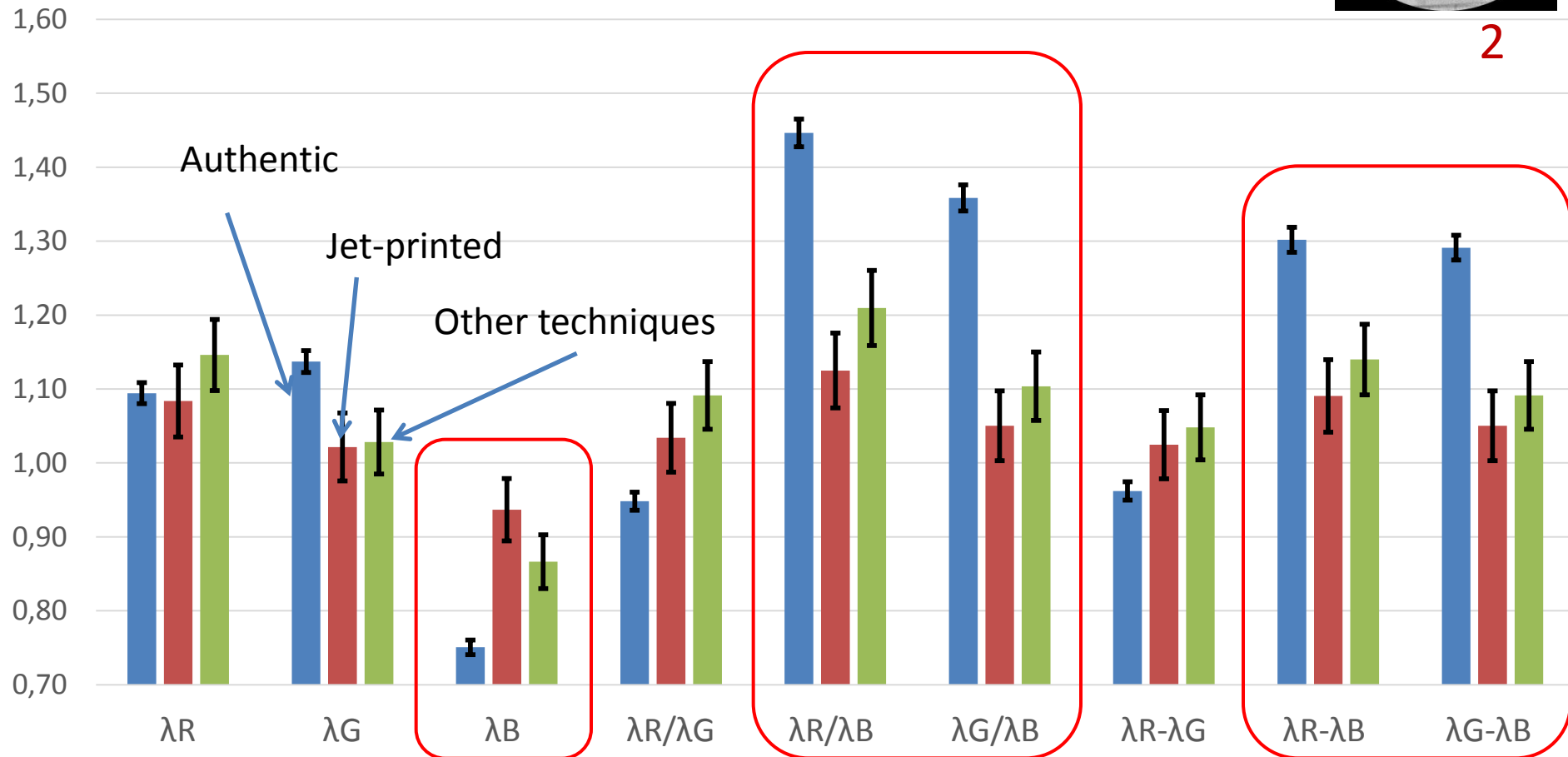
Mean pixel values over the selected ROI are calculated/divided



# k-values of the same fragment of 50 EUR banknotes (29 samples, reported in Dubrovnik)



2





# New data: 500 EUR

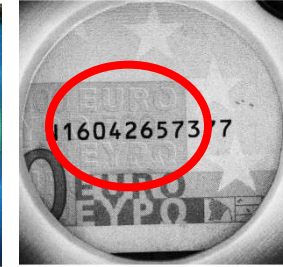
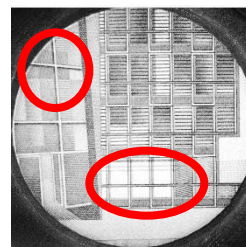
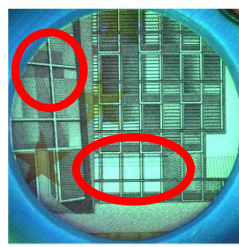
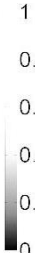
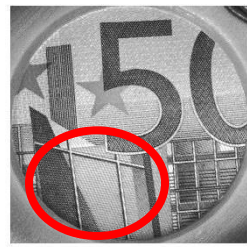
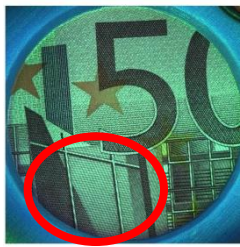


532 nm

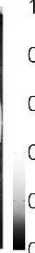
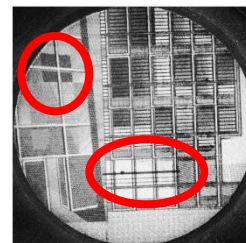
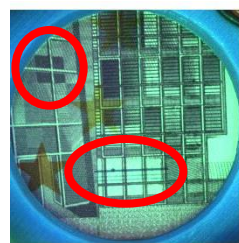
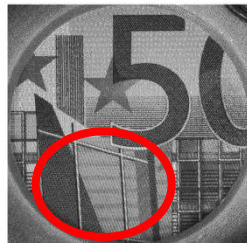
659 nm

448 nm

Authentic



Counterfeit



1

2

3



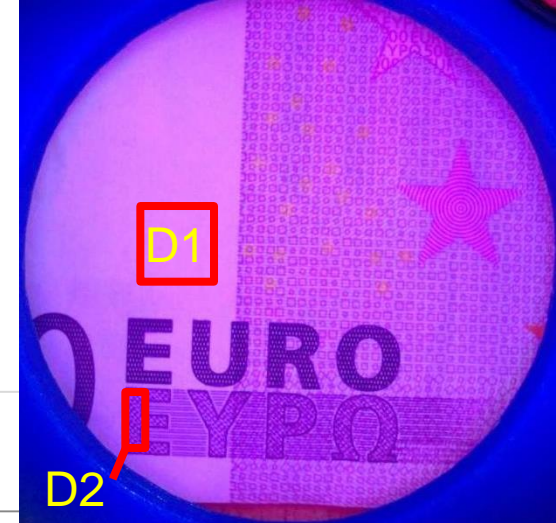
# Elements (RoI's) for numerical research of the 500 EUR banknotes



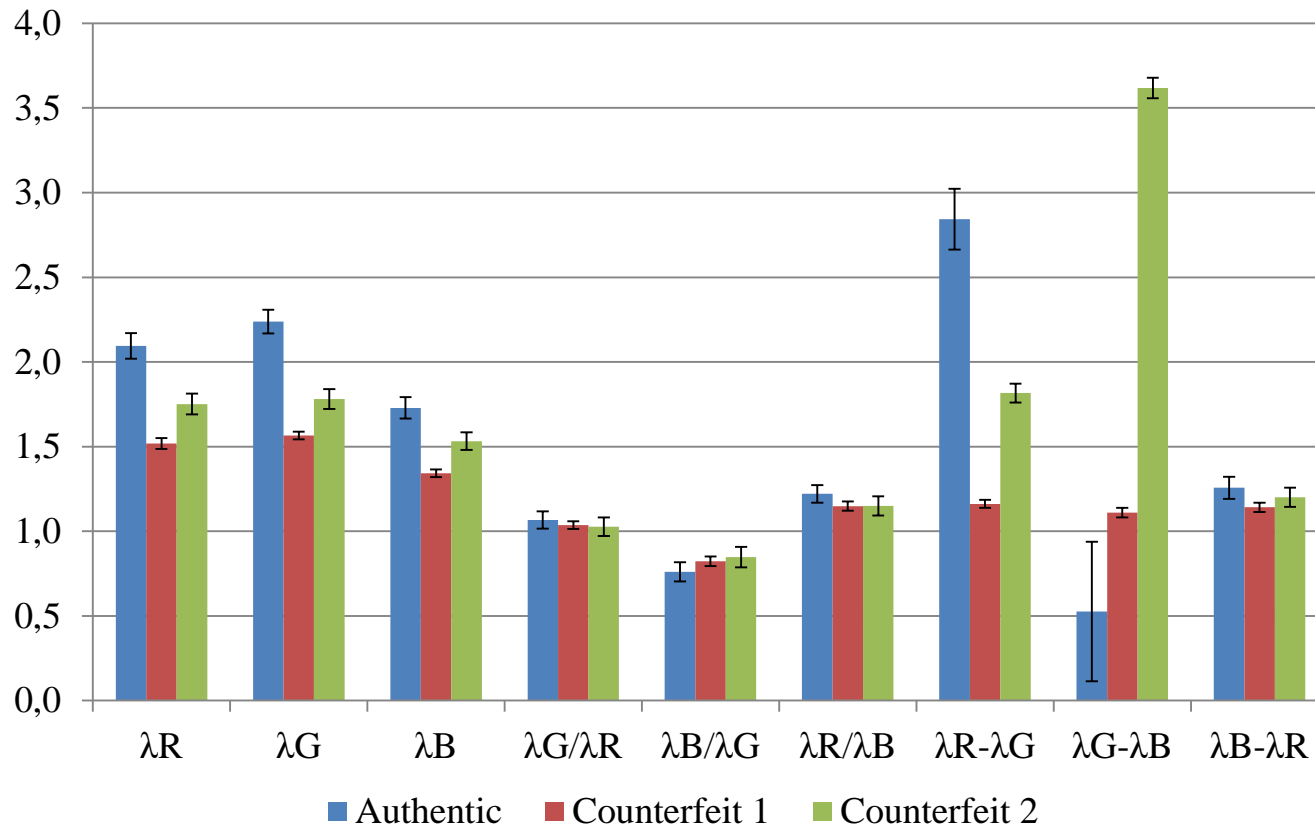


# Elements for numerical research on the 500 EUR banknote



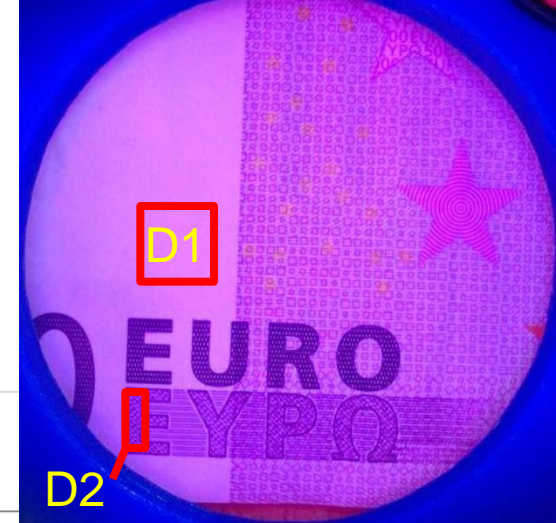


## Ratio between elements D1 and D2

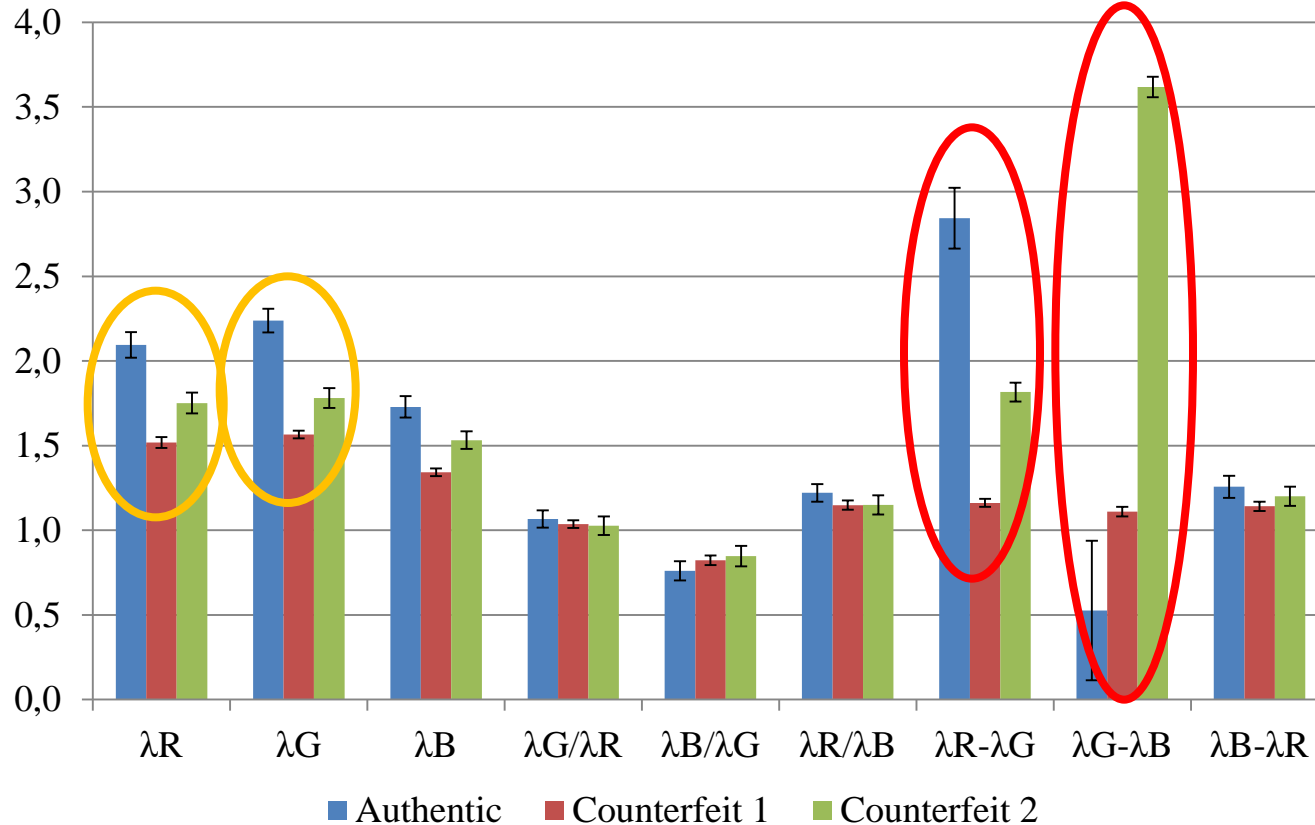


$\lambda_R$  – 659 nm illumination  
 $\lambda_G$  – 532 nm illumination  
 $\lambda_B$  – 448 nm illumination

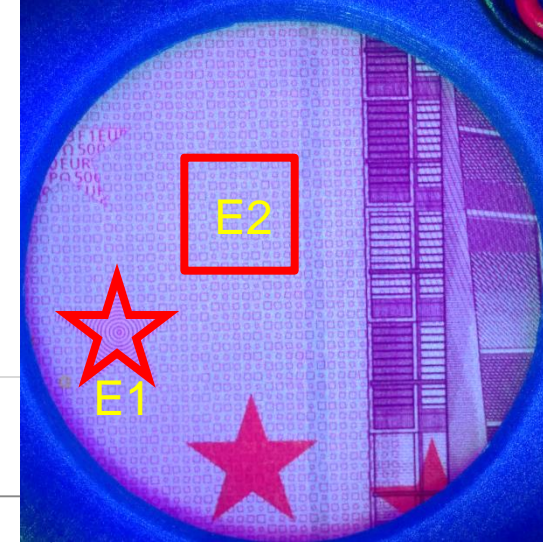




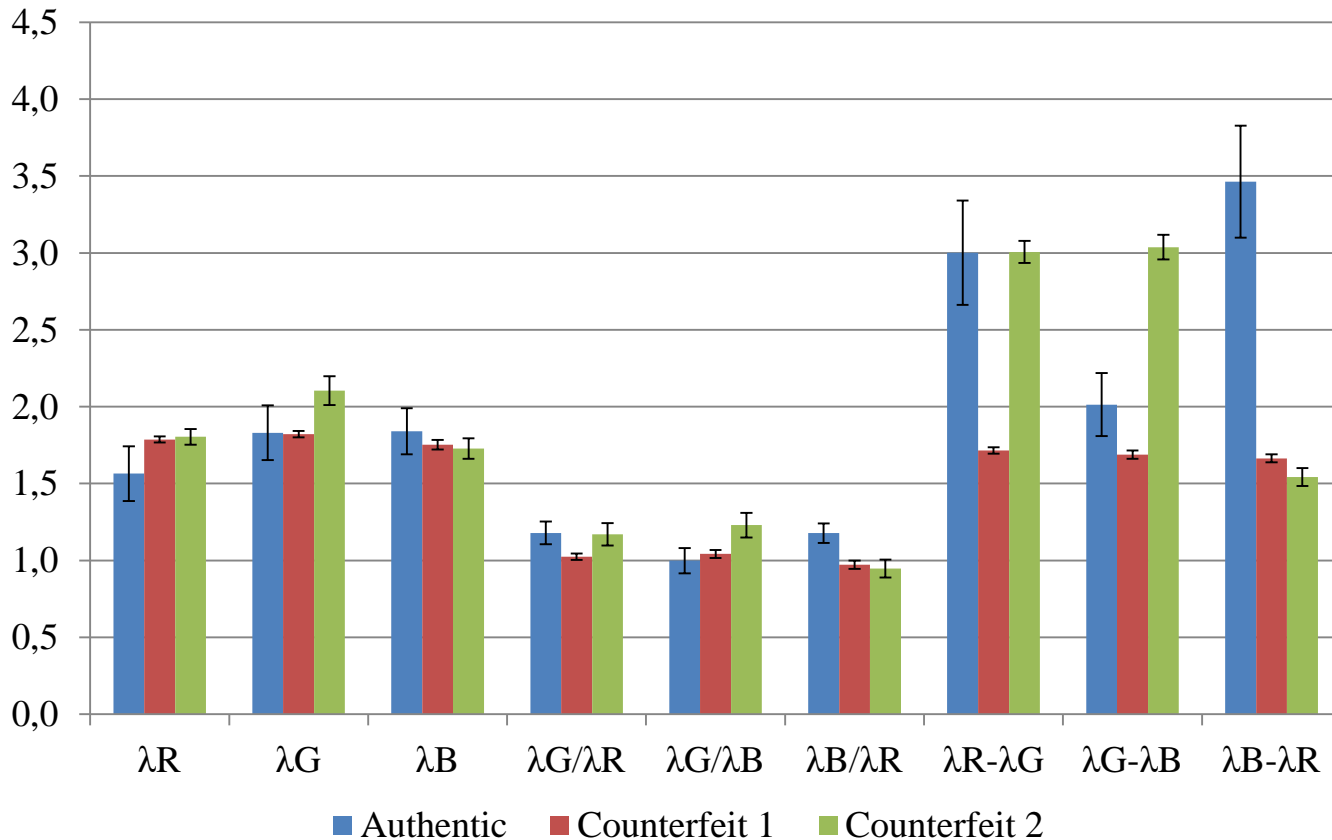
## Ratio between elements D1 and D2



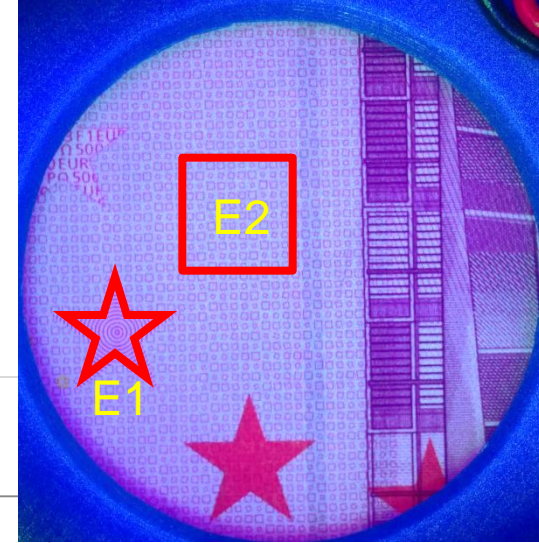
$\lambda_R$  – 659 nm illumination  
 $\lambda_G$  – 532 nm illumination  
 $\lambda_B$  – 448 nm illumination



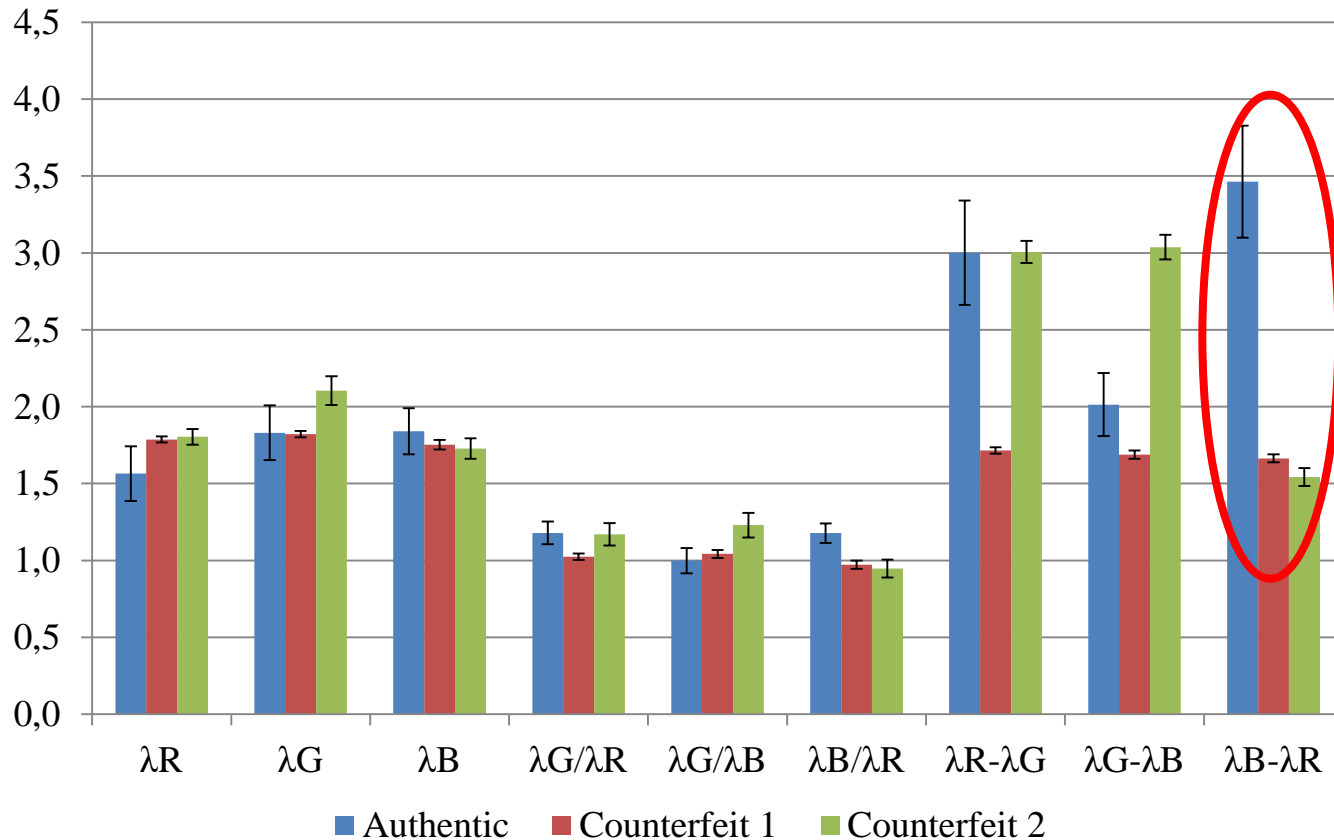
## Ratio between elements E1 and E2



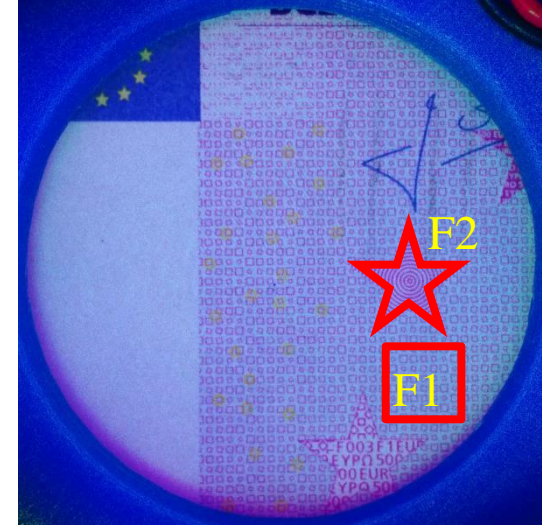
$\lambda_R$  – 659 nm illumination  
 $\lambda_G$  – 532 nm illumination  
 $\lambda_B$  – 448 nm illumination



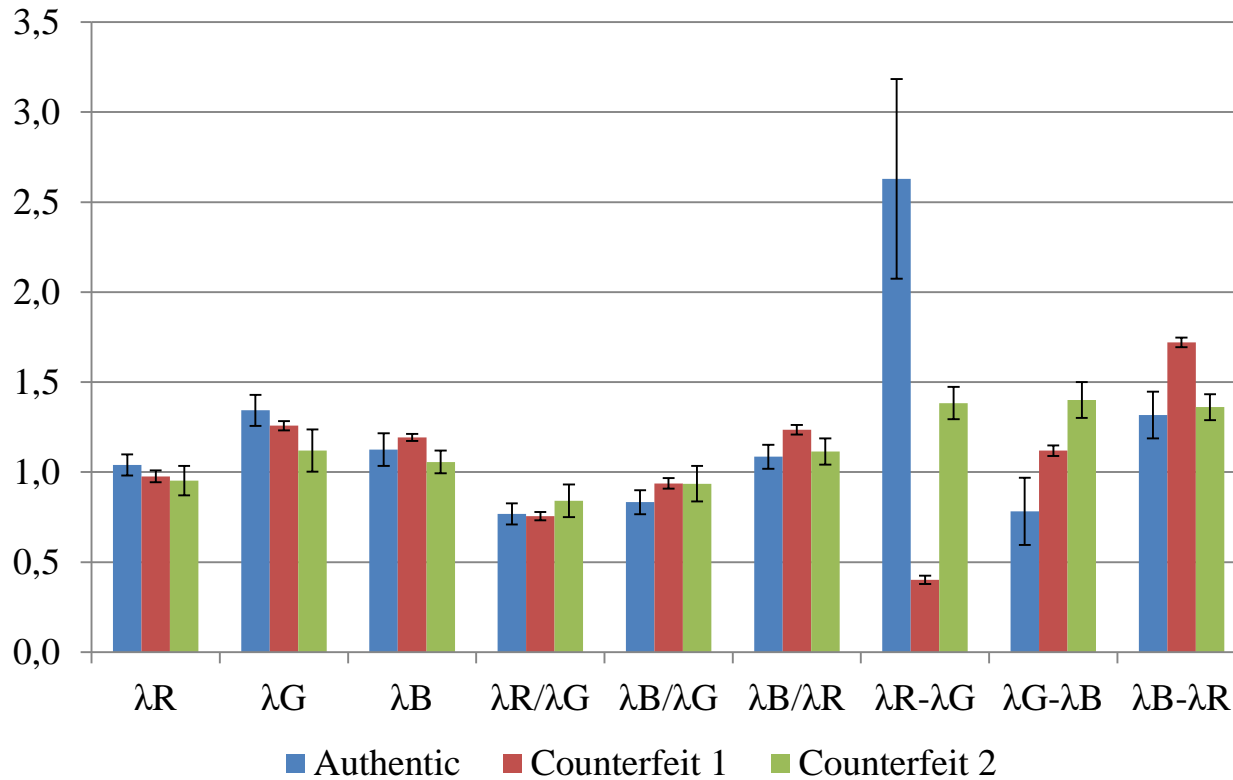
## Ratio between elements E1 and E2



$\lambda_R$  – 659 nm illumination  
 $\lambda_G$  – 532 nm illumination  
 $\lambda_B$  – 448 nm illumination

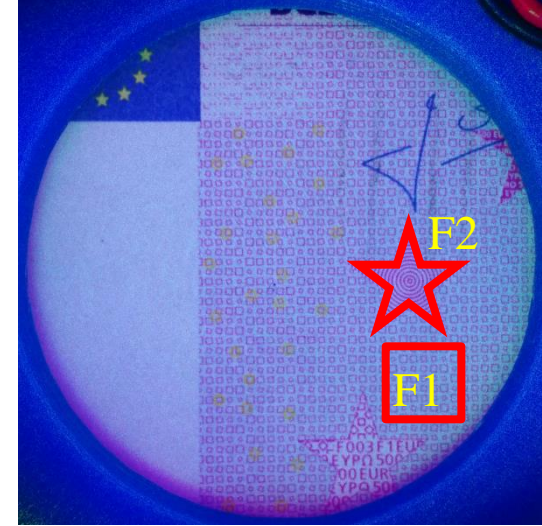


## Ratio between elements F1 and F2

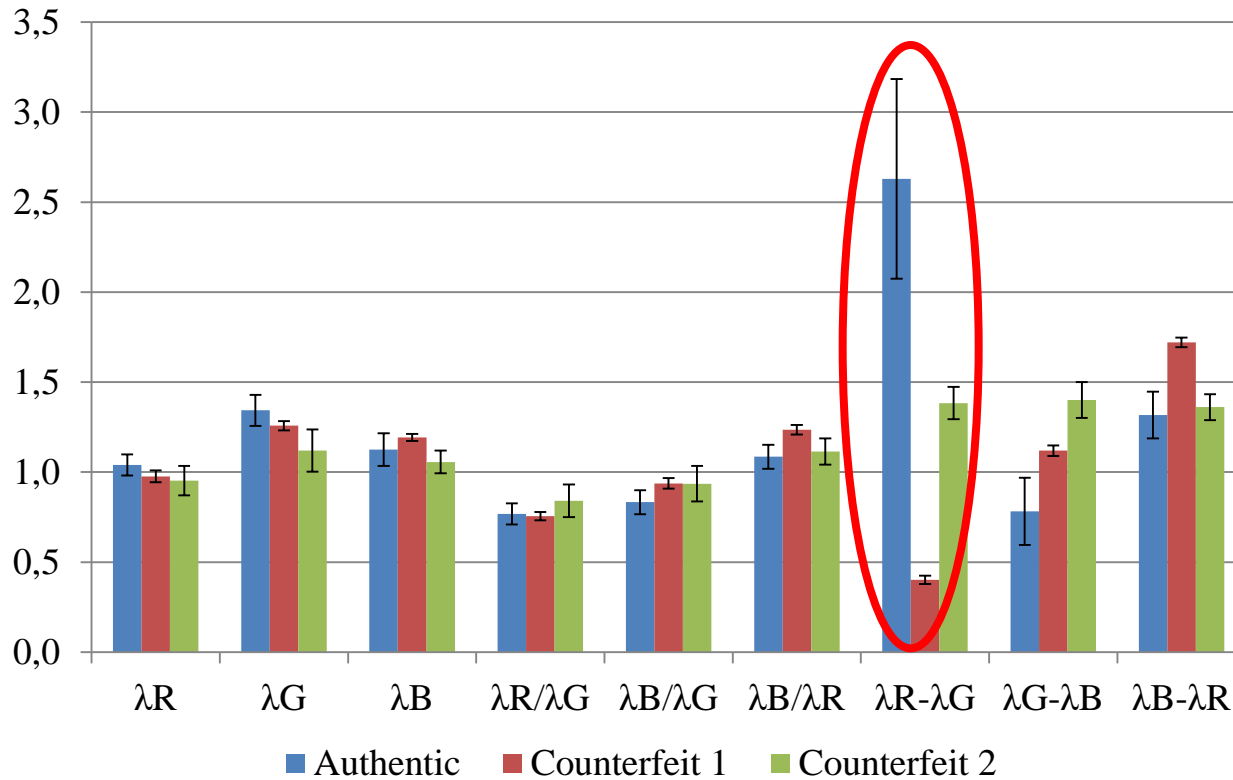


$\lambda_R$  – 659 nm illumination  
 $\lambda_G$  – 532 nm illumination  
 $\lambda_B$  – 448 nm illumination



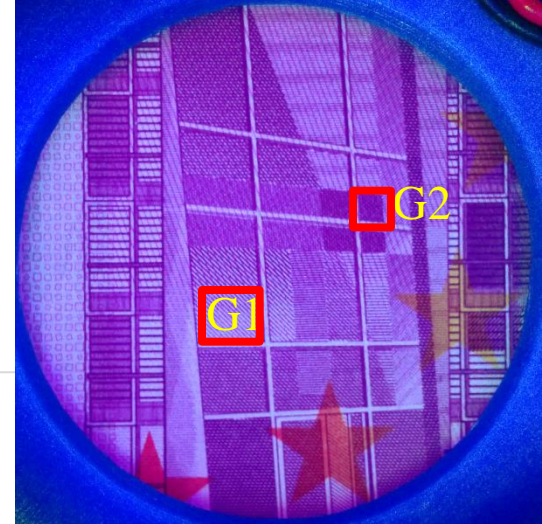


## Ratio between elements F1 and F2

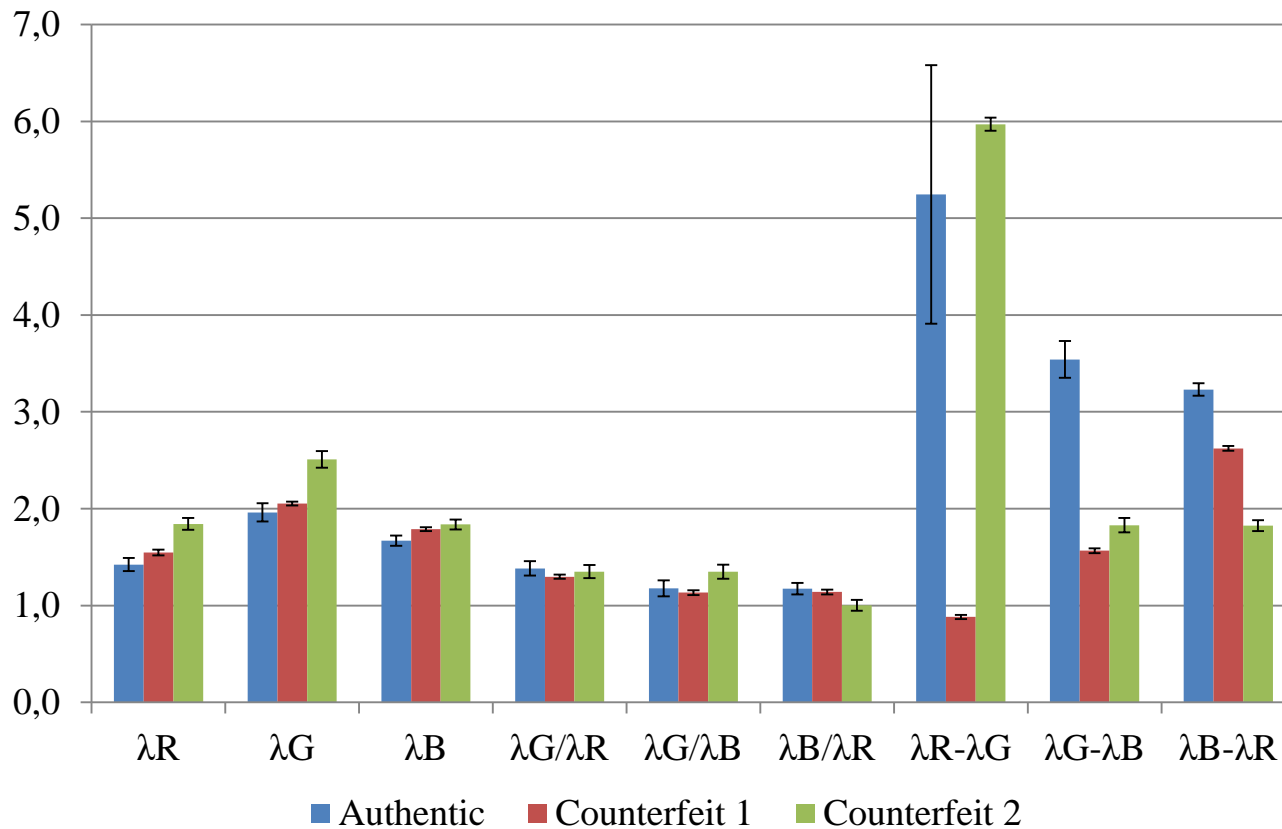


$\lambda_R$  – 659 nm illumination  
 $\lambda_G$  – 532 nm illumination  
 $\lambda_B$  – 448 nm illumination

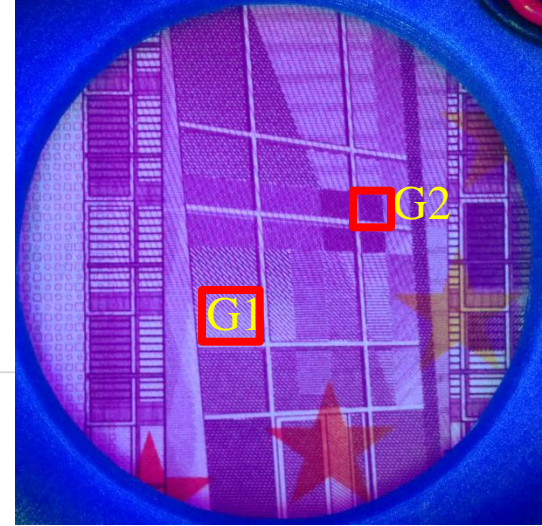




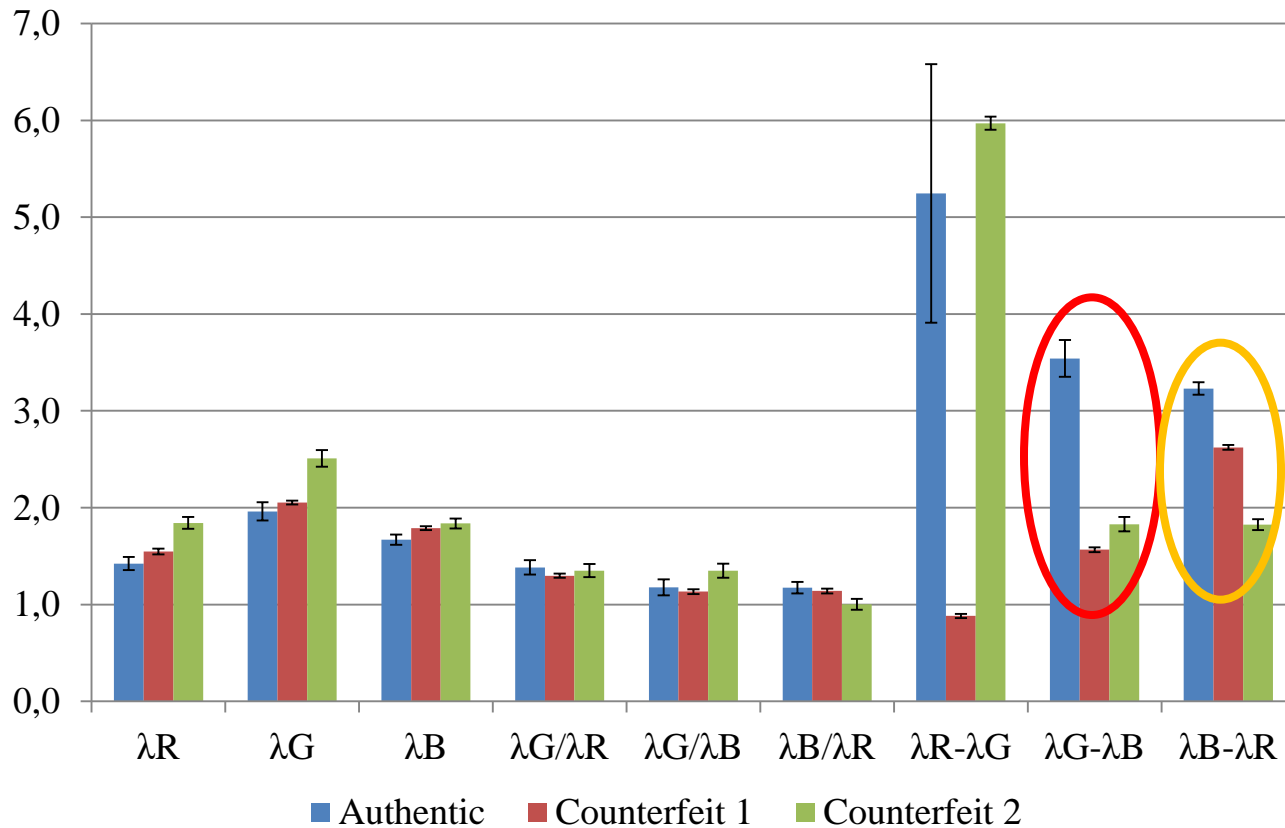
## Ratio between elements G1 and G2



$\lambda_R$  – 659 nm illumination  
 $\lambda_G$  – 532 nm illumination  
 $\lambda_B$  – 448 nm illumination



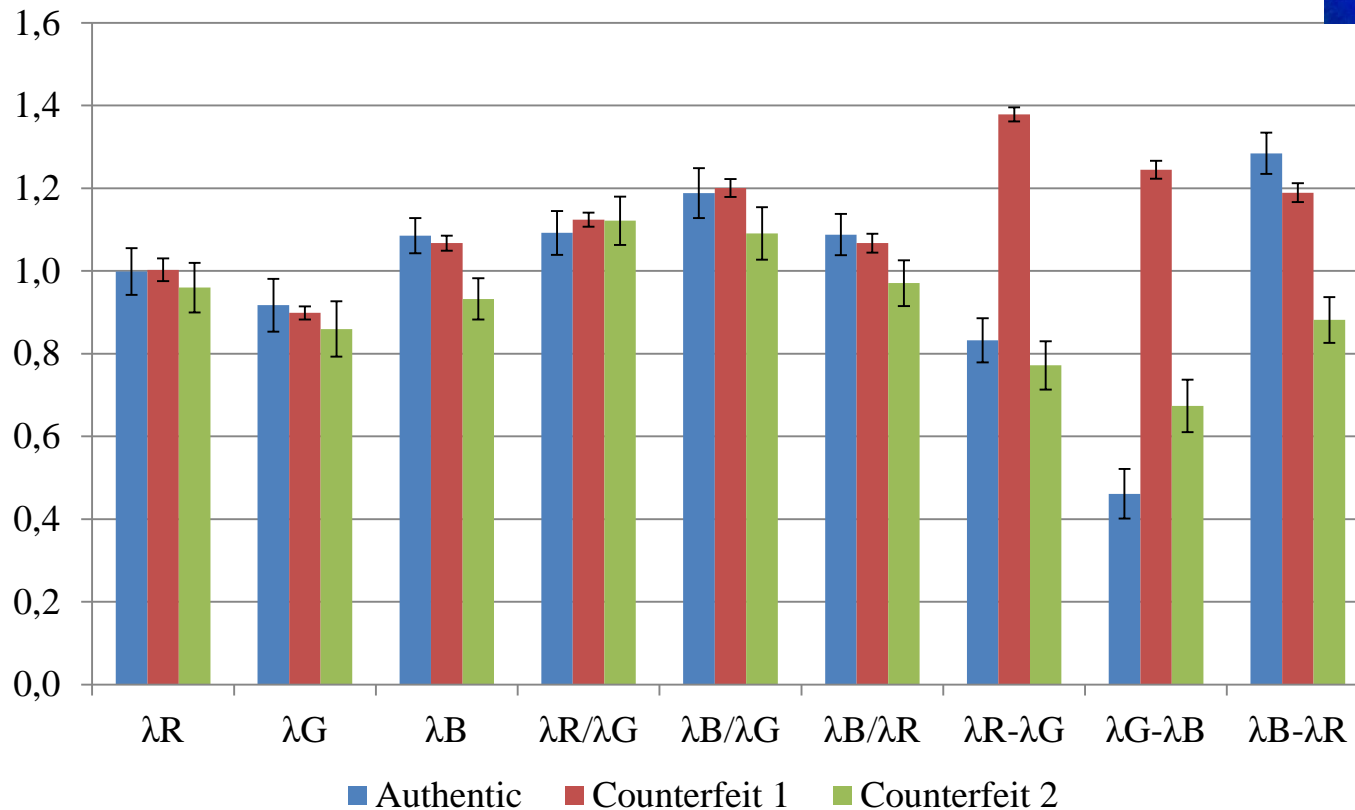
## Ratio between elements G1 and G2



$\lambda_R$  – 659 nm illumination  
 $\lambda_G$  – 532 nm illumination  
 $\lambda_B$  – 448 nm illumination



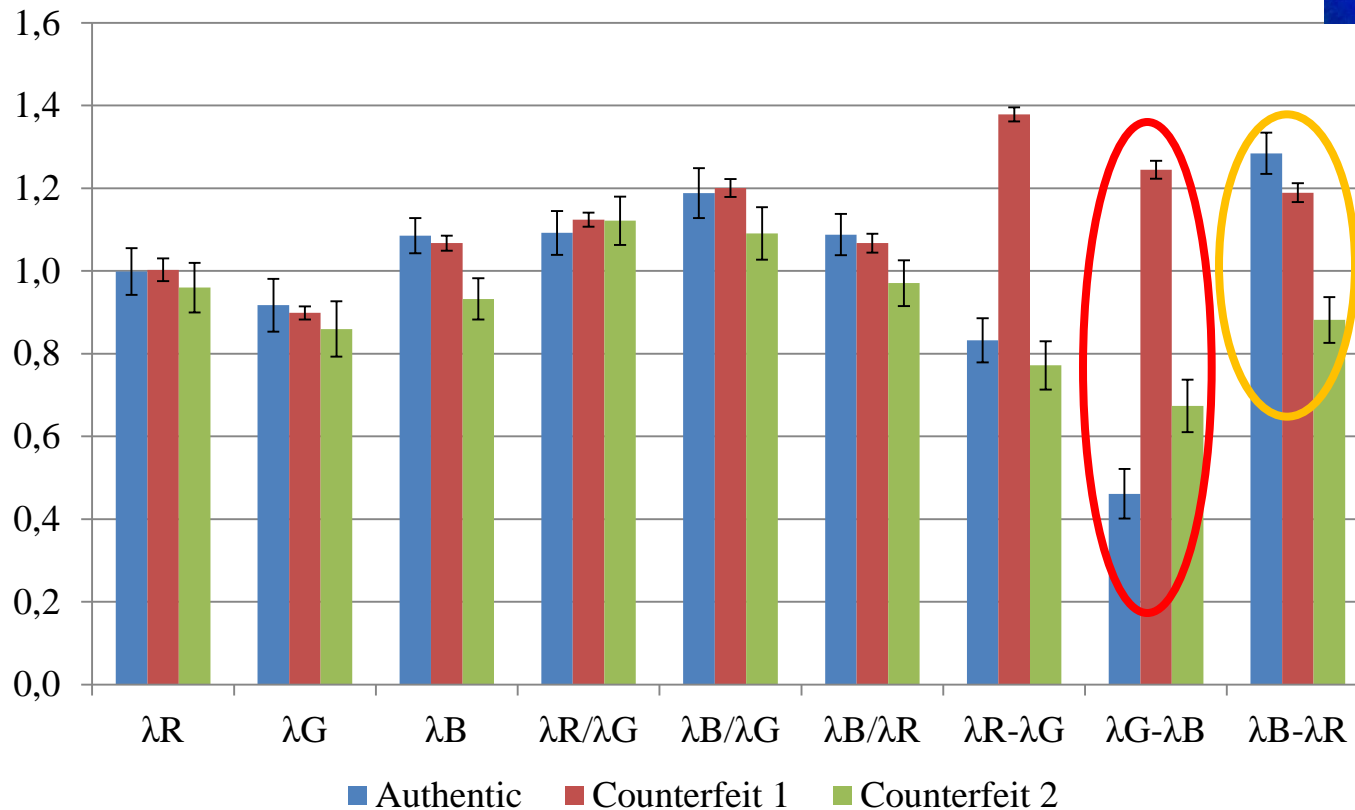
## Ratio between elements H1 and H2



$\lambda_R$  – 659 nm illumination  
 $\lambda_G$  – 532 nm illumination  
 $\lambda_B$  – 448 nm illumination



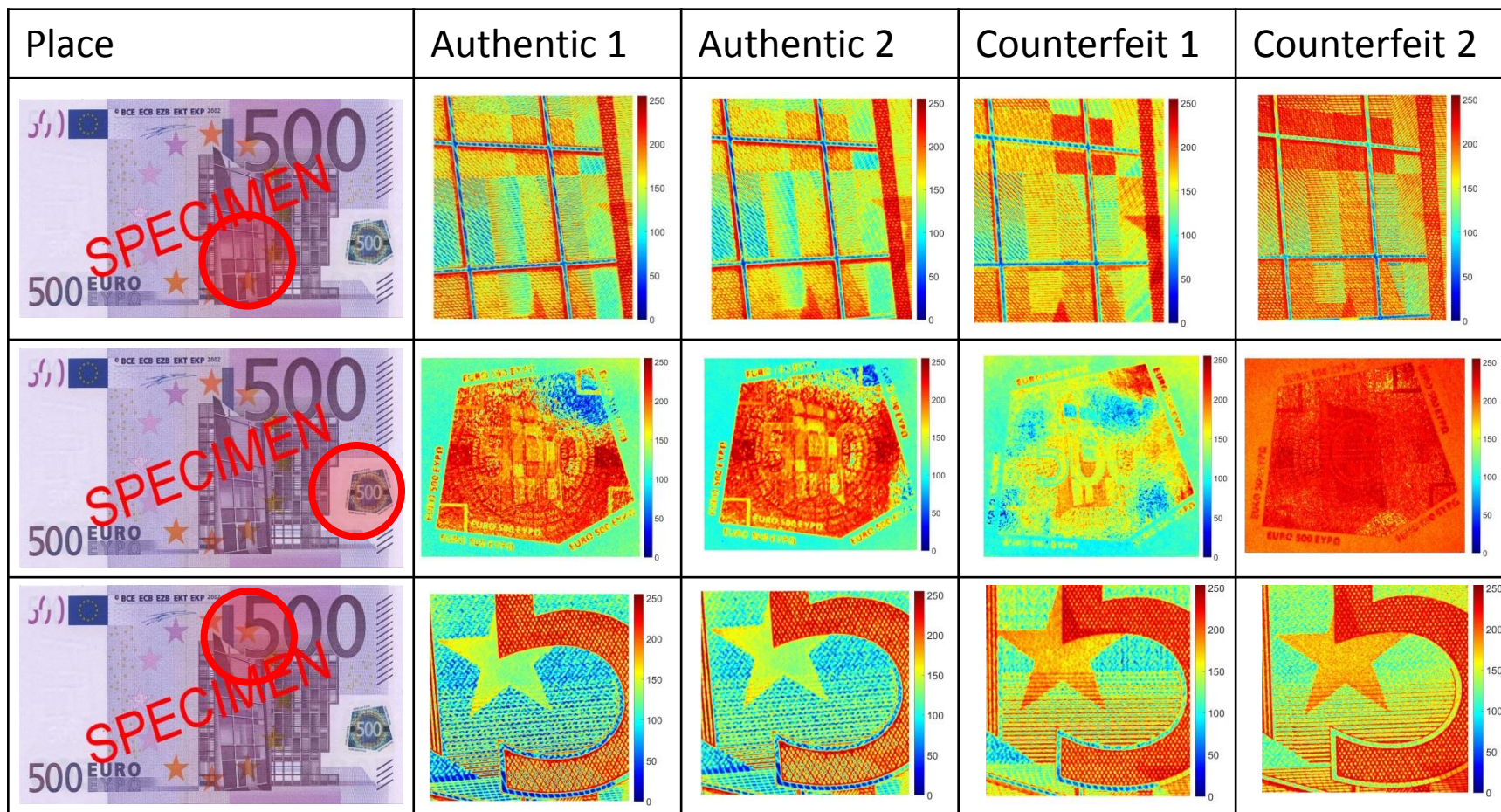
## Ratio between elements H1 and H2



$\lambda_R$  – 659 nm illumination  
 $\lambda_G$  – 532 nm illumination  
 $\lambda_B$  – 448 nm illumination



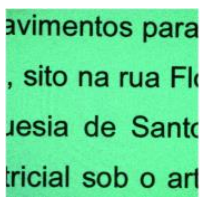
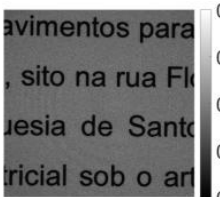
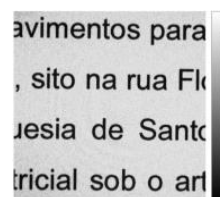
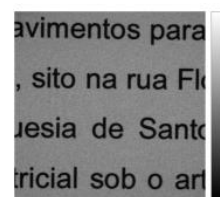
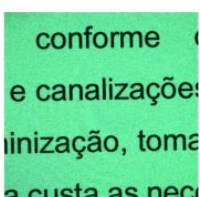
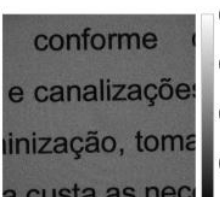
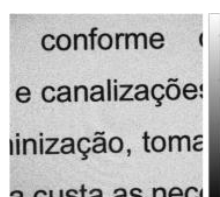
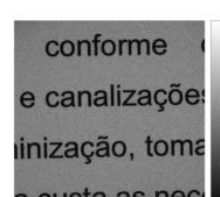
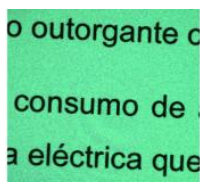
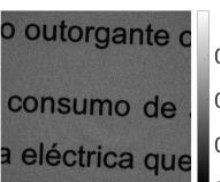
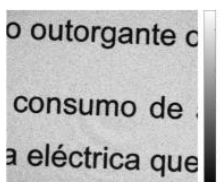
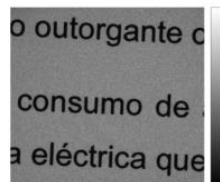
# Principal component analysis (first component)



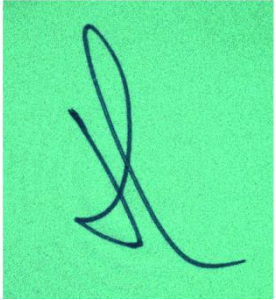
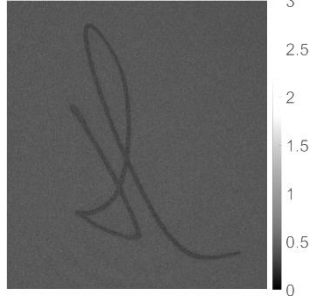
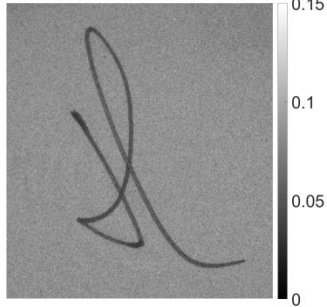
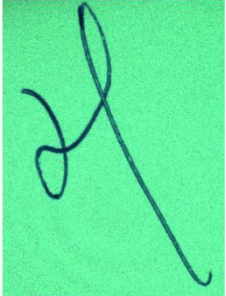
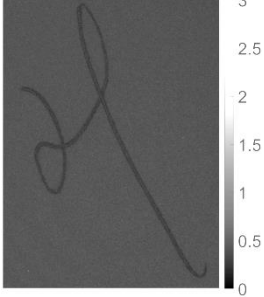
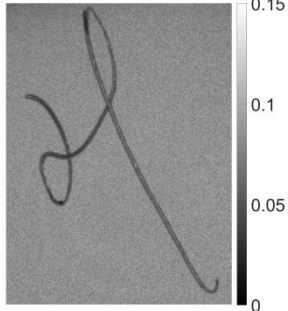
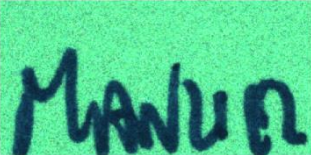
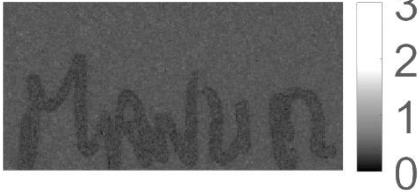
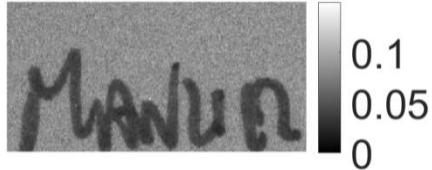


# RRS: triple spectral line approach for document counterfeit detection

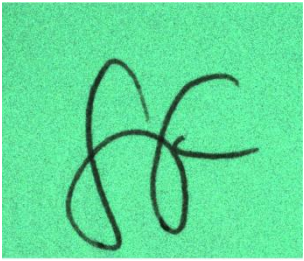
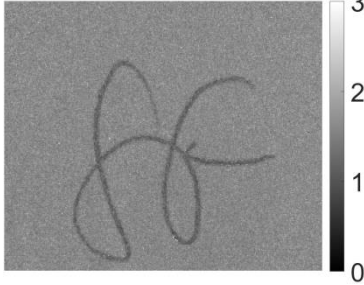
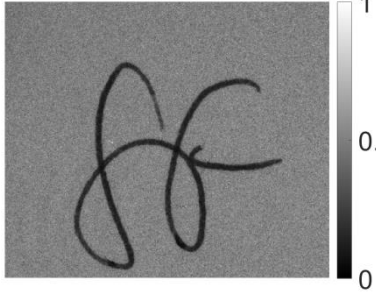
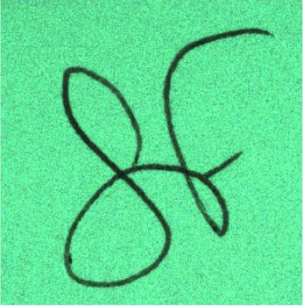
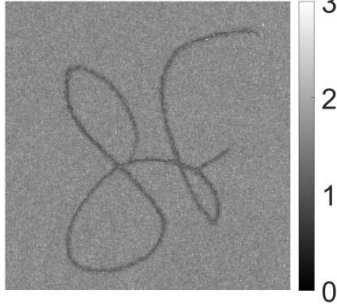
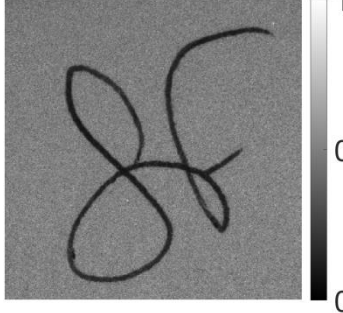
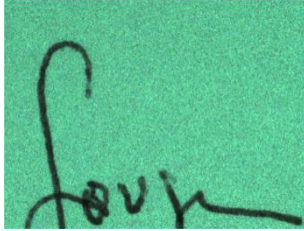
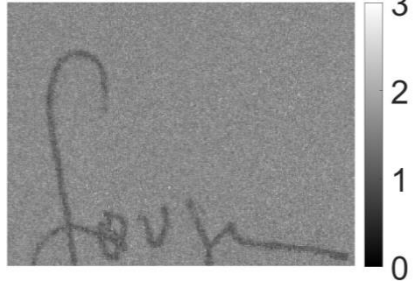
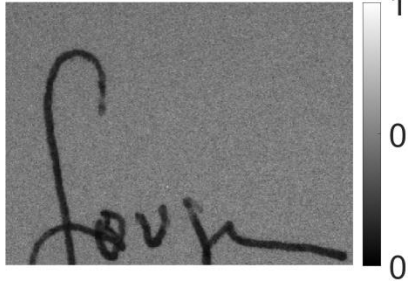
Spectral line images and the respective normalized printed letter values for the three pages (standard deviations)

Page No.	RGB image with three lasers	659 nm	Mean printed text values	532 nm	Mean printed text values	448 nm	Mean printed text values
1			$0.029 \pm 0.015$		$0.078 \pm 0.035$		$0.051 \pm 0.004$
2			$0.042 \pm 0.017$		$0.098 \pm 0.036$		$0.063 \pm 0.004$
3			$0.028 \pm 0.015$		$0.073 \pm 0.033$		$0.051 \pm 0.004$

# First signature

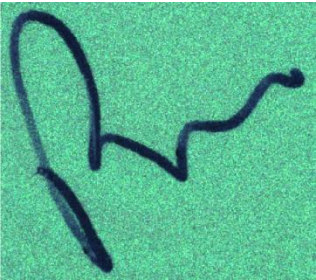
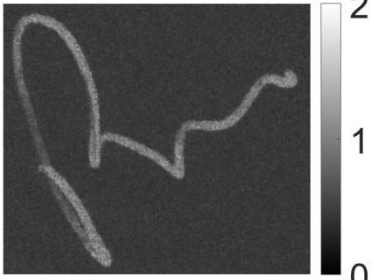
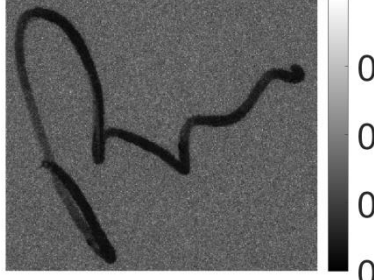

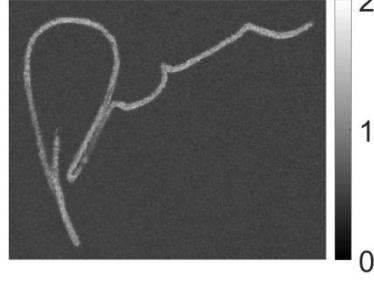

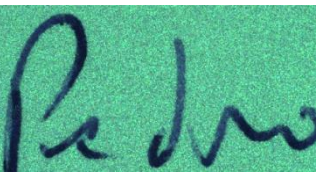
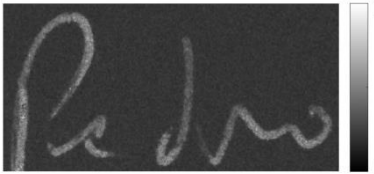
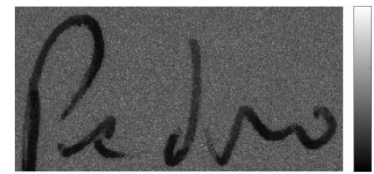
Page No.	RGB image	659 nm / 532 nm	Mean written text values	532 nm	Mean written text values
1			$0.315 \pm 0.059$		$0.050 \pm 0.008$
2			$0.300 \pm 0.060$		$0.051 \pm 0.010$
3			$0.315 \pm 0.067$		$0.041 \pm 0.007$

# Second signature

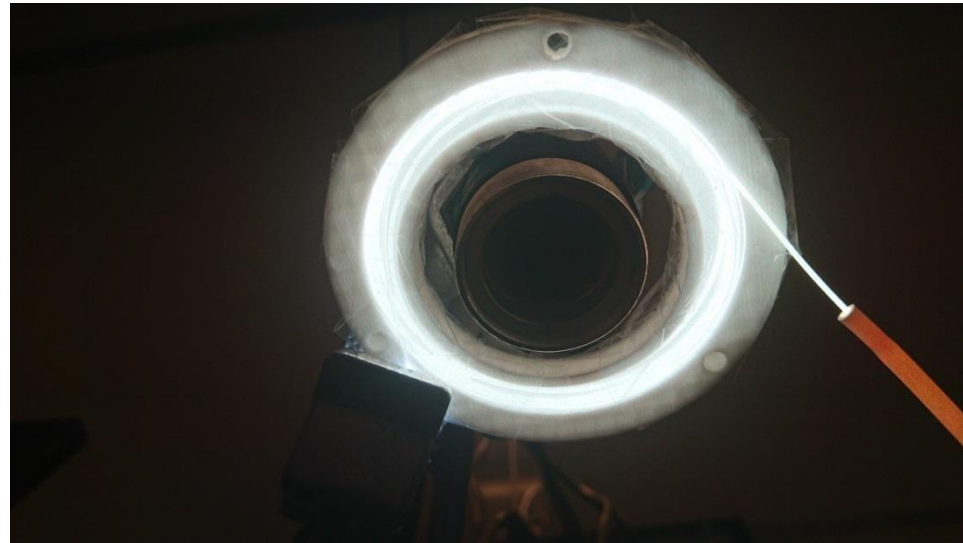
Page No.	RGB image	448 nm / 659 nm	Mean written text values	448 nm	Mean written text values, $\cdot 10^{-2}$
1			$1.245 \pm 0.190$		$0.159 \pm 0.045$
2			$1.271 \pm 0.205$		$0.155 \pm 0.044$
3			$1.245 \pm 0.173$		$0.153 \pm 0.047$



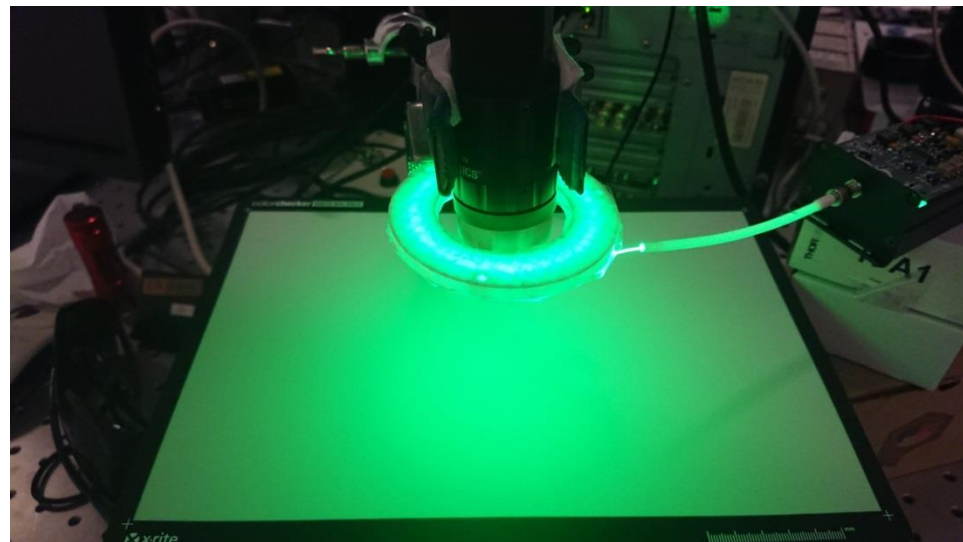
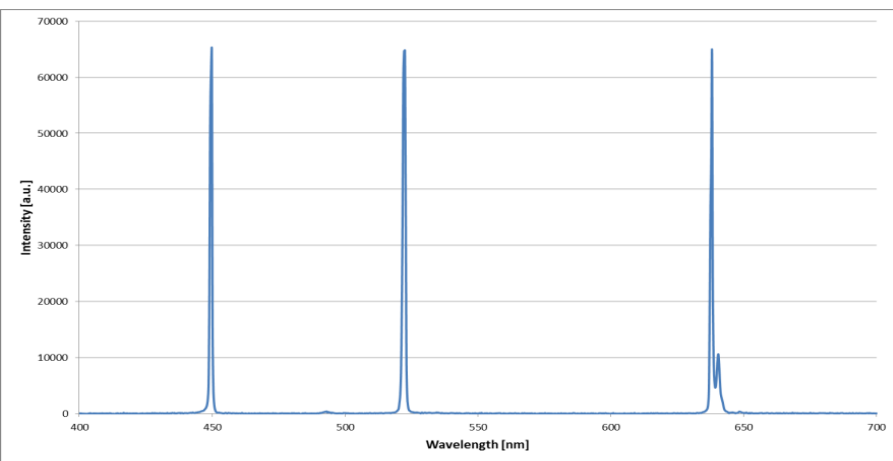
# Third signature

Page No.	RGB image	448 nm / 532 nm	Mean written text values	659 nm	Mean written text values, $\cdot 10^{-2}$
1			$0.911 \pm 0.166$		$0.090 \pm 0.045$
2			$1.055 \pm 0.181$		$0.084 \pm 0.035$
3			$0.839 \pm 0.166$		$0.099 \pm 0.046$

# Current project: 4 laser line illumination by a side-emitting optical fiber ring



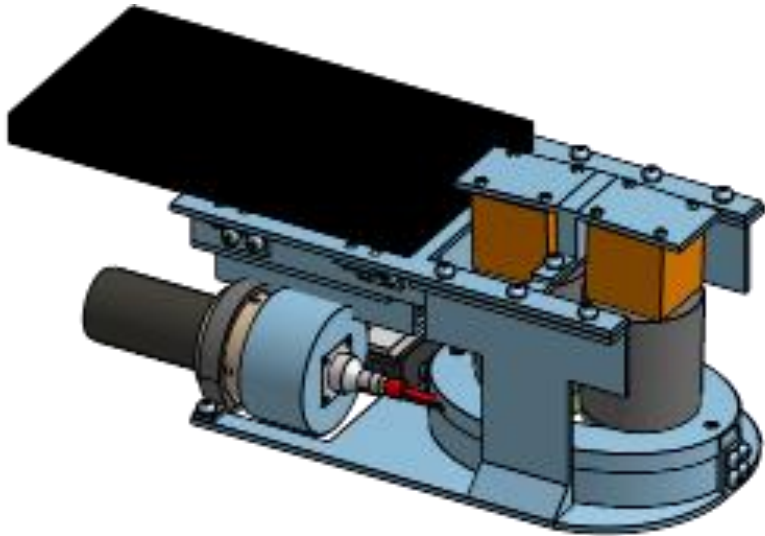
450/523/638 nm + 850 nm



LV 11644 B, 1995. Side-emitting optical fiber (D. Pfafrods, M. Stafeckis, J. Spigulis, D. Boucher);  
LV patent application # P-19-45, 21.08.2019.

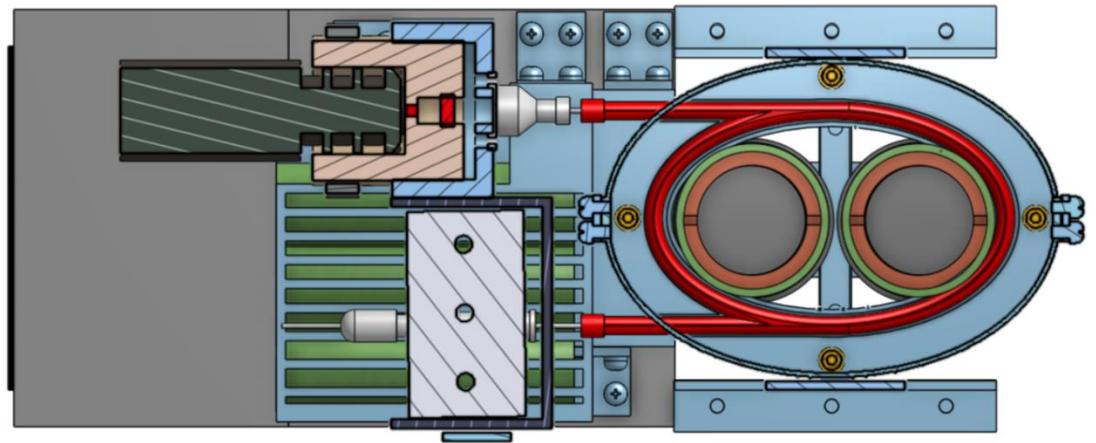


# The new (4+1) wavelength prototype: design concept



**Step 1** - 450/523/638/850 nm illumination for snapshot mapping of 4 skin chromophores (HbO, Hb, Mel, Blr) and calculation of the MM criterion;

**Step 2** – 4 x 405nm LD excitation for skin fluorescence imaging (MM – SK differentiation)



# Summary

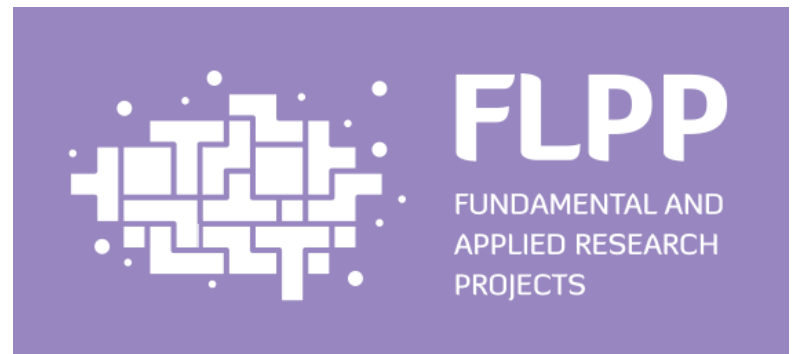
- Advanced multi-spectral imaging technique (band → line, sequential → snapshot) developed and tested
- Application: color pigment analysis
- Triple spectral line imaging approach works for paper counterfeit detection
- Counterfeit 50 EUR banknote studies: most sensitive are the blue line (448nm) images and the ratios of red (659nm) and blue images
- Counterfeit 500 EUR banknote studies: most sensitive are the differences between the mono-spectral images
- Potential for document forgery detection demonstrated
- Further improvements (n=3 → n=4) in progress

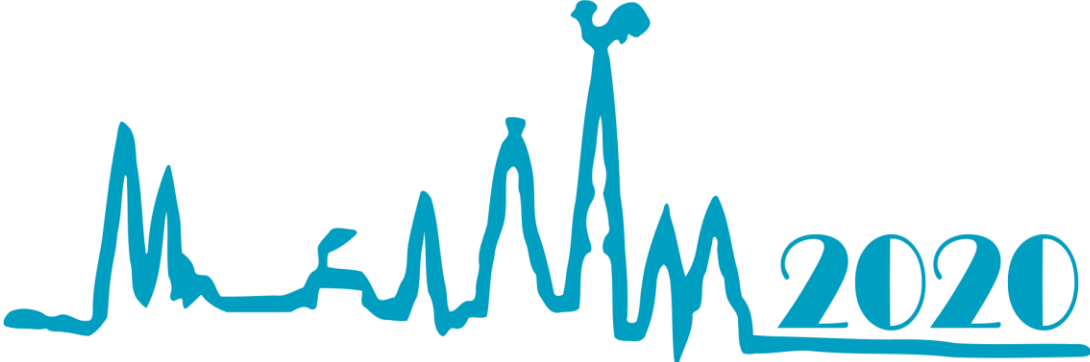
# Acknowledgements

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Latvian Council of Science





**Biophotonics - Riga**  
3rd International Conference

**24 – 26 August 2020**  
**Riga, Latvia**

**The main topics:**

- **Biomedical tissue imaging**
- **Optical clinical diagnostics and monitoring**
- **Skin optics and spectroscopy**



# Thank You!

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