Incorporating Perceptual Quality Measures in Super-Resolution for Enhanced Environmental Monitoring:

ROMANIA REGION

Sentinel-2 for Waste Detection

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INNOVATING SOLUTIONS

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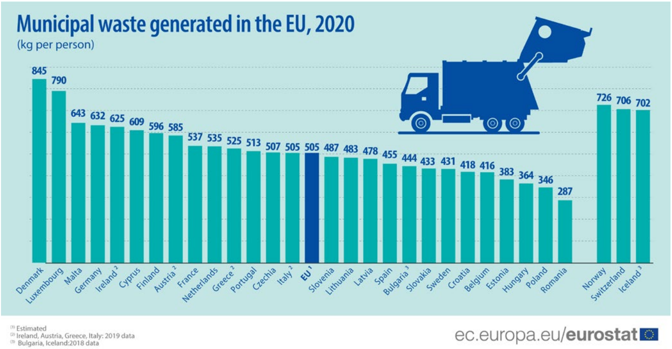
Motivation

Problem: WASTE DETECTION

Continuous growth of global population and its behaviour when it comes to socio-economic practices set the premise for a lot of environmental crimes. Illegal deposits and dump sites are the results of those practices. Globally, by 2040 there will be around 3.4 billion tons of waste. (Kaza, 2018).

In Romania stricter EU regulations and imports of waste created an environment prone to multiplication of ***illegal waste dumps.***



EO Data

Waste detection AI on high-resolution: high resolution-> high cost, low temporal frecquency

SPOT 6/7 - 1.5 m

SENTINEL-2 - 10 m

Motivation

Problem: WASTE DETECTION

Increased quantity of waste
-> global level

EU level

Reduce muncipal waste

waste detection on site

- laborious
- inaccessible in some regions

Earth Observation (EO)

Waste detection

AI on high-resolution

- Illegal waste: small area and ir-regular shape -> difficult to identify
- High-resolution data: high cost and low temporal resolution of commercial satellite imagery

Generating synthetic high-resolution data

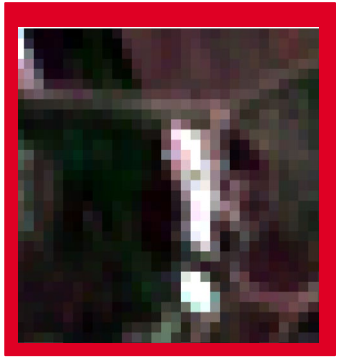
SR + DL

- improves the visual experience
- provide support for the actual task of waste detection, by super-resolving the images
- Generalization of the results: satellite images of urban periphery and agricultural areas

Problem Statement

SR on EO data
- Intra-Band SR
- On a LR version of the HR (as in CV)
- **Across Sensors: Sentinel-2 (LR) and Spot 6/7 (HR): factor of x4**

Low Resolution (LR) – Sentinel-2



High Resolution (HR) – Spot 6/7

SR Assesment Metrics

PSNR

- focuses solely on pixel-wise differences and does not account for perceptual quality
- measures the fidelity of the pixel values but not the perceived visual quality of the image
- multi-sensor applications, images from different sensors might have inherent differences in pixel values due to varying sensor characteristics

SSIM

- takes into account changes in structural information, luminance, and contrast
- images from different sensors may capture different structural details due to variations in sensor technology, angles, and lighting conditions.

LPIPS

- is a learned perceptual metric that evaluates the similarity between two images based on features extracted from deep neural networks.
- relies on features extracted from pre-trained neural networks, typically trained on natural images from datasets like ImageNet

SR Assesment Metrics

Balanced Metric:

$$\mathscr{B}(\mathbb{I}_{\mathrm{SR}}) = \frac{1}{3}\left[\frac{\mathrm{PSNR}(\mathbb{I}_{\mathrm{bic}}, \mathbb{I}_{\mathrm{HR}})}{\mathrm{PSNR}(\mathbb{I}_{\mathrm{SR}}, \mathbb{I}_{\mathrm{HR}})} + \frac{\mathrm{SSIM}(\mathbb{I}_{\mathrm{bic}}, \mathbb{I}_{\mathrm{HR}})}{\mathrm{SSIM}(\mathbb{I}_{\mathrm{SR}}, \mathbb{I}_{\mathrm{HR}})} + \frac{\mathrm{LPIPS}(\mathbb{I}_{\mathrm{SR}}, \mathbb{I}_{\mathrm{HR}})}{\mathrm{LPIPS}(\mathbb{I}_{\mathrm{bic}}, \mathbb{I}_{\mathrm{HR}})}\right];$$

Kowaleczko, P., Tarasiewicz, T., Ziaja, M., Kostrzewa, D., Nalepa, J., Rokita, P., & Kawulok, M. (2023). A real-world benchmark for sentinel-2 multi-image super-resolution. *Scientific Data*, *10*(1), 644.

What Do We Look For in Waste Super-Resolution?

Texture Consistency

- Waste material have different textures -> help in their identification
- Maintaining the integrity of surface details -> distinguishing waste from non-waste areas

Reflectance Consistency

- Consistent reflectance values ensure -> super-resolved image accurately represents the material properties of the original scene

Spectral Consistency

- Maintaining spectral consistency across different bands (wavelengths) ensures that the multi-spectral information used for analysis is accurate.

Proposed SR Assesment Metrics

Texture Consistency Index (TCI)

$$\mathrm{TCI}(I_{\mathrm{SR}}, I_{\mathrm{HR}}) = 1 - \frac{\sum_{i=1}^{N} \|T(I_{\mathrm{SR}}^{i}) - T(I_{\mathrm{HR}}^{i})\|_2}{\sum_{i=1}^{N} \|T(I_{\mathrm{bic}}^{i}) - T(I_{\mathrm{HR}}^{i})\|_2}$$

- ensures that the textures in the super-resolved image closely match those in the high-resolution image, for identifying waste regions that often have distinct textural patterns

Reflectance Preservation Index (RPI)

$$\mathrm{RPI}(I_{\mathrm{SR}}, I_{\mathrm{HR}}) = \frac{1}{N} \sum_{i=1}^{N} \frac{\sum_{j=1}^{M} (R_{\mathrm{SR}}(i,j) - R_{\mathrm{HR}}(i,j))^2}{\sum_{j=1}^{M} (R_{\mathrm{bic}}(i,j) - R_{\mathrm{HR}}(i,j))^2}$$

- ensures that the reflectance properties of materials are preserved
- evaluates the preservation of reflectance properties across different spectral bands

Spectral Consistency Measure (SCM)

$$\mathrm{SCM}(I_{\mathrm{SR}}, I_{\mathrm{HR}}) = 1 - \frac{\sum_{i=1}^{N} \|S(I_{\mathrm{SR}}^{i}) - S(I_{\mathrm{HR}}^{i})\|_2}{\sum_{i=1}^{N} \|S(I_{\mathrm{bic}}^{i}) - S(I_{\mathrm{HR}}^{i})\|_2}$$

- ensures that the spectral information is consistent between the super-resolved and high-resolution images, which is essential for distinguishing waste materials from other objects based on their spectral signatures

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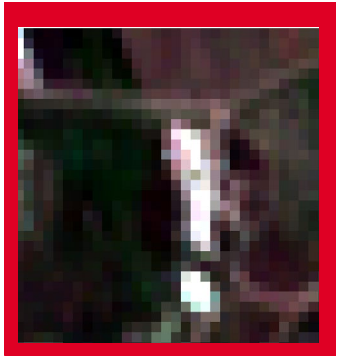
Low Resolution (LR) – Sentinel-2



High Resolution (HR) – Spot 6/7

Experimental Setup

Dataset

- **7 cities from Romania (Alba Iulia, Brasov, Bucharest, Deva, Sibiu, Sighisoara and Suceava)**
- **Sentinel-2 (LR) + Spot(HR)**
- **Patch size: (64, 64) LR, (256,256) HR**
- **No. Pair Patches 1339**

Experimental Design

- **5 different models:**
  - SRCNN
  - SRResNet
  - EDSR
  - SRDenseNet
  - RRDB
- Scaling factor x4
- No pretraining

Visual Results: Example I

LR

HR

Bicubic

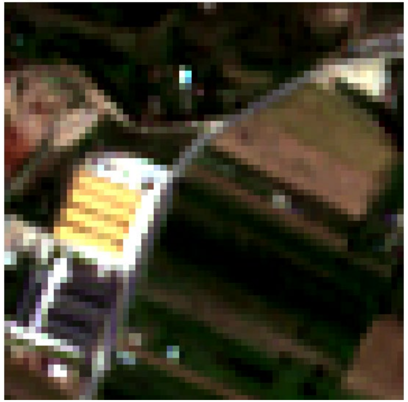
Visual Results: Example II

LR

HR

Bicubic

Visual Results: Example III



LR

HR

Bicubic

Visual Results: Example I

HR
PSNR
SSIM
LPIPS
Baln 1

TCI
RPI
SCM
Balan 2

SRCNN
20.19
0.5190
7.6247
0.8960

0.3657
1.4472
0.5227

SRResNet
21.001
0.573
7.3697
0.8471

0.6191
1.7562
0.6038

HR

SRDense Net
21.091
0.5695
7.330
0.8459

0.6595
1.7930
0.6119

EDSR
20.942
0.55191
7.3254
0.8559

0.6060
1.7212
0.59837

RRDB
20.98515
0.5694
7.2074
0.8421

0.627269
1.75526
0.6023

Visual Results: Example II

HR
PSNR
SSIM
LPIPS
Baln 1

TCI
RPI
SCM
Balan 2

SRCNN
19.896
0.5369
7.6583
0.9428

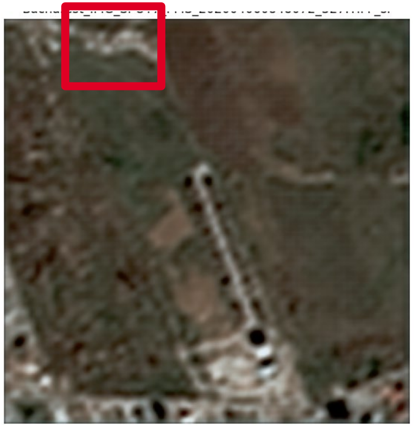
0.2635
1.3703
0.47739

SRResNet
20.402
0.577
7.277
0.896

0.311
1.5478
0.5347

SRDenseNet
20.453
0.5716
7.3772
0.9037

0.3613
1.5621
0.5402



EDSR
20.178
0.5587
7.4216
0.9161

0.31326
1.4583
0.5102

RRDB
20.311
0.5705
7.287
0.9020

0.3251
1.51746
0.5249

Visual Results: Example III

HR
PSNR
SSIM
LPIPS
Baln 1

TCI
RPI
SCM
Balan 2

SRCNN
19.434
0.4852
8.1855
0.679

0.3216
6.1242
0.8465

SRResNet
19.516
0.5036
8.093
0.6685

0.3727
6.25201
0.84940

SRDense
Net
19.8702
0.5148
7.9956
0.6576

0.4336
6.8008
0.861

EDSR
20.05
0.521
8.164
0.659

0.4989
7.1440
0.8671

RRDB
20.125
0.524
7.911
0.649

0.5080
7.2593
0.8691

Performance Results – New Metrics

Model	PSNR	SSIM	LPIPS	Baln 1	TCI ⬆	RPI ⬇	SCM ⬆	Baln2 ⬆
scrnn	15.46	0.3886	13.4171	0.8262	0.273	2.687	0.434	0.446
srresnet	15.99	**0.439**	**12.89**	**0.777**	**0.390**	2.898	**0.503**	0.48064
edsr	15.71	0.404	13.17	0.807	0.338	**2.865**	0.462	0.4657
srdensenet	**16.03**	0.431	13.03	0.787	0.389	2.999	**0.503**	**0.48065**
rrdb	15.88	0.423	13.04	0.794	0.375	2.964	0.485	0.4763s

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Conclusions & Future Work

What did we do?

1. Highlight the challenges encountered when SR Waste Dumps on a multi-sensor SR dataset
2. Experimented with 5 different SISR models
3. Analyzed classic assement metrics – overall + 3 visual examples: PSRN, SSIM, LPIPS
4. Analyzed a balanced metric based on the previous three metrics
5. Proposed new assement metrics for our use-case:
    1. TCI
    2. RPI
    3. SCM
    4. Balanced metric

What's next?

1. Comparison with new SR metrics: Aybar, C., Montero, D., Donike, S., Kalaitzis, F., & Gómez-Chova, L. (2024). A Comprehensive Benchmark for Optical Remote Sensing Image Super-Resolution. IEEE Geoscience and Remote Sensing Letters.
2. Integrate Difussion Models
3. Test with Sen2NAIP and Satellogic DS
4. Experiment the new metrics with various loss functions
5. Integrate the NIR band - problematic

Thank you!

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Keep in touch!

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Questions?

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