Pothole Detection

Computer Vision project

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1- Introduction

Motivation

- Roads are an important part of infrastructure
- Maintaining roads is challenging
- Potholes impact safety, comfort, and costs
- Using cameras and computer vision for automatic detection

Problem definition: how do we detect potholes?

👉 Analyze road images

👉 Binary classification

- 1 = Pothole detected
- 0 = No pothole

Computer Vision extracts important features:

1. Image: $I \in \mathbb{R}^{p \times p}$
2. Extraction of relevant features: $Z = g(I)$
3. Prediction of the labels $\hat{Y} = f(Z) = f(g(I))$

Problem Definition: evaluation?

F1-score: $$F_1 = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}$$

- Precision = Out of all the potholes detected by the model, how many are real potholes?
- Recall = Out of all the real potholes, how many were correctly detected?

Dataset balanced: F1-score sufficient

2 - Related work

Authors	Data	Method	Descriptions
Makone and Rathod (2002) [130]	Grayscale image	Mean shift-based filtering, an iterative process for edge detection	Applying a moving window to reduce speckle noise, enhances edge and texture preservation, and detects potholes based on size constraints from extracted road section images.
Koch and Brilakis (2011) [21]	Color image	Histogram-based thresholding, morphological operations, elliptic regression	Road pothole detection by segmenting damaged and undamaged road regions and comparing textures inside and outside ellipses.
Buza et al. (2013) [27]	Color image	Otsu's thresholding, spectral clustering	Segmentation of road images and extraction of damaged road areas (potholes) using spectral clustering.
Ryu et al. (2015) [117]	Color image	Histogram-based thresholding, morphological filters, geometric properties	Processing road images with morphological filters, segmenting using thresholding, and extracting potential pothole contours based on geometric properties.
Schiopu et al. (2016) [115]	Color image	Histogram-based thresholding, geometric properties	Generation of road pothole candidates through thresholding and determination of potholes based on specific geometric properties.
Akagic et al. (2017) [118]	Color image	RGB color space manipulation, dynamic road pixel selection, comparison	Detection of road potholes by manipulating RGB color space, dynamic pixel selection, and comparison based on previous methods.
Wang et al. (2017) [123]	Grayscale image	Wavelet energy field, morphological filters, Markov random fields	Construction of wavelet energy fields for highlighting road potholes, segmentation using Markov random fields, and refinement with morphological filters.

- Yousaf et al. (2018) : SIFT + BoW -> SVM

3 - Methodology

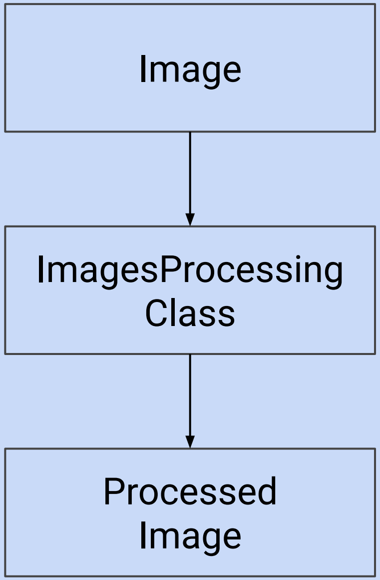
ImagesProcessing Class

Goal: improve image quality before feature extraction

- Load, resize and process images
  - ensure consistency

- Filters
  - remove noise and enhance image quality

- Histogram equalization
  - improve contrast



Three Filters for Image Enhancement

- **Gaussian Filter**
  - smooths image, reduces noise, preserves some edges
  - Gaussian kernel: more weights to the pixels near the center

- **Median Filter**
  - better edge preservation, removes impulse noise
  - replaces each pixel by the median value of its neighboring pixels

- **Bilateral Filter**
  - non-linear, smooths image, considers pixel location and intensity similarity
  - best edge preservation, keeps sharp details

Histogram Equalization for Contrast Enhancement

How it works?

- Adjusts pixel intensities for better contrast
- Helps reveal important edges and textures

Methods:

- Standard Histogram Equalization
- CLAHE (used for SIFT)
- No Equalization

Improves visibility but can degrade images in some cases

Best Processing Method

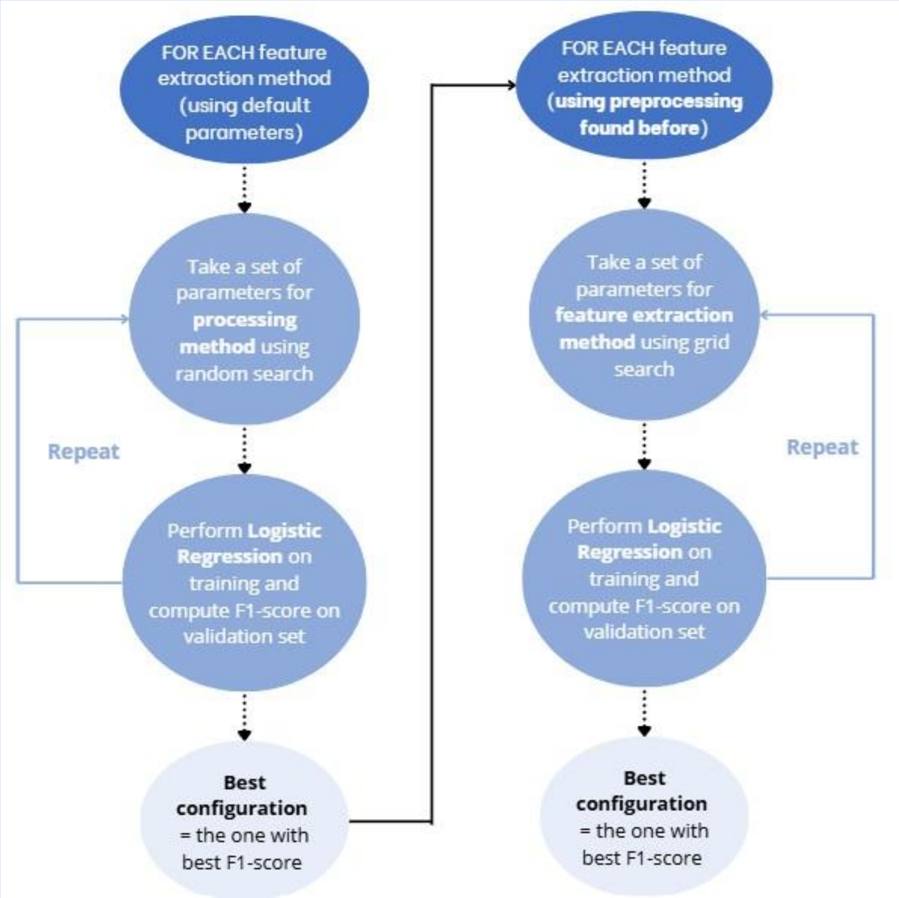
Literature review and personal knowledge:

- Bilateral Filter: SIFT, ORB, Harris, Edge, Gabor
- Gaussian Filter: LBP, Otsu

Testing all combinations = time consuming

-> fix these parameters and focus on the rest

Image Processing & Feature Extraction



Get best parameters for processing

Get best parameters for feature extraction

Figure 1. Methodology to find best parameters for image processing and best parameters for feature extraction methods.

Feature Extraction methods studied

- Keypoints detection: SIFT, ORB, Harris
- Edge detection: Canny, Sobel, Prewitt
- Other methods: LBP, HOG, Gabor filters, Adaptive and Otsu’s thresholding

Classification

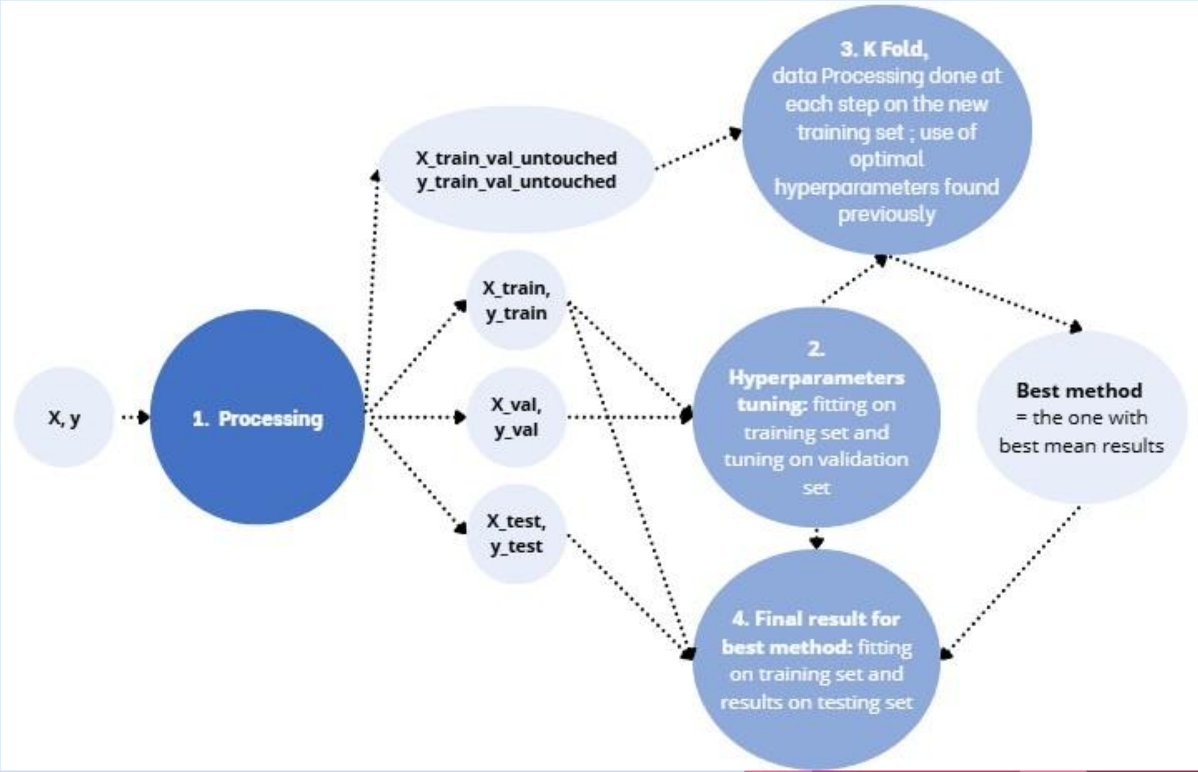


Figure 2. Methodology to find best hyperparameters for each classification method and select the one between the three that performs best

\+ implementation of a CNN and Resnet50

4 - Evaluation

Dataset

Available on Kaggle

352 images

329 images

Results

	Test accuracy	Test F1-score	Features
SIFT	75.00	73.89	5
ORB	61.03	59.67	5
Harris	76.47	76.14	7
Edge	**83.09**	**82.39**	20
Otsu	63.97	59.97	256
Adaptive	56.62	55.75	256
Gabor	53.68	50.78	12
LBP	80.15	79.33	26
HOG	**83.82**	**83.30**	980
CNN	86.86	86.36	-
Resnet50	92.70	92.06	-

Table 1. **Classification results comparison between feature extraction methods on images with no processing, simply resized.** For all models but CNN and Resnet, the choice of "best model" was done with the highest validation F1-score. For the deep learning models it was done using the highest accuracy (F1-score could have also been used for more equal comparison). The column features contains the number of features extracted by the methods.

	Test accuracy	Test F1-score	Features
SIFT	71.32	70.87	5
ORB	55.88	53.63	5
Harris	76.47	75.84	7
Edge	76.47	76.22	20
Otsu	69.85	64.92	256
Adaptive	61.76	58.88	256
Gabor	77.94	76.96	12
LBP	85.29	84.90	26
HOG	**90.44**	**90.11**	980

Table 2. Classification results comparison between feature extraction methods applied after image processing

	Test accuracy	Test F1-score	Features
SIFT + Edge	77.94	77.35	25
SIFT + HOG	88.24	87.71	985
HOG + PCA	86.03	85.62	209
SIFT + HOG + PCA	85.29	84.90	211

Table 3. Other results obtained from concatenating features from different methods and/or using PCA

5 - Conclusion

Conclusion

- The application of classical approaches
- **Compare** the effectiveness of **different feature extraction methods**
- Spend a good amount of time searching for the right image processing and hyperparameters

Limitations and Future Work

- Increase the number of configurations for Processing and Feature Extraction
- Delve more deeply and detail about the implementation of Python function
- Merging multiple feature extraction method
- Explore more classification methods
- Deeper analysis on the feature extracted

References & Credits

- **Dataset:** Atulya Kumar. Pothole detection dataset

- **Related work:** Masoud Mahdianpari Yashar Safyari and Hodjat Shiri. A review of vision-based pothole detection methods using computer vision and machine learning. 2024.

- See report