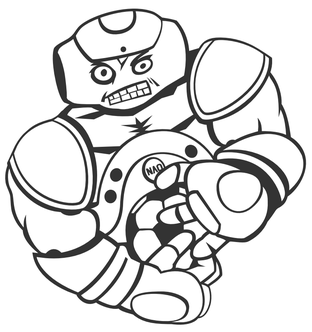
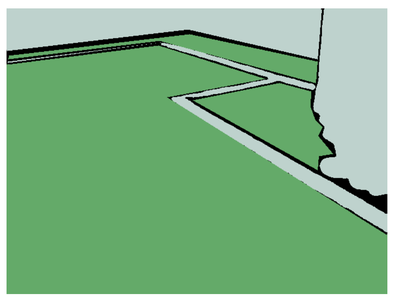
HULKs - RoboCup SPL Team



Exploring Lightweight Data-Driven Methods for Image Segmentation

Problem Definition

- Image Segmentation: *field* (true) or *not field* (false)
- Needed for line detection and localization



Challenges:

- Real-time system
- Resource-constrained system
- Varying lighting and field conditions

Figure 1: Examples of varying lighting/field conditions and a segmentation mask.

Selected Methods

Classification Methods

- Histogram-Thresholding (Baseline)
- Decision Tree (DT)
- Linear Support Vector Machine (SVM)
- Kernel Approximation (Nyström Method)
  - Radial Basis Function (RBF) Kernel
  - Polynomial Kernel

Color Features

- RGB, rgbI, L*a*b*, HSV, YCrCb

Texture Features

- Neighboring Pixel (NP)
- Local Binary Pattern (LBP)
- Histogram of Oriented Gradients (HoG)
- Gabor filters

Optimization Pipeline

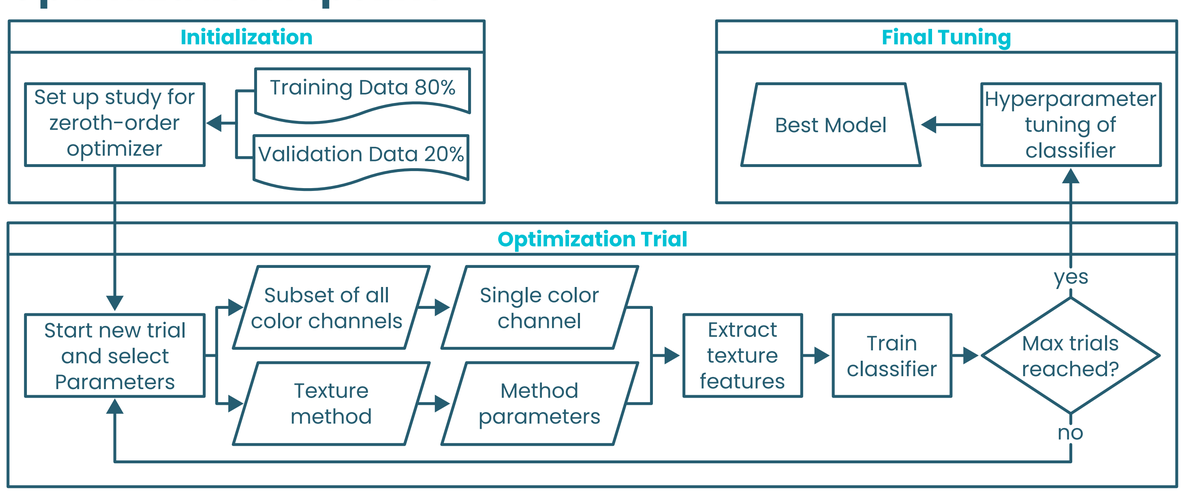


Figure 2: Proposed optimization pipeline for finding the most suitable classifier, color channels, and texture method.

Results

Group	F2 Score	F2 Score (tuned)	Color Channels	Texture Method
Baseline	0.8745	-	Y, G, H, S	-
Decision Tree	0.9509	0.9557	Y, **Cb**, B, I	NP
	0.9499	0.9621	Y, **Cb**, B	NP
	0.9399	0.9519	**Cr**, g	NP
	0.9374	0.9656	**g**	NP
Linear SVM	0.9357	0.9545	Cr, B, r, **L***, a*	HoG
	0.9356	0.9524	Cb, R, **L***, a*	HoG
	0.9332	0.9537	R, **L***, a*	HoG
	0.9221	0.9487	**L***, a*	HoG
	0.8825	0.9175	**g**	HoG
Nyström RBF	0.9526	0.9678	**g**, a*	LBP
	0.9408	0.9470	**a***	LBP
Nyström Polynomial	0.9357	0.9619	**g**, S	NP
	0.9356	0.9554	**g**	NP

Table 1: Results of the best trials. Bold channels used for extraction of texture features.

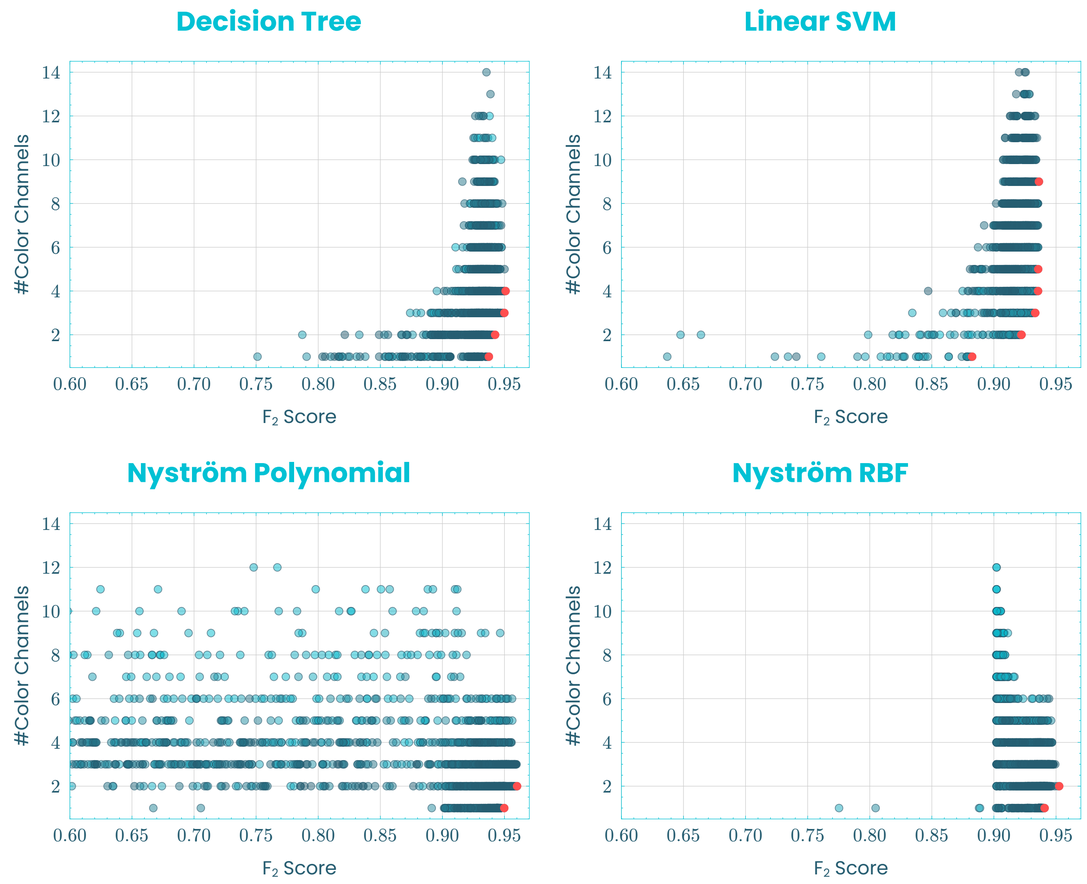
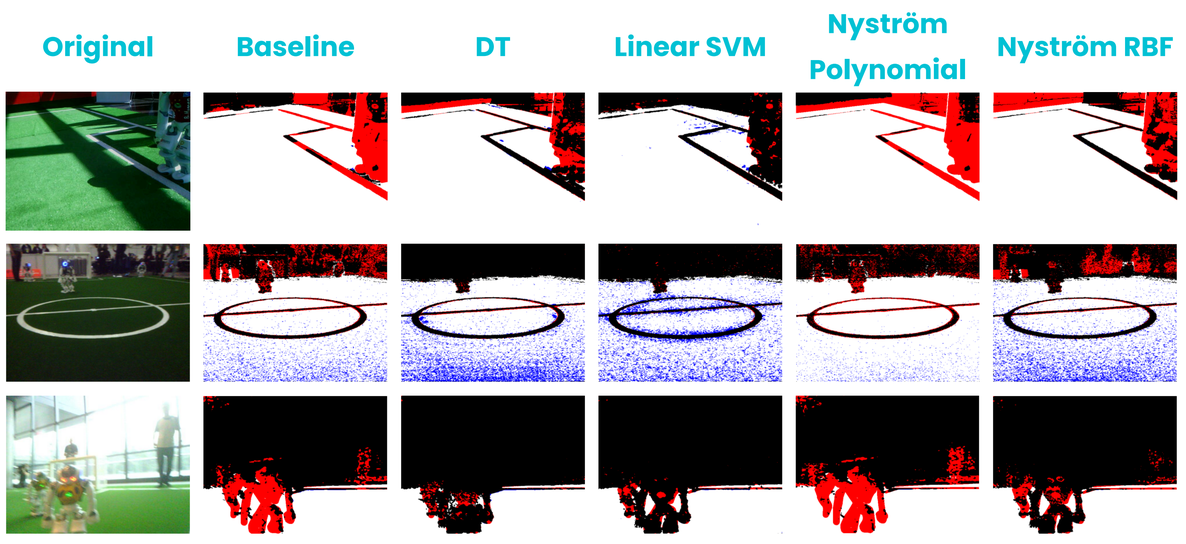


Figure 3: The Pareto fronts of each classifier with the trial number and best trials found by a Tree-structured Parzen Estimator (TPE) sampler.



True Positive: □ True Negative: ■ False Positive: ■ False Negative: ■

Figure 4: Predicted segmentation masks with confusion matrix of the baseline and the best classifiers.

Summary

- Effective exploration of search space by proposed optimization pipeline
- Best performing methods: **DT** and **Nyström RBF**
- Lowest-cost method: **DT**

Classifier	False Positive	False Negative	#Color Channels	Complexity (Classifier)	Complexity (Texture Method)
Baseline	-	-	4	$\mathcal{O}(d)$	-
DT	↓↓	↑	1	$\mathcal{O}(h)$	$\mathcal{O}(o)$
Linear SVM	↓↓	↑↑	5	$\mathcal{O}(d)$	$\mathcal{O}(o)$
Nyström Polynomial	-	↓	2	$\mathcal{O}(d+m^2)$	$O(b^2 \cdot o)$
Nyström RBF	↓	-	2	$\mathcal{O}(d+m^2)$	$\mathcal{O}(o)$

Table 2: Summary of the results, with d features, maximum height h of trained DT, dimensionality m of approximate feature space, o orientations, and block size b. Changes w.r.t. the baseline are indicated by ↓ (fewer), - (same), and ↑ (more).

Future Work

- Train specialized classifiers for specific scenarios (e.g., bright/dark lighting)
- Explore further classifiers (e.g., small Multi-Layer Perceptron) or texture descriptors
- Implement and benchmark models on the NAO robot

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