

Improving Smartphone-Based Dental Ceramic Manufacturer Classification Across Different Devices

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August 21, 2026



Background

- Project with a dental company
- General goal: non-invasive manufacturer classification of unprocessed dental ceramics using only object surface images taken via smartphone camera
- Zirkon oxide blocks



Findings in previous work:

- Intra-smartphone ✓ works well

Train/enroll on smartphone A → Test/evaluate on smartphone A

- Cross-smartphone ✗ results unsatisfying

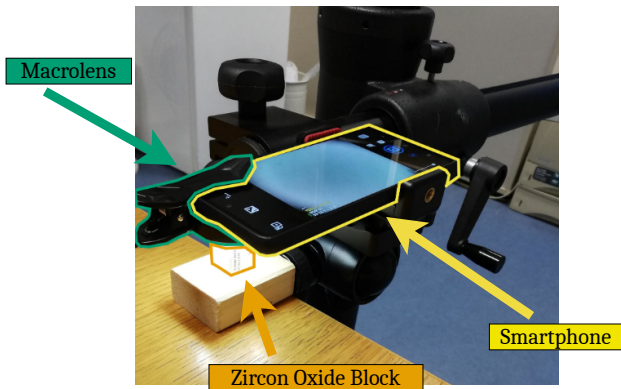
Train/enroll on smartphone A → Test/evaluate on smartphone B

Assumption: Smartphone image processing pipeline interferes with subtle ceramic surface texture

Aim of this research: Overcome A-to-B cross sensor limitations by using raw imaging sensor data

Data Acquisition Setup

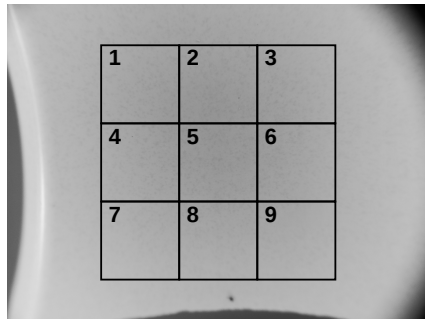
Smartphone	Abbrev.	Image Resolution
iPhone 13 1	i13-1	3024 × 4032
iPhone 13 2	i13-2	3024 × 4032
iPhone XS 1	iXS-1	3024 × 4032
iPhone XS 2	iXS-2	3024 × 4032
iPhone X	iX	3024 × 4032
iPhone 11	i11	3024 × 4032
iPhone 13 Pro	i13P	3024 × 4032
Google Pixel 4a 1	GP4-1	3024 × 4032
Google Pixel 4a 2	GP4-2	3024 × 4032
Google Pixel 4a 3	GP4-3	3024 × 4032
Google Pixel 1	GP1	3036 × 4048
LG Nexus 5 1	LGN5-1	2448 × 3264
LG Nexus 5 2	LGN5-2	2448 × 3264
Nokia 6.1 1	N61-2	3456 × 4608
Nokia 6.1 2	N61-1	3456 × 4608
Huawei P20 Lite	P20	3456 × 4608
Huawei P30 Pro	P30	2736 × 3648
Xiaomi Mi A3	Xia	3000 × 4000
Samsung Galaxy A52	SGA52	3468 × 4624



Makrolens: Agritix WIDK-24X01 Xylorix Wood Identification Tool

Dataset size and patching

Manufacturer	Blocks	Images	Total Patches
Ivoclar Vivadent	16	64	576
3M	10	40	360
Dentsply Sirona	6	24	216



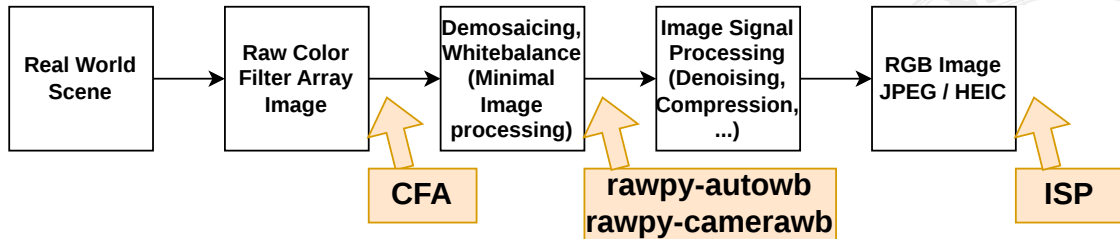
Raw data

Raw data captured with:

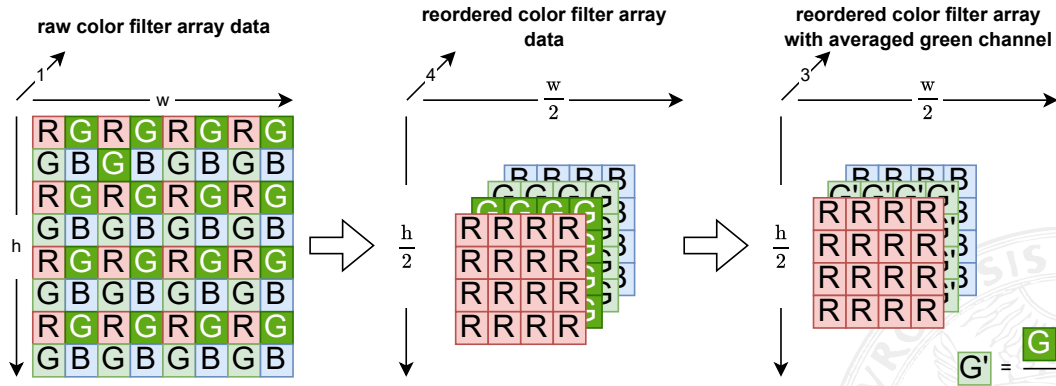
- Android: OpenCamera (<https://opencamera.org.uk/>)
- iPhone: Halide Mark II (<https://halide.cam/>)

Variants:

- Color Filter Array (CFA)
- rawpy minimal processing with automatic white balancing
- rawpy minimal processing with meta data white balancing
- Imaging Signal Processing (ISP) - "normal image"

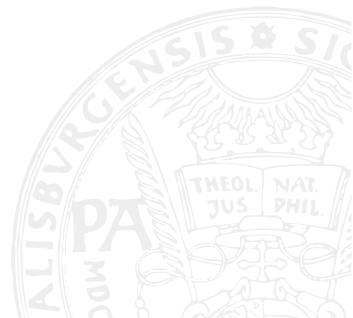


Raw image reordering from color filter array



Minimal processing: apply whitebalance as derived from metadata

- **no-norm:** no normalization
- **z-norm train-set:** normalize everything using parameters from train set
- **z-norm set-wise:** normalize train and test set individually
- **z-norm sample-wise:** sample-wise normalization



Exemplary samples; variety in lighting / color

	i13-1	i13-2	iXS-1	iXS-2	iX	i11	i13P	GP4A-1	GP4A-2	GP4A-3	GP1	LGN5-1	LGN5-2	N61-1	N61-2	P20	P30	Xia	SGA52
M1																			
M2																			
M3																			

M1-3: Manufacturers

Comparison Sets

	i13-1	i13-2	iXS-1	iXS-2	iX	i11-1	i13P	GP4A-1	GP4A-2	GP4A-3	GP1	LGN5-1	LGN5-2	N61-1	N61-2	P20	P30	Xia	SGA52
i13-1	I	P	M	M	M	M	M	U	U	U	U	U	U	U	U	U	U	U	U
i13-2	P	I	M	M	M	M	M	U	U	U	U	U	U	U	U	U	U	U	U
iXS-1	M	M	I	P	M	M	M	U	U	U	U	U	U	U	U	U	U	U	U
iXS-2	M	M	P	I	M	M	M	U	U	U	U	U	U	U	U	U	U	U	U
iX	M	M	M	M	I	M	M	U	U	U	U	U	U	U	U	U	U	U	U
i11-1	M	M	M	M	M	I	M	U	U	U	U	U	U	U	U	U	U	U	U
i13P	M	M	M	M	M	M	I	U	U	U	U	U	U	U	U	U	U	U	U
GP4A-1	U	U	U	U	U	U	U	I	P	P	M	U	U	U	U	U	U	U	U
GP4A-2	U	U	U	U	U	U	U	P	I	P	M	U	U	U	U	U	U	U	U
GP4A-3	U	U	U	U	U	U	U	P	P	I	M	U	U	U	U	U	U	U	U
GP1	U	U	U	U	U	U	U	M	M	M	I	U	U	U	U	U	U	U	U
LGN5-1	U	U	U	U	U	U	U	U	U	U	U	I	P	U	U	U	U	U	U
LGN5-2	U	U	U	U	U	U	U	U	U	U	U	P	I	U	U	U	U	U	U
N61-1	U	U	U	U	U	U	U	U	U	U	U	U	U	I	P	U	U	U	U
N61-2	U	U	U	U	U	U	U	U	U	U	U	U	U	P	I	U	U	U	U
P20	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	I	M	U	U
P30	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	M	I	U	U
Xia	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	I	U
SGA52	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	I

I Identical Device: 19 **M** Same Make: 46
P Pair: 14 **U** Unrelated: 282



Results on unpaired set

timm name	#Params Mio.	ISP	rawpy camera-wb	rawpy auto-wb	custom raw CFA to RGB
mobilenetv4_conv_small	3.77	0.877 _{0.37}	0.914 _{0.33}	0.920 _{0.34}	0.969 _{0.60}
efficientnet_b0	5.29	0.919 _{0.40}	0.936 _{0.34}	0.938 _{0.37}	0.981 _{0.70}
tinynet_a	6.19	0.935 _{0.50}	0.958 _{0.49}	0.955 _{0.41}	0.979 _{0.56}
densenet121	7.98	0.950 _{0.47}	0.930 _{0.33}	0.945 _{0.33}	0.986 _{0.66}
resnet18	11.69	0.908 _{0.39}	0.906 _{0.33}	0.907 _{0.33}	0.979 _{0.66}
mobilevit_xxs	1.27	0.957 _{0.54}	0.964 _{0.37}	0.953 _{0.34}	0.979 _{0.56}
mobilevit_xs	2.32	0.955 _{0.49}	0.951 _{0.33}	0.946 _{0.33}	0.980 _{0.59}
fastvit_t8	4.03	0.936 _{0.35}	0.955 _{0.35}	0.959 _{0.36}	0.985 _{0.67}
tiny_vit_5m_224	5.39	0.943 _{0.44}	0.962 _{0.49}	0.964 _{0.42}	0.985 _{0.67}
fastvit_s12	9.47	0.956 _{0.56}	0.968 _{0.35}	0.963 _{0.36}	0.985 _{0.66}

Note: each value aggregates results from 5 runs x 282 unrelated cases = 1410 experiments.

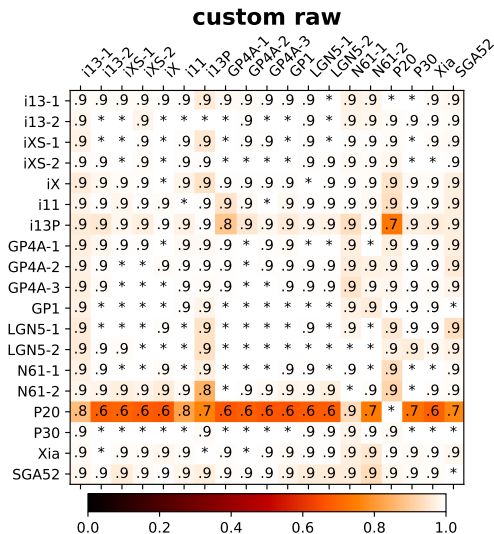
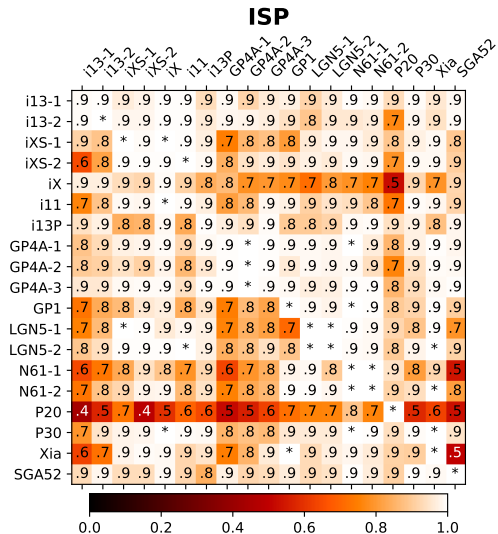
Ablation: Data Normalization

Norm	ISP	rawpy camera-wb	rawpy auto-wb	custom raw CFA to RGB
no norm	0.589 _{0.16}	0.746 _{0.31}	0.925 _{0.41}	0.621 _{0.15}
z-norm train-set	0.562 _{0.17}	0.753 _{0.26}	0.932 _{0.40}	0.607 _{0.12}
z-norm set-wise	0.884 _{0.35}	0.922 _{0.29}	0.959 _{0.48}	0.924 _{0.33}
z-norm sample-wise	0.943 _{0.44}	0.962 _{0.49}	0.964 _{0.42}	0.985 _{0.67}

Ablation: Additive Uniform Noise

Noise Augmentation	Noise Strength	ISP	rawpy camera-wb	rawpy auto-wb	custom raw CFA to RGB
no	–	0.886 _{0.33}	0.943 _{0.33}	0.951 _{0.34}	0.965 _{0.36}
yes	± 1 %	0.935 _{0.38}	0.966 _{0.34}	0.965 _{0.35}	0.988 _{0.64}
yes	± 2.5 %	0.943 _{0.44}	0.962 _{0.49}	0.964 _{0.42}	0.985 _{0.67}
yes	± 5 %	0.950 _{0.48}	0.966 _{0.39}	0.968 _{0.50}	0.986 _{0.65}

Minimum score over 5 runs per cross-smartphone scenario



rows = training device; cols = testing device

Conclusion

This study did:

- solve 1:1 cross sensor material classification for subtle signals (if we have access to raw data)
- confirm that the ISP pipeline was indeed the culprit

Future Directions:

- Learn to remove ISP per smartphone (no need for raw capturing)
- (ideally, but maybe not feasible?) Single model to remove all ISP artifacts (removes need for training a model for every smartphone type)
- Use different material where there is unlimited real world samples (like copy paper)

Q & A

Find resources here:

Data



Code

