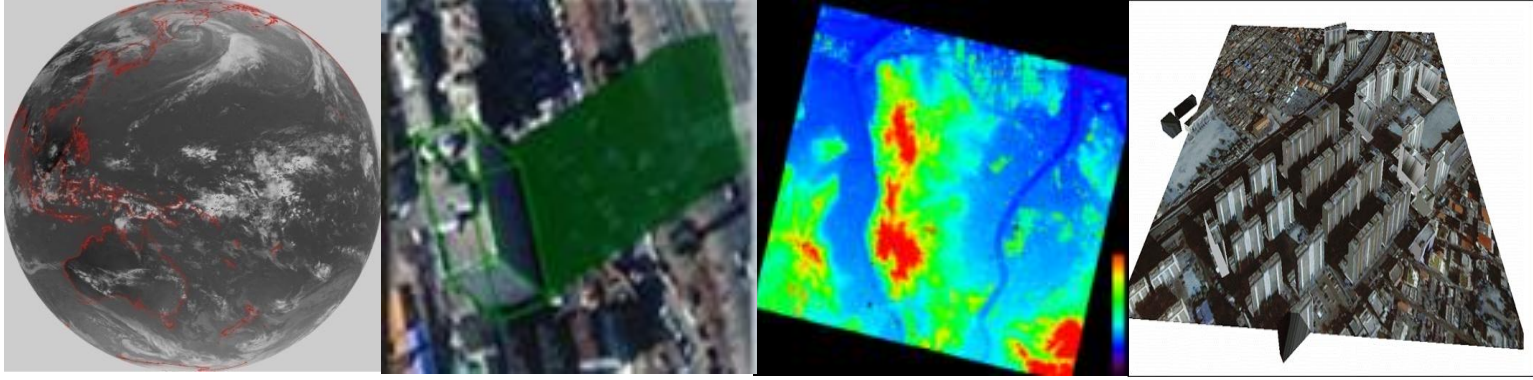

Automated Assessment of NIIRS and GRD of High Resolution Satellite Images through Edge Profile Analysis of Natural Targets

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Backgrounds

❖ Various ways of describing image quality

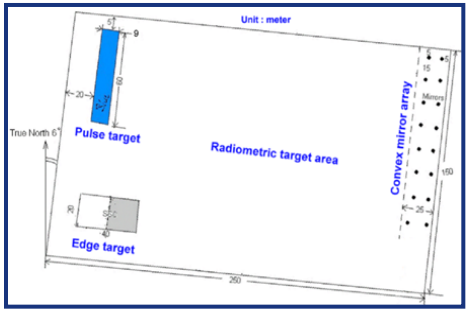
- From engineering side, there are many technical parameters
  - Ground sampling distance,
  - Modulation Transfer Function(MTF) (ratio @ sampling freq.),
  - Signal to Noise Ratio (SNR),
  - Relative Edge Response (RER), etc.

- Tech. parameters may not represent "image quality" for user
  - Image users may be more interest in other parameters
  - mapping accuracy, interpretability, etc.

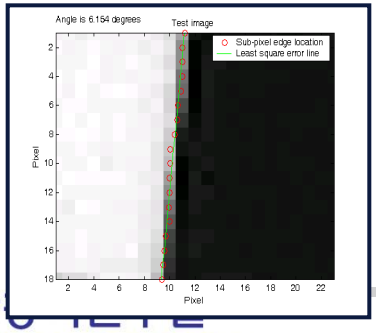
- Image quality regarding interpretability
  - NIIRS (National Image Interpretability Rating Scales)
  - GRD (Ground Resolvable Distance)

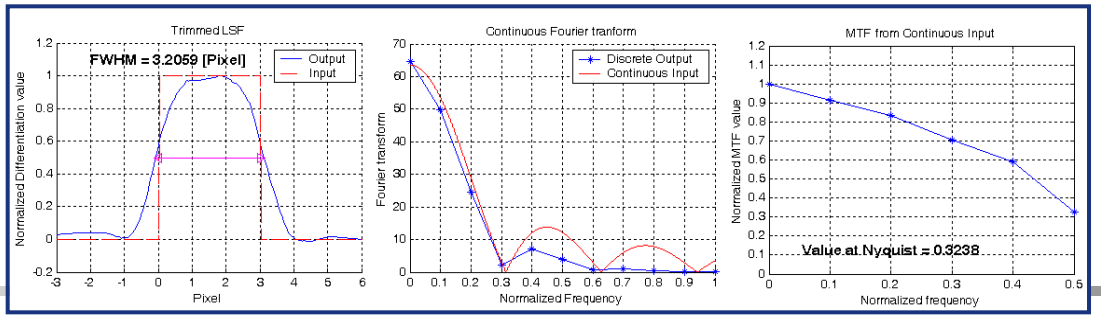
Backgrounds

- **Image quality assessed mostly by Artificial Targets**
  - Usually for calibration / validation purpose
  - Specially manufactured artificial targets are used
  - Special arrangements (target size, orientation) are required
  - Images around targets are analyzed for RER and SNR
  - Edge profiles are transformed to MTF through curve fitting



(Helder et al., 2004)





Research Purpose

❖ **Automated image quality assessment from natural targets**

- artificial targets → natural targets
- manual edge selection → automated selection
- RER, MTF, SNR → GRD, NIIRS
- reliability of image quality parameters

➔ Operational image quality assessment of all remote sensing images without extra costs

Research Purpose

❖ NIIRS (National Image Interpretability Rating Scales)

- Originally used for intelligence/military images
- In 1996, published by IRARS (Imagery Resolution Assessments and Reporting Standards)
- For each rating, identifiable targets are defined
- Separate rating scales exist for military targets and civil/natural targets and for panchromatic, multispectral, radar images
- NIIRS values are assessed visually by certified image analysts
- NIIRS values are provided within the satellite metadata

Research Purpose

Level	GRD (m)	Visible NIIRS
0	-	Interpretability of the imagery is precluded by obscuration, degradation, or very poor resolution
1	over 9.0	Detect a medium-sized port facility and/or distinguish between taxi-ways and runways at a large airfield.
2	4.5 – 9.0	Detect large hangars at airfields. Detect large static radars (e.g., AN/FPS-85, COBRA DANE, PECHORA, HENHOUSE).
3	2.5 – 4.5	Identify the wing configuration (e.g., straight, swept, delta) of all large aircraft (e.g., 707, CONCORD, BEAR, BLACKJACK).
4	1.2 – 2.5	Identify all large fighters by type (e.g., FENCER, FOXBAT, F-15, F-14). Detect the presence of large individual radar antennas (e.g., TALL KING).
5	0.75 – 1.2	Distinguish between a MIDAS and a CANDID by the presence of refueling equipment (e.g., pedestal and wing pod). Identify radar as vehicle-mounted or trailer-mounted.
6	0.40 - 0.75	Distinguish between models of small/medium helicopters (e.g., HELIX A from HELIX B from HELIX C, HIND D from HIND E, HAZE A from HAZE B from HAZE C).
7	0.20 – 0.40	Identify fitments and fairings on a fighter-sized aircraft (e.g., FULCRUM, FOXHOUND).
8	0.10 – 0.20	Identify the rivet lines on bomber aircraft. Detect horn-shaped and W-shaped antennas mounted atop BACKTRAP and BACKNET radars.
9	less than 0.10	Differentiate cross-slot from single slot heads on aircraft skin panel fasteners. Identify small light-toned ceramic insulators that connect wires of an antenna canopy.

Research Purpose

❖ NIIRS assessment by GIQE

- General Image quality Equation
- Proposed by regression analysis between NIIRS, GSD, MTF and SNR values of images
- Enables assessment of NIIRS from tech. parameters determined by edge analysis

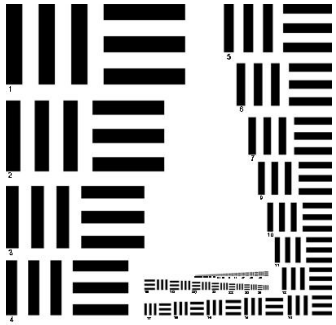
$$NIIRS = a - b^* \log(GSD_{GM}) + c^* \log(RER_{GM}) - (d^*H) - (e^*G/SNR)$$

- RER_{GM}: Geometric means of Relative Edge Response in x and y direction
- H: Geometric means of Overshoot height
- G: Noise gain due to Edge sharpening, Kernel Value of MTF Correction
- GSD: Ground Sampling Distance
- SNR: Signal to Noise Ratio

Research Purpose

❖ GRD (Ground Resolvable Distance)

- The minimum distance between two objects to be identified as separate objects
- Inverse of Line pairs per mm (lp/mm)
- GRD is assessed by image analysts

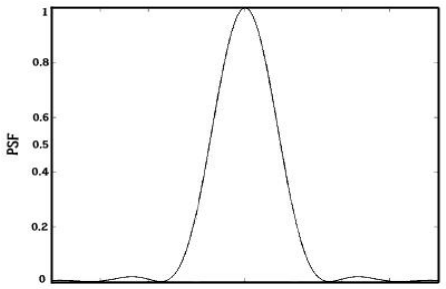


❖ GRD assessment

- GRD can be assessed from PSF (Point Spread Function)

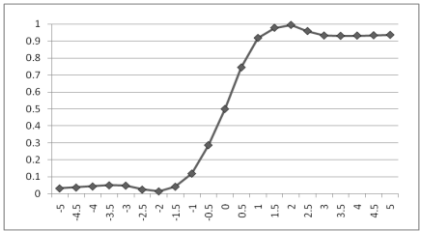
$$GRD = \frac{H}{f} R$$

- H : Flying height
- f : Focal length
- R : Half peak width of PSF



Research Purpose

❖ Proposed procedures

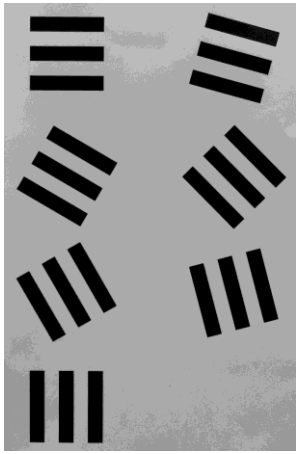


- Select initial edge points
  - from artificial vs. natural targets
  - manually vs. automatically
- Determine edge orientation and generate edge profiles
- Calculate normalized edge profile and edge center
- Check the criteria for accepting edge profiles
- Calculate RER, H, SNR and NIIRS
- Generate point spread function and calculate GRD
- Repeat the process for other edge points (usually > 50)
- Determine NIIRS and GRD for the whole scene

Validation of GRD/NIIRS Assessment

❖ Orientation-invariant edge analysis

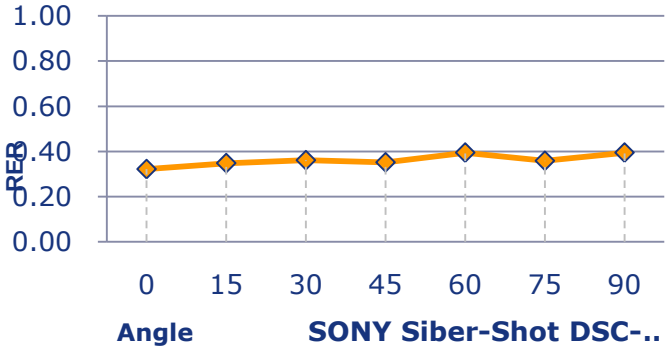
- GIQE uses RER in only x- and y-directions
- For natural targets, we have to use edges of arbitrary orientation
- We need to extract edge profiles perpendicular to edge orientation
- Test image: bar patterns with orientation changed incrementally by 15° by different cameras

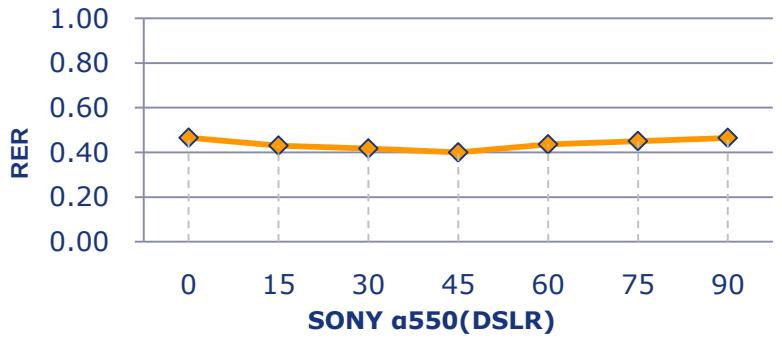


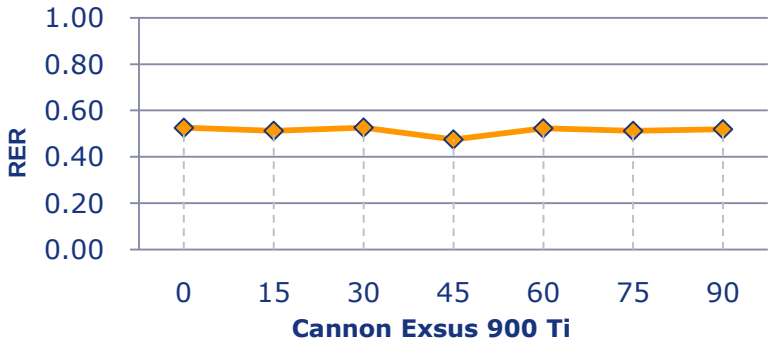
Camera Tested:
SONY Siber-Shot DSC-S950
SONY α550(DSLR)
Cannon Exsus 900 Ti
Samsung Kenox S500

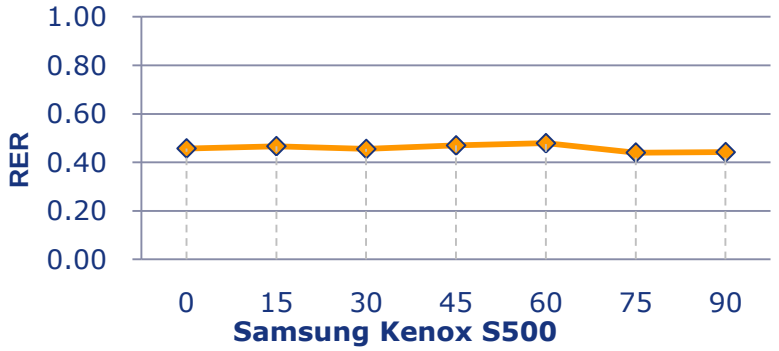
Validation of GRD/NIIRS Assessment

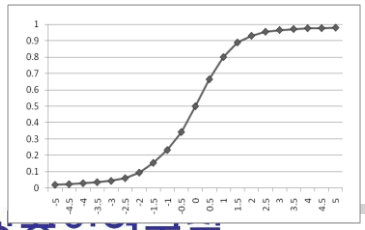
❖ Orientation-invariant edge analysis

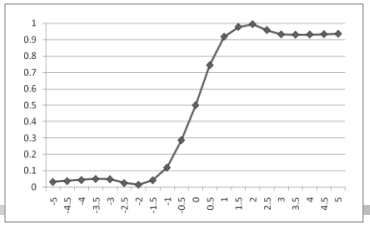


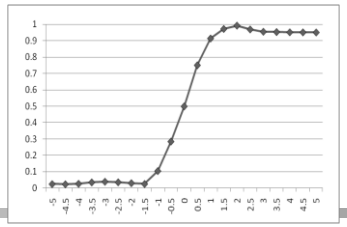


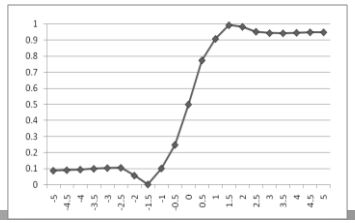








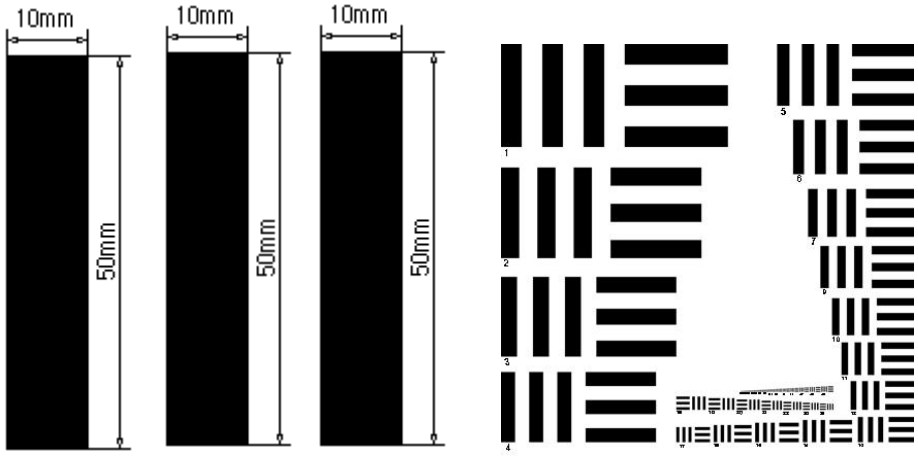




Validation of GRD/NIIRS Assessment

❖ GRD estimation from in-door scenes

- Test image:



- Camera spec.:

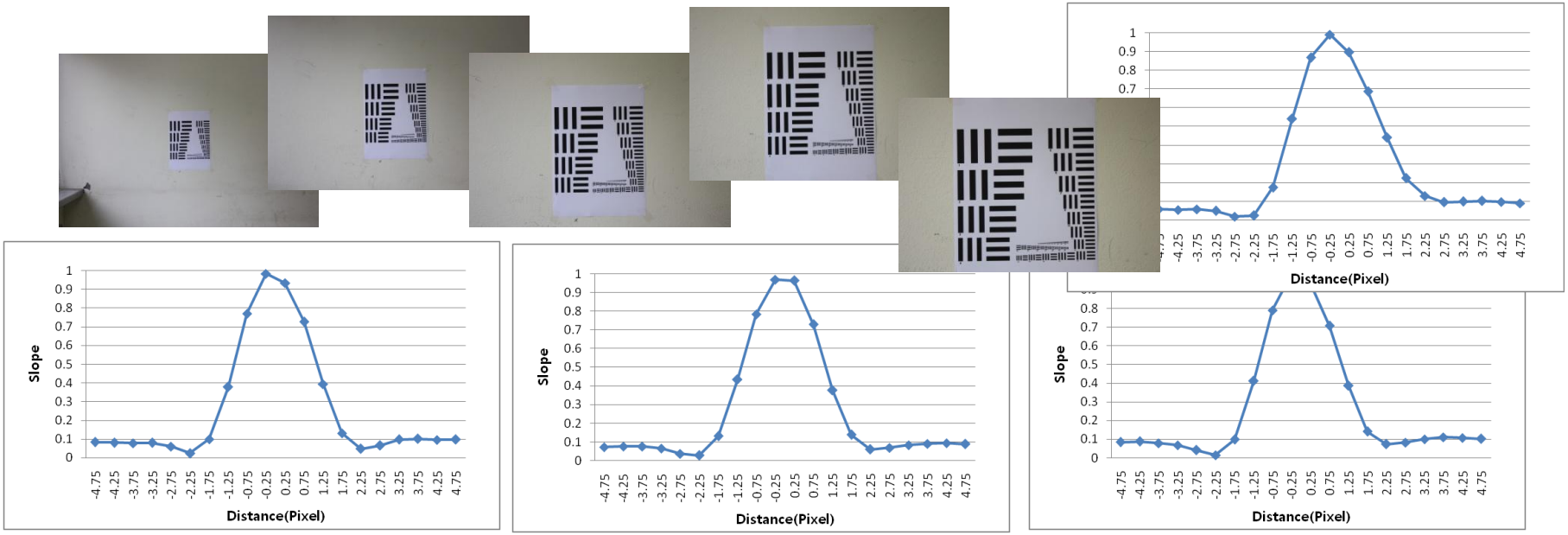
Model	EOS 450D
CCD size	22.2mm × 14.8mm
Focal Length	55mm
Image Size	4272 × 2848
CCD Cell size	0.005197mm

- Imaging distance (Flying height):
  981mm, 1232mm,1454mm, 2090mm, 3132mm

Edge analysis for quality assessment

❖ GRD estimation from in-door scenes

- From bar pattern, extract edge profiles, PSF and GRD
- GRD values assessed by 7 researcher were averaged as reference GRD values

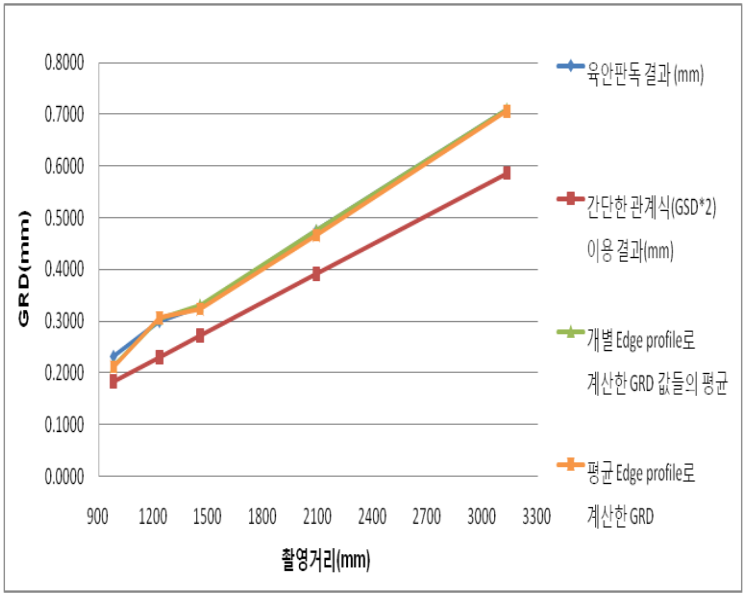


Validation of GRD/NIIRS Assessment

❖ GRD estimation from edge analysis

- **GRD values from edge analysis were almost identical to reference (RMSE: 0.01mm)**

Imaging Distance	Reference GRD	2 * GSD	GRD	
			Average of Individual GRDs	GRD of Average Edge Profile
3132mm	0.7081mm	0.5863mm	0.7094mm	0.7057mm
2090mm	0.4753mm	0.3912mm	0.4747mm	0.4665mm
1454mm	0.3288mm	0.2722mm	0.3305mm	0.3230mm
1232mm	0.3001mm	0.2306mm	0.3058mm	0.3063mm
981mm	0.2324mm	0.1836mm	0.2127mm	0.2112mm



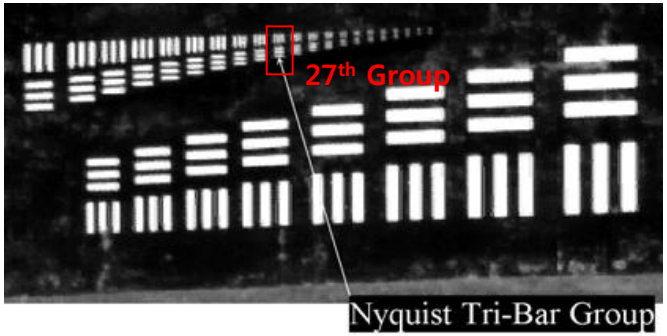
Validation of GRD/NIIRS Assessment

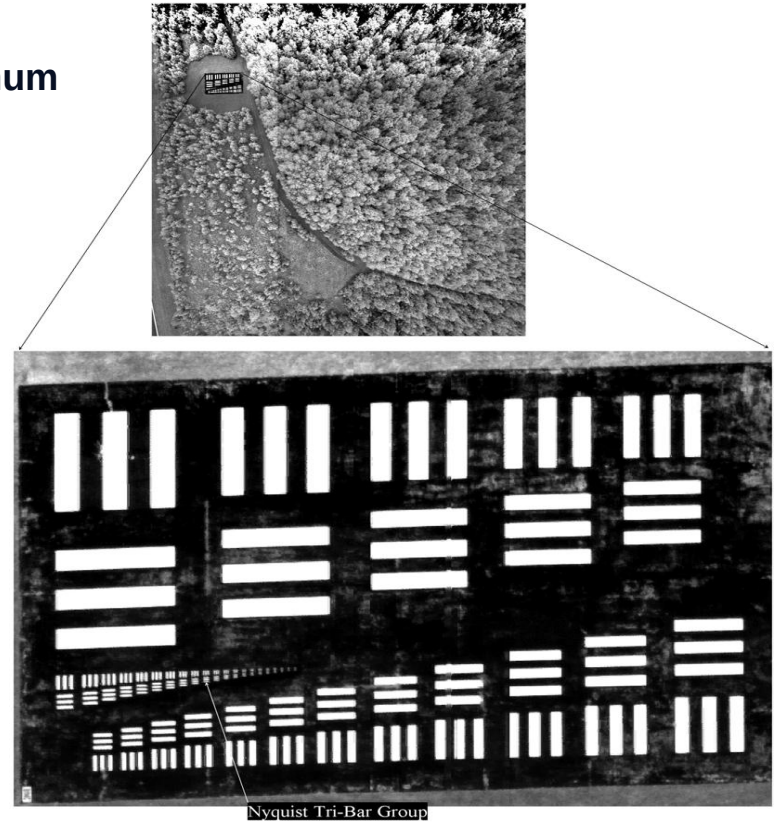
❖ GRD estimation from an out-door scene

- **Test data** (Bruce Mathews and Theodore Zwicker, 1999)

  - Tri bar pattern with varying sizes
  - Reference GRD is estimated by checking minimum identifiable bar pattern

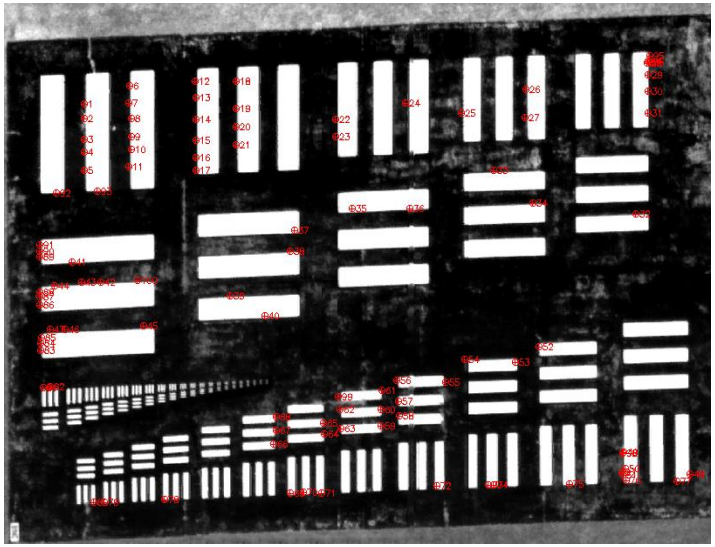
Bar Group	Size(inches)			Bar Group	Size(inches)		
	Horiz.	Vert.	GRD (in)		Horiz.	Vert.	GRD (in)
1	151.25	30.25	60.50	20	16.84	3.37	6.74
7	75.60	15.13	30.25	26	8.42	1.68	3.37
8	67.40	13.47	26.95	**27**	**7.50**	**1.50**	**3.00**
9	60.00	12.00	24.01	**28**	**6.68**	**1.34**	**2.67**
10	53.50	10.69	21.39	29	5.96	1.19	2.38
11	47.60	9.53	19.06	30	5.31	1.06	2.12



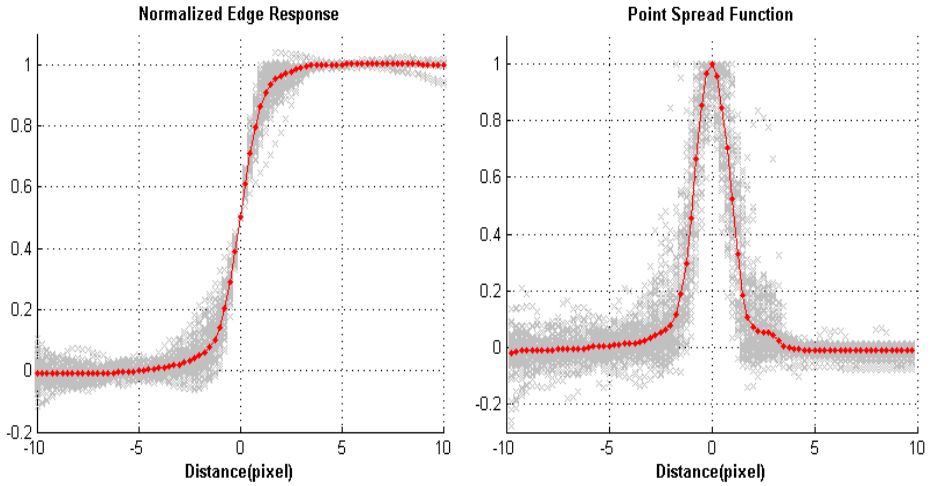


Validation of GRD/NIIRS Assessment

❖ GRD estimation from an out-door scene



100 Edge locations were selected



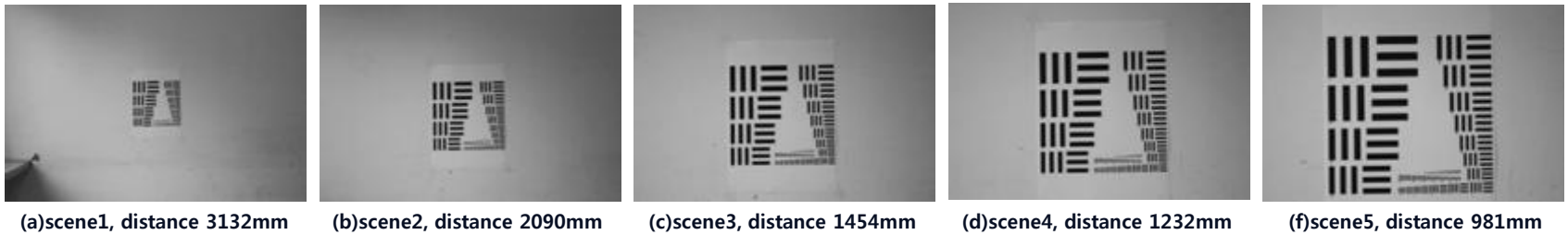
Extracted Edge Profile and Point Spread Function

	Reference	GSD*2	GRD	
			Average of Individual GRDs	GRD of Average Edge Profile
inches	2.8350	2.7400	2.7784	2.6552
Pixel	2.0693	2.0000	2.0280	1.9381

Validation of GRD/NIIRS Assessment

❖ GRD estimation from simulated images

- from each ref. images, 3 simulated images were generated

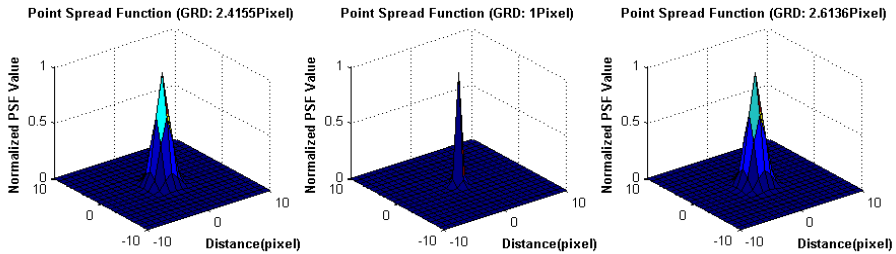


(a)scene1, distance 3132mm (b)scene2, distance 2090mm (c)scene3, distance 1454mm (d)scene4, distance 1232mm (f)scene5, distance 981mm

Ref. Image * PSF (Gaussian with GRD 1,2,3)

5 refs X 3 PSFs = 15 simulated images

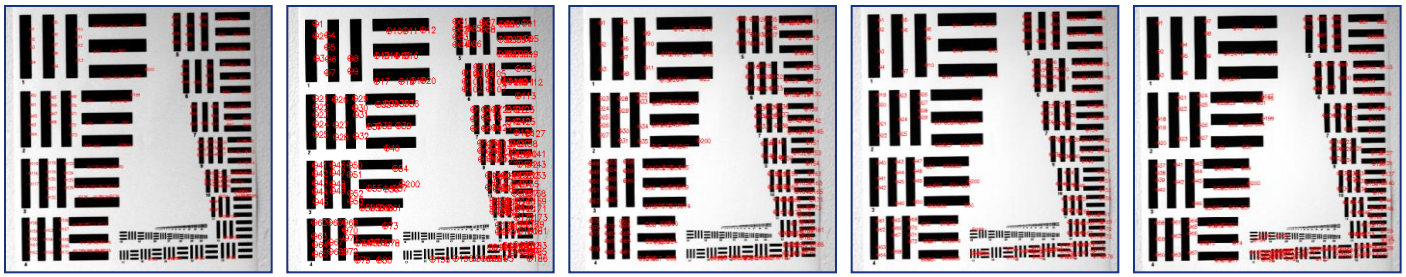
- reference GRDs were estimated by visual inspection
- theoretic GRDs were also calculated mathematically



Validation of GRD/NIIRS Assessment

❖ GRD estimation from simulated images

- For each image, edge profiles at 200 locations were extracted



Scene 1 Scene 2 Scene 3 Scene 4 Scene 5

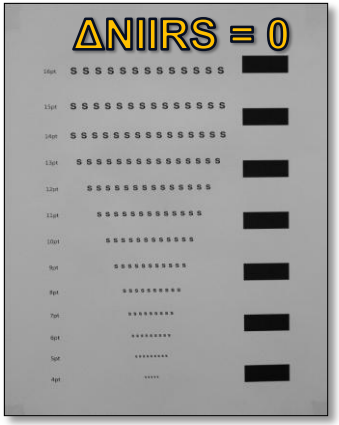
Difference between theoretically driven GRDs vs estimated GRDs

Conv PSF's GRD	0001	0002	0003	0004	0005	Total RMSE(Pixel)
기준영상	0.0756	0.0177	0.0227	-0.2043	0.0309	0.0992
1.0Pixel	0.0493	0.2727	-0.0007	-0.2051	0.0027	0.1542
2.0Pixel	0.0327	0.0261	-0.1624	-0.1480	0.0589	0.1034
3.0Pixel	-0.0223	-0.2207	-0.1842	-0.2021	-0.1369	0.1690

Validation of GRD/NIIRS Assessment

❖ NIIRS estimation from simulated images

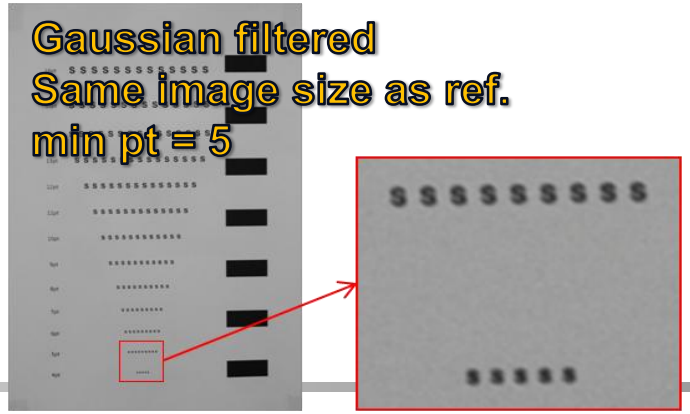
- generated images with ΔNIIRS by changing GSDs
- check the minimum identifiable font size for each image
- blur the reference by Gaussian filter to make the same minimum font size as the images with different GSDs



GSD_0, Reference

$$\Delta NIIRS = -3.32 \mathrm{Log}\left(\frac{GSD}{GSD_0}\right)$$

	Reference	1.4145 x GSD_0	2.0000 x GSD_0	2.8302 x GSD_0
ΔNIIRS	0.0	-0.5	-1.0	-1.5
Minimum font size (pt)	4	5	7	11
Image size	1000 x 1500	707 x 1060	500 x 750	353 x 530



Validation of GRD/NIIRS Assessment

❖ NIIRS estimation from simulated images

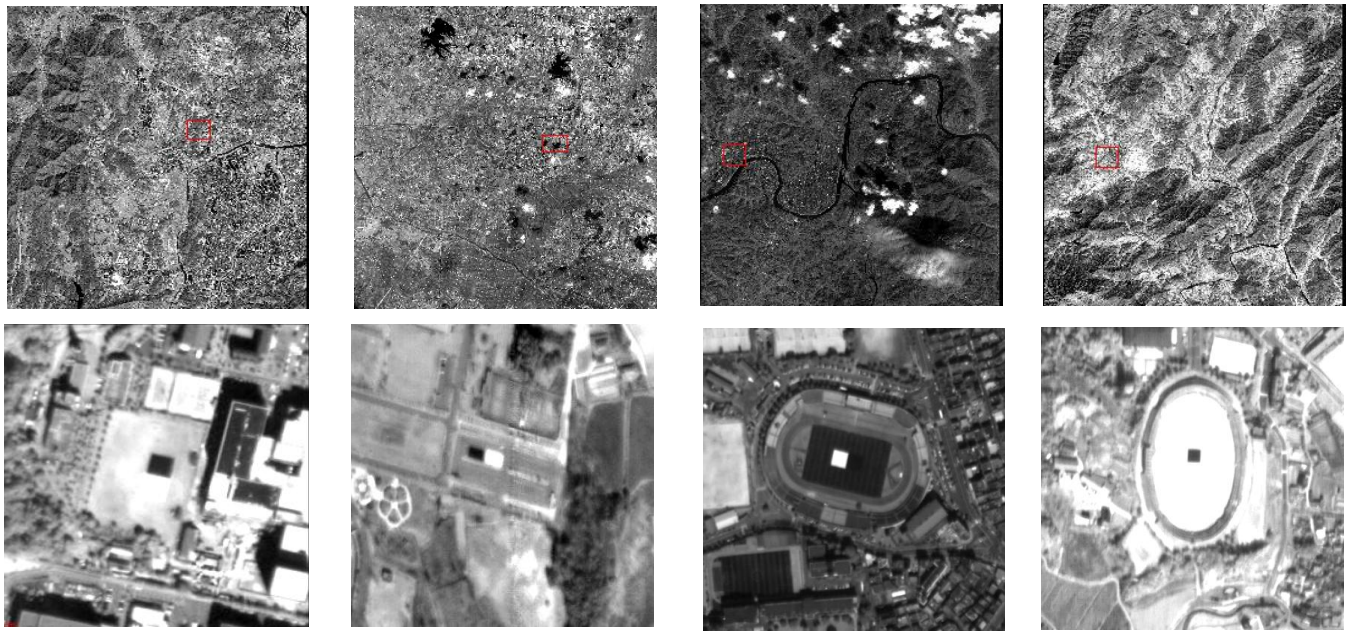
- **Estimated ΔNIIRS were very close to the true values**

	Reference	Min. pt = 5	Min pt = 7	Min pt = 11
RER	0.6376	0.3993	0.2347	0.1560
SNR	47.5078	162.0340	92.2690	21.9131
H	1.0664	0.9692	0.7727	0.6898
GRD	1.5861	2.3732	3.8407	5.5866
NIIRS	3.9320	3.4427	2.9258	2.4688
True ΔNIIRS		-0.5000	-1.0000	-1.5000
Estimated ΔNIIRS		-0.4893	-1.0062	-1.4632
|Error|		0.0107	0.0062	0.0368

Validation of the use of natural targets

❖ Artificial targets vs. natural targets

- Test images: Komspat-2 images with tarps



Area	Taejeon	Kimje	Jinju	Hamyang
GSDx	0.979	1.000	0.980	1.092
GSDy	0.994	1.000	0.996	1.048

Validation of the use of natural targets

❖ Artificial targets vs. natural targets

- Using natural targets, similar quality parameters were assessed
- Differences in NIIRS are within the error range of GIQE (1σ=0.30)
- Degradation in SNRs from natural targets
- We need more test with other dataset

Daejeon	Tarp	Natural
Points	10	2069
RER	0.2967	0.3028
SNR	59.10	49.48
H	0.8353	0.8834
GRD(m)	2.37	2.68
NIIRS	3.53	3.48

Kimje	Tarp	Natural
Points	10	976
RER	0.2238	0.2768
SNR	38.18	36.84
H	0.7987	0.8324
GRD(m)	2.89	2.87
NIIRS	3.15	3.40

Jinju	Tarp	Natural
Points	10	730
RER	0.3065	0.2898
SNR	59.52	42.94
H	0.8058	0.8529
GRD(m)	2.56	2.86
NIIRS	3.62	3.46

Hamyang	Tarp	Natural
Points	10	707
RER	0.2413	0.2736
SNR	48.68	44.04
H	0.7704	0.8357
GRD(m)	3.34	3.26
NIIRS	3.21	3.29

Validation of automated edge selection

❖ Automated edge selection

- apply line detection algorithm
- check line length (10 pixels)
- Extract edge profiles
- edge profile selection criteria are same as manual selection

Validation of automated edge selection

- Tests with Kompsat-2 images
  - Quality degradation for automated edge selection (in particular in GRD)
    - better edge selection criteria required
  - Differences in NIIRS are within the error range of GIQE (1σ=0.30)

Daejeon	Tarp	Natural Manual	Natural Auto
Points	10	2069	55806
RER	0.2967	0.3028	0.2837
SNR	59.10	49.48	39.38
H	0.8353	0.8834	0.8474
GRD(m)	2.37	2.68	3.03
NIIRS	3.53	3.48	3.44

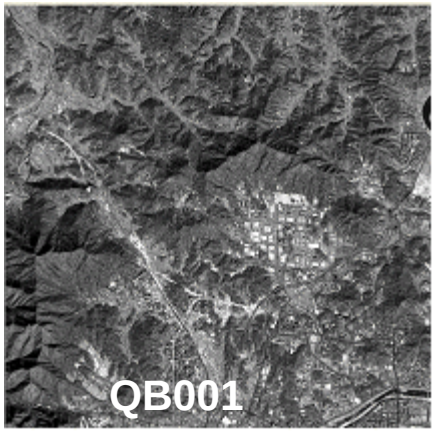
Kimje	Tarp	Natural	Natural Auto
Points	10	976	55806
RER	0.2238	0.2768	0.2707
SNR	38.18	36.84	34.49
H	0.7987	0.8324	0.8198
GRD(m)	2.89	2.87	3.11
NIIRS	3.15	3.40	3.39

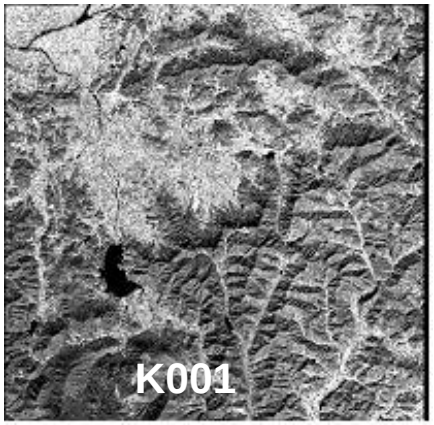
Jinju	Tarp	Natural	Natural Auto
Points	10	730	17858
RER	0.3065	0.2898	0.2768
SNR	59.52	42.94	38.15
H	0.8058	0.8529	0.8445
GRD(m)	2.56	2.86	3.31
NIIRS	3.62	3.46	3.40

Hamyang	Tarp	Natural	Natural Auto
Points	10	707	36101
RER	0.2413	0.2736	0.2716
SNR	48.68	44.04	36.02
H	0.7704	0.8357	0.8314
GRD(m)	3.34	3.26	3.44
NIIRS	3.21	3.29	3.28

Validation of automated edge selection

❖ GRD/NIIRS estimation from sat. images





	QB001	IK001	K001
Acquisition date	2005/1/15/2/27	2002/2/7/2/34	2007/2/23/01/49
Area	Daejeon	Daejeon	Damyang
Image size	25044×27552	11004×11004	15000×15500
GSD X(m)	0.793	0.90	1.086
GSD Y(m)	0.711	0.96	1.039
G(Noise Gain)	4.16	4.16	2.34

Validation of automated edge selection

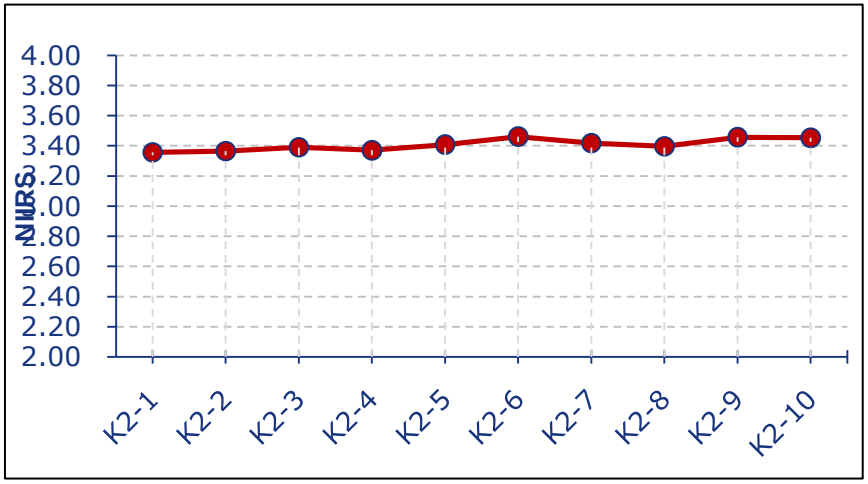
- GRD/NIIRS estimation from sat. images
  - **using natural targets**
  - **manual or automatic selection**
  - **Published NIIRS : Value in Metadata (QB) or in literature (IK)**
  - **Slight quality degradation for automated selection (but not big)**
  - **Differences in NIIRS are within the error range of GIQE (1σ=0.30)**

type	edge selection	points	RER	SNR	H	GRD(m)	NIIRS	Published NIIRS
QuickBird	manual	2692	0.6389	42.89	1.037	1.11	4.65	4.5000
	auto	20991	0.6128	38.55	1.043	1.15	4.57	
IKONOS	manual	1247	0.5354	38.04	1.012	1.46	4.11	4.3000
	auto	7387	0.5334	36.67	1.023	1.49	4.09	
Kompsat-2	manual	372	0.3705	36.41	0.957	2.68	3.51	-
	auto	11749	0.3336	34.29	0.932	2.99	3.39	

Validation of automated edge selection

❖ **Automated NIIRS estimation for images along the same strip (Komspat-2 strip)**

ID	1	2	3	4	5	6	7	8	9	10
Points	2316	2054	2493	1995	3059	3876	4336	3683	3497	2310
RER	0.3841	0.3894	0.3966	0.3901	0.4026	0.4186	0.4205	0.4160	0.4190	0.4201
SNR	36.34	34.77	35.19	35.24	34.80	34.10	34.41	35.17	35.32	35.32
H	1.051	1.056	1.057	1.055	1.059	1.060	1.058	1.064	1.066	1.071
GRD(m)	2.92	2.93	2.89	2.91	2.87	2.79	2.78	2.81	2.82	2.82
NIIRS	3.36	3.36	3.39	3.37	3.41	3.46	3.42	3.40	3.46	3.45



❖ GRD distribution
- ➢ Mean: 2.86m, Stdev: 0.06m

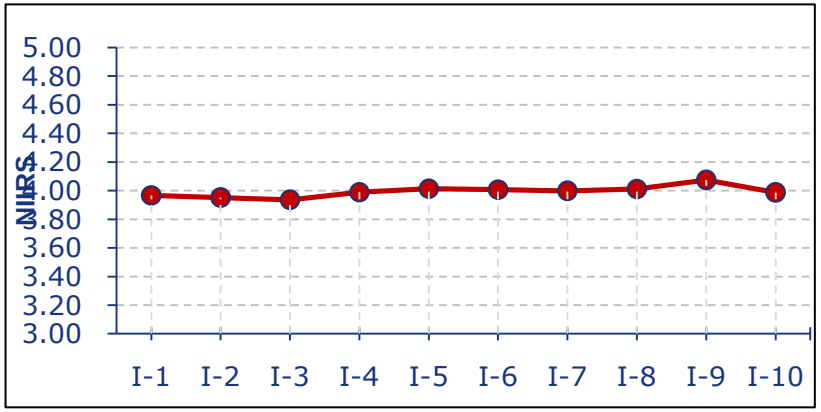
❖ NIIRS distribution
- ➢ Mean: 3.40, Stdev: 0.04

❖ All images on the same strip showed very constant GRD/NIIRS values. NIIRS values are within the error range of GIQE (1σ=0.30)!

Validation of automated edge selection

❖ **Automated NIIRS estimation for images along the same strip (IKONOS strip)**

ID	1	2	3	4	5	6	7	8	9	10
Points	2236	1960	1503	1523	5230	6618	4574	4487	4099	3712
RER	0.5107	0.4998	0.4932	0.5089	0.5206	0.5209	0.5160	0.5219	0.5225	0.5137
SNR	39.90	38.91	41.17	41.77	46.30	46.72	46.82	45.01	42.60	42.11
H	1.033	1.020	1.021	1.017	1.029	1.034	1.031	1.032	1.036	1.028
GRD(m)	1.69	1.71	1.72	1.67	1.60	1.60	1.61	1.63	1.65	1.67
NIIRS	3.97	3.95	3.94	3.99	4.01	4.01	4.00	4.01	4.07	3.99



❖ GRD distribution
- ➢ Mean: 1.65m, Stdev: 0.04m

❖ NIIRS distribution
- ➢ Mean: 3.99, Stdev: 0.04

❖ All images on the same strip showed very constant GRD/NIIRS values. NIIRS values are within the error range of GIQE (1σ=0.30)!

Conclusions

❖ Conclusions

- GRD/NIIRS estimation through edge analysis
  - Feasible but tests with ref. NIIRS are required.
- The use of natural target
  - Feasible but tests with more dataset are required.
- Automated image quality assessment is feasible
  - But, more rigorous selection criteria is required

- Can the proposed method be used for image quality assessment for operational basis?