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ISO-less?

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Executive Summary

Exposure is more complex than you think it is.

Emulsion Sensitivity To Light

- How much exposure is needed to obtain the same image qualities with fixed development?
- Sensitivity represented as a single value:
  - 1880: Warnerke's Sensitometer
  - 1934: DIN standard 4512, $\log_{10}$ °
  - 1943: ASA Z38.2.1-1943, arithmetic
  - 1974: ISO number pairs, e.g., ISO 100/21°
- Different spec's for B&W, color negs, slides

Image Sensor Sensitivity

- Extend ISO to apply to digital cameras...
- 1998: ISO 12232:20076

  Photography – Digital still cameras – Determination of exposure index, ISO speed ratings, standard output sensitivity, and recommended exposure index.

  3 methods based on sensitivity and noise
- 2006: added 2 methods
  - SOS (Standard Output Sensitivity) matching JPEG Y-channel reference
  - REI (Recommended Exposure Index)

Can Sensitivity Be Changed?

- For film, "push processing" allowed modest adjustment of effective film speed per roll
- **Most digital cameras allow changing ISO on a per-shot basis**
  - High-end cameras often support large ISO ranges, e.g., 100 – 12800
  - Webcams often have no aperture and no shutter adjustments

What Are We Changing?

- QE (Quantum Efficiency) is fraction of photons that contribute to the accumulated charge... and generally can't be changed!
- Things we could change:
  - **Analog** gain; amplification before ADC
  - **Digital** gain; computational processing of the digitized signal values
- A camera in which analog/digital processing can produce identical images is "**ISO-less**"

Questions This Paper Answers

- Are commodity cameras ISO-less?
- How can we use this new understanding to adjust exposure parameters to potentially improve image quality?

We don't try to explain or understand why these ISO behaviors happen... this isn't a paper about modeling sensor noise, etc.

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Cameras Used In Experiments

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Measured Dynamic Range

- Dynamic Range recorded is an obvious and popular IQ metric (e.g., DxO published data)
- ISO-less ⇒ DR increases as ISO decreases

Camera Model	DR @ 8MP	100	200	400	800	1600	3200	6400	12800	25600
Sony A100	11.2	10.9	10.2	*8.9*	*7.7*	*6.9*				
Sony A350	11.5	11.1	*10.3*	*9.2*	*7.6*	7.2	*6.2*			
Sony SLT-A55	12.4	12.0	11.5	11.0	*10.2*	*9.4*	*8.4*	*7.3*	*6.2*	
Sony NEX-5	12.2		11.9	11.6	*10.6*	*9.4*	8.7	*7.5*	*6.4*	
Fuji X10	11.3	11.2	*10.4*	9.8	9.3	*8.2*				
Sony NEX-7	13.4	12.8	*11.9*	*11.1*	*10.1*	*9.1*	*8.2*	7.9	*6.7*	6.4
Canon EOS-M	11.2	10.7	10.7	10.5	10.0	9.3	8.6	*7.4*	*6.5*	
Sony A7	14.2	13.4	*12.5*	11.9	11.1	10.5	*9.3*	*8.3*	*7.3*	6.7

Table 1. DxO measured dynamic ranges in stops at various ISO settings

ISO-less Is More Than DR

- By DR alone, **no camera was ISO-less** but every camera had a *potentially* ISO-less range
- What about all the other IQ metrics?
  - Don't need to evaluate quality, just **same** vs. **different**
  - Lots of test scene images published, but not many using gross underexposure
- Empirically tested 19 cameras over thousands of **raw** exposures with the same test scene...

Camera Model	Year	Prog	Sensor	MP	Min ISO	Max ISO	BPP
Canon G1	2000		CCD	3	50	400	10
Sony F828	2004		CCD	8	64	800	14
Canon A620	2005	CHDK	CCD	7	50	400	10
Canon A640	2006	CHDK	CCD	10	80	800	10
Sony A100	2006		CCD	10	100	1600	12
Canon A590	2008	CHDK	CCD	8	80	1600	10
Canon SD770	2008	CHDK	CCD	10	80	1600	12
Sony A350	2008		CCD	14	100	3200	12
Canon A480	2009	CHDK	CCD	10	80	1600	12
Sony SLT-A55	2010		CMOS	16	100	12800	12
Sony NEX-5	2010		CMOS	14	200	12800	12
Fuji X10	2011		CMOS	12	100	3200	12
Sony NEX-7	2011		CMOS	24	100	16000	12
Canon A4000	2012	CHDK	CCD	16	100	1600	12
Canon EOS-M	2012	ML	CMOS	18	100	12800	14
Canon ELPH115	2013	CHDK	CCD	16	100	1600	12
Canon N	2013	CHDK	CMOS	12	80	6400	12
Sony A7	2013		CMOS	24	50	25600	14
Sony A7 II	2014		CMOS	24	50	25600	14

Table 2. Some properties of the cameras used in the experiments

Test Scene

Is A Canon A4000 ISO-less?

Is A Canon A4000 ISO-less?

- To a good *approximation*, yes.
  - CHDK raws show *small* variations in IQ across most of the advertised ISO range
  - With postprocessing, *even camera JPEGs underexposed at base ISO can get close*
- Similar behavior from: Canon A620, Canon A640, Canon A590, Canon SD770, Canon A480, Canon A4000, Canon ELPH115, and Canon N

Is A Sony NEX-7 ISO-less?

Is A Sony NEX-7 ISO-less?

- People say Sonys are ISO-less, but no.
  - Lower ISOs are often sharper, but noisy, sometimes with reduced dynamic range
  - Sony F828's 14-bit raws *best* at base ISO
- Similar behavior from:
  Sony F828, Sony A100, Sony A350, Sony SLT-A55, Sony NEX-5, Fuji X10, Sony NEX-7, Sony A7, and Sony A7 II

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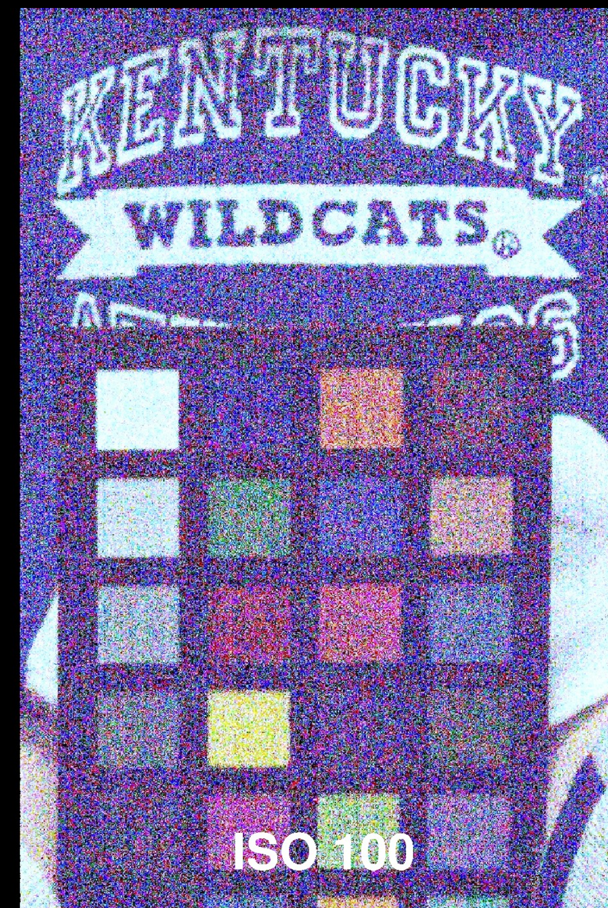
Is A Canon EOS-M ISO-less?



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Is A Canon EOS-M ISO-less?

- People say Canon EOS aren't ISO-less, and they're right: **NO**!
  - Detail improves, noise worse, at lower ISO
  - Severe loss of DR for some ISO drops, but not problematic for others
- Similar behavior from: Canon G1 (but more dramatically) and Canon EOS-M

But That Was Postprocessing...

- Although the experiments were controlled fairly well, raw post-processing is a major variable; in-camera processing to JPEG might reveal different behaviors...
- Using CHDK, reprogrammed PowerShots to use the camera's JPEG pipeline after simple adjustment of raw buffer data
  - In paper: Lua script using raw merge
  - Now: C code adjusting raw buffer data

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A4000 CHDK/Lua JPEGs; ISO 1600, 16X100, 16X100 Filtered

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In-Camera JPEG Processing

- Canon does a lot of funny things inside (probably most cameras do):
  - "Market" vs. "real" values for ISO, etc.
  - High ISO JPEGs get heavily smoothed
  - Color/black point seem to be tweaked
- Lower ISOs give more detail with worse grain (and color), but easy to fix in postprocessing
- Not ISO-less, with potential to improve!

Ok, Let's Improve Exposure

ISOs were really all about exposure...
is there a better way to compute exposure?

APEX Exposure Computation

- Additive System of Photographic Exposure

$$Av + Tv = Bv + Sv = Ev$$

Av Aperture value; if f/1.0=0, f/1.4=1
Tv Time value; if 1s=0, 1/2s=1
Bv Brightness value; if 1fL=0, 2fL=1
Sv Speed value; if ISO100=5, ISO200=6
Ev Exposure value for judging equivalence

APEX "P mode" Logic

- Pick shutter & aperture to avoid blur and not exceed aperture (diffraction) limit

if $Ev_{target} - Av_{min} < Tv_{blur}$ ***then***

$\{ Av = Av_{min} ; Tv = Ev_{target} - Av_{min} \}$

else if $Ev_{target} - Tv_{blur} < Av_{limit}$ ***then***

$\{ Tv = Tv_{blur} ; Av = Ev_{target} - Tv_{blur} \}$

else $\{ Av = Av_{limit} ; Tv = Ev_{target} - Av_{limit} \}$

APEX-based Auto ISO

- For a webcam that does not have control over *Av* nor *Tv*, Auto ISO is just:

$$Sv = (Av_{used} + Tv_{used}) - Bv$$

- Fancier Auto ISO logic is similar to P mode and bumps *Sv* to stay above Tv_{blur}

ISO-less Exposure

- Cameras are generally **NOT** ISO-less...
- ISO has both analog & digital components, and the mix of the two is significant to IQ
- Exposure algorithm should be ISO-less in the sense that optimal ISO component values should be **outputs**, not **inputs**

APEX Shift Exposure

- *Sv* is really the sum of two effects:

$$Sv = Sv_{analog} + Sv_{digital}$$

- Use standard APEX exposure, but pick decomposition of *Sv* that maximizes IQ
- Digital exposure shift is $Sv_{digital} = Sv - Sv_{analog}$
- If ISO-less, ***always*** make $Sv_{analog} = Sv_{min}$

Maximize Information Content?

- Linear recording of a log-perceived quantity; e.g., 14EV 14-bit raw, 8192-16383 in 1 stop!
- Try to maximize information content by:
  - DxO: compute ISO by exposure to saturate
  - Reichmann: **ETTR** (Expose To The Right)
- Problems with these approaches:
  - Where do middle tones go?
  - Doesn't actually maximize total information content because it avoids clipping

Measure Information Content

- Information content of a pixel is determined by **SNR** (signal/noise ratio)
- The SNR for a value v_j obtained under a set of exposure parameters p_j (including the Sv_{analog}, $Sv_{digital}$ components) is

$$information\_content(v_j, p_j)$$

- Unrecoverable clipped pixels yield 0... or -*k*

Estimate Information Content

- How do we know v_j without a p_j capture?
- Can easily capture a test image p_{test}:
  - Literally make a test capture
  - Use image data from live view stream
- Can estimate v_j from v_{ref} under p_{test}:

$$V_j = estimate\_value(v_{ref}, p_{test}, p_j)$$

Maximize Information Content

- Determine p_{best} by processing a test capture:

```
capture a test image, i, with exposure parameters p_test
for (p_j is each viable exposure parameter set) {
    c_j = 0
    for (v_ref is each pixel value in i) {
        v_j = estimate_value(v_ref, p_test, p_j)
        c_j = c_j + information_content(v_j, p_j)
    }
}
p_best = p_j with maximum c_j
```

Maximize Number Of Pixels Of Sufficient Quality

- In determining the dynamic range, how does one determine the darkest tone?
  - When similar tones can't be distinguished?
  - Minimum SNR? 1.0 stops? 0.1 stops? (e.g., Imatest computes several values)
- Simply modify *information_content()* to return 1 when expected SNR is acceptable, else 0

Zone System

- The Zone System (codified by Ansel Adams):

*"The Zone System allows us to relate various luminances of a subject with the gray value from black to white that we **visualize** to represent each one in the final image."*

- Specific kinds of objects, human skin, sky, snow, etc. should land in specific "zones"
- Often simplified, e.g., Wolfcrow System
- Change *information_content()* to score based on recognized objects landing in their zone

Conclusions

- Cameras are **NOT** completely ISO-less
- IQ depends on combination of analog + digital scaling used to implement an ISO
- Exposure computation can be ISO-less:
  - APEX shift
  - Maximizing information content
  - Maximizing pixels of sufficient quality
  - Zone System (using object recognition)
- Implementable in cameras (CHDK tests)

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