Color Night Vision for Security and Surveillance

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Color Night Vision

- CNV is the ability to image in color in the visible-light waveband (VIS) in situations where the human eye and/or typical color video cameras may not perceive color.
- CNV is used in security and surveillance applications where the color of clothing or a vehicle is helpful information for making an ID.
- CNV is also useful in situation where colored signal lights convey information (airports, harbor approaches).
- CNV imaging technologies include CCD, EMCCD, **sCMOS**, EBAPS (and multi-tube I^2).

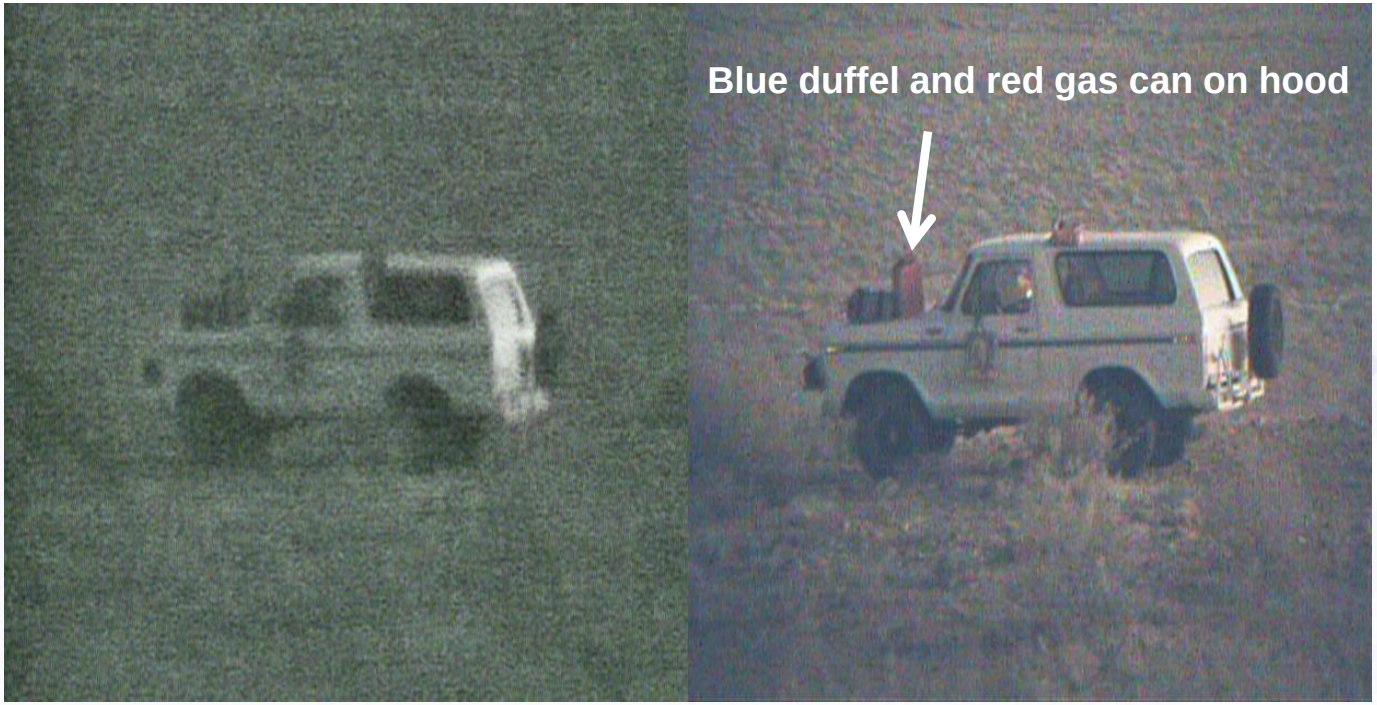
Moonbow formed by full moon and garden hose spray imaged by CNV camera

Dark-adapted eye see a silvery sheen, but no color

Illumination level is about 0.5 lux, or about 3E11 ph/cm^2/s for a sCMOS camera in color mode

Color imaging in low light

Deep twilight conditions (~1 lux). Human eye view looked more like CCD image on left

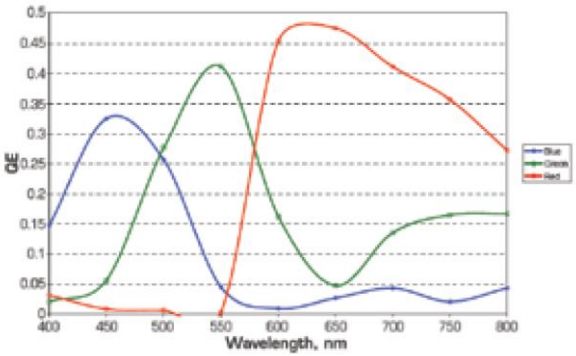


Low-Light CCD Sensor **sCMOS Sensor**

FLIR Tau CNV camera specs

Image Sensing	Color or Monochrome
Pixel Type	6.5 µm² 5T active pixels
Resolution	1280 x 960
Active Area (H x V)	0.33" x 0.26" / 8.3 mm x 6.7 mm
Active Area Diagonal	0.4" / 10.7 mm
Standard Lens Format	2/3"
Dynamic Range	25,000:1
Read Noise (RS mode)	<2e- RMS
Frame Rate / Image Lag	30 FPS @ HD resolution / <0.1%
Anti-Blooming	>1000:1
Shutter Mode	Rolling

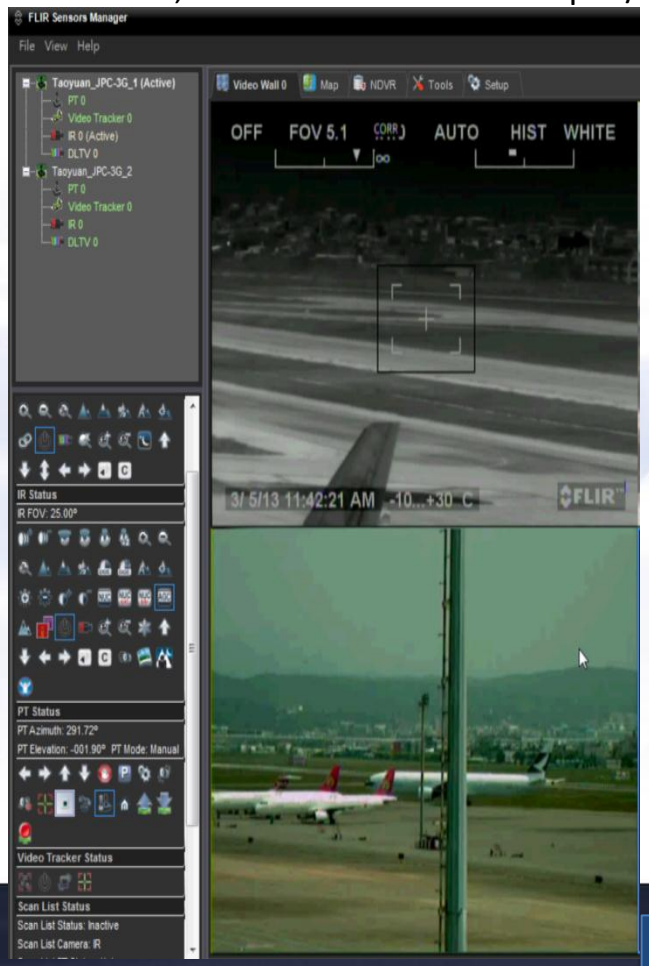
Color



- Camera/lens combination **controls exposure** three ways: motorized iris on lens, auto integration time control, AGC.
  - Camera can image in direct sunlight without saturation.
  - Camera has super low noise so it can also see in very low light conditions!
- Color processing in camera designed to give good **color fidelity** over a wide range of illumination conditions – automatic and stored **white balances**.
  - Direct sunlight
  - Metal halide lighting
- Switching to night filter admits any available NIR radiation (750-1100nm). This gives brighter image

FLIR CNV Systems

- SBA Integration Team has recently integrated the Tau CNV into two long-range camera systems now installed at the Taoyuan Airport in Taiwan.
- These camera systems are called LRV (Long Range Visible) cameras and mount on pan/tilts with HRC IR cameras.
- LRV assembly is water-resistant, has heated window and sunshade, mounts on EVPU MSO-2 pan/tilt units.



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FLIR LRV System

- The FLIR LRV consists of
  - MWIR HRC sensor and zoom optic
  - E/O sensor and zoom optic
    CNV Camera
    Fujinon zoom lens: 16.7 to 2000 mm focal length, auto iris, retractable NIR-only filter
  - Optical stabilization (option)
  - Laser Range Finder (option)
  - Illuminator (option)

- Relative aperture (f/number) varies from F/3.5 to F/18 over zoom range

- Camera/lens combo can be configured to be visible only, visible plus NIR, NIR only
  - Visible only for best color fidelity
  - Visible plus NIR for maximum sensitivity
  - NIR-only mode for seeing through haze and improving target contrast

Commercial security CNV applications

- Tests at SBA indicate Tau CNV **5 times** more sensitive than good CCD camera (Hitachi KP-D5010) under similar test conditions (same lens, f/number, integration time, etc.)

- In areas with little or no man-made illumination, a 30 Hz CNV camera extends color vision around sunset compared to CCDs especially with moon light present

- Zoom lenses get “slow” as you zoom in, so you may not see anything at the zoom setting you want. This light penalty is a factor of 26 for Fujinon D60 lens over zoom range

- In areas with significant man-made light, the Tau CNV can sometimes see color when conventional cameras do not. Good for airports and big parking lots where there is **always** some illumination.

Silicon imaging sensor backgrounds

In-band (silicon sensor) outdoor illumination levels **vary tremendously**:

Illumination Condition	Lux value	Si In-Band Flux Density	Color Temp.
Direct sunlight	100,000	1e17 ph/s/cm^2	5500 K
Sunset	100	1e14 ph/s/cm^2	4500 K
Full Moon	0.1	1e11 ph/s/cm^2	4150 K
“Quarter” Moon	0.01	1e10 ph/s/cm^2	4150 K
No Moon	0.001	1e9 ph/s/cm^2	nightglow, stars
Overcast, no moon	0.0001	1e8 ph/s/cm^2	nightglow, stars

Factor of 1 billion! Huge compared to thermal IR diurnal background variation

Rural Shootout between Tau CNV and Hitachi

- Two identical lenses and lens settings (Fujinon D60, 1000mm FL, f/8.8)
- Camera facing directly away from sunset
- Clear skies, ¼ moon phase, targets at 132 meters

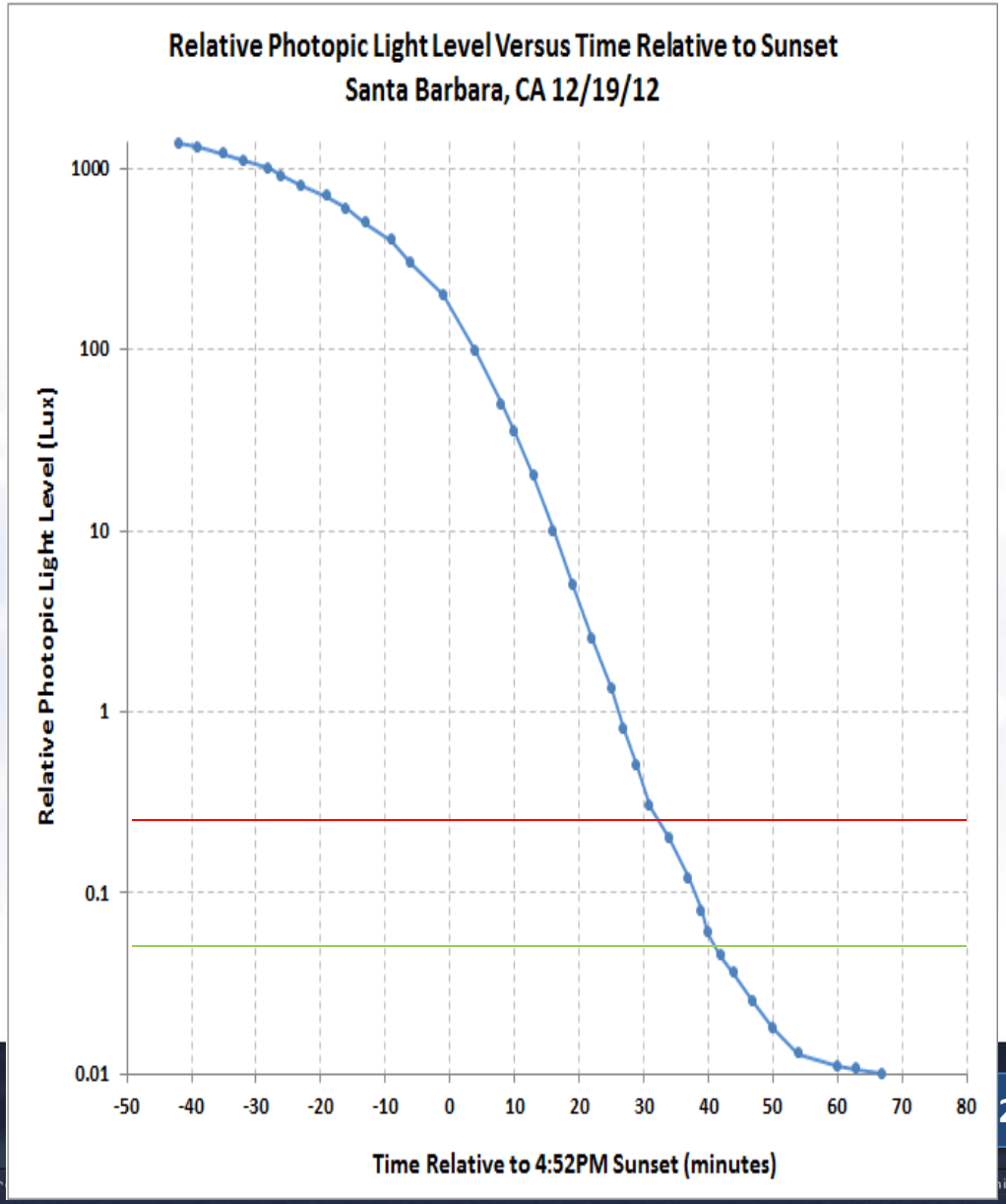
Sunset light curve for rural area

Once the light level got below 10 lux, the camera system was running at maximum sensitivity (33 msec int. time, iris fully dilated)

The light level fell by ~10X every 10 minutes down to ~10 millilux

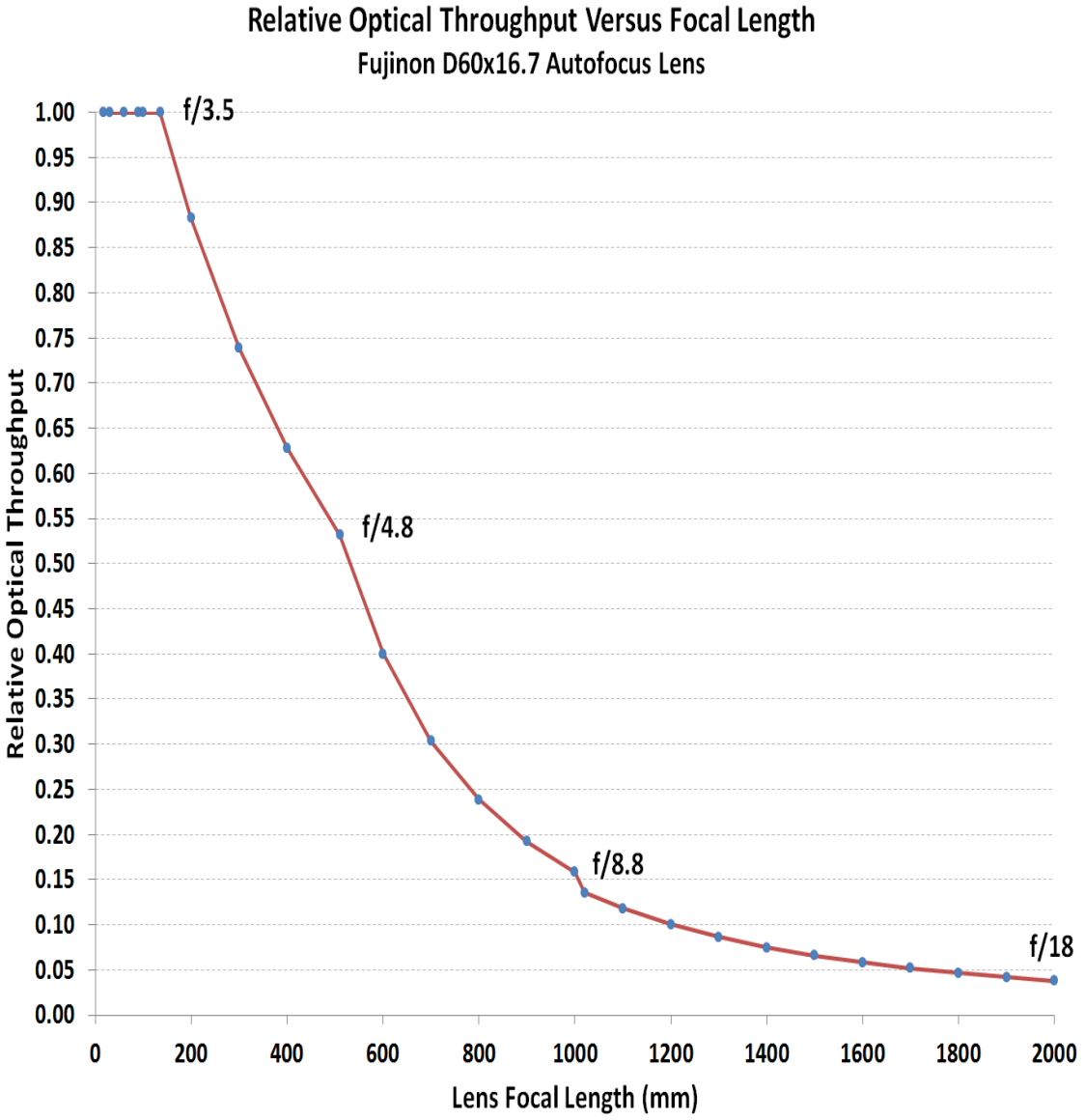
Increasing sensor sensitivity by 10X = an additional 10 minutes of imaging time

The images eventually went dark at 30 Hz frame rates – not enough light



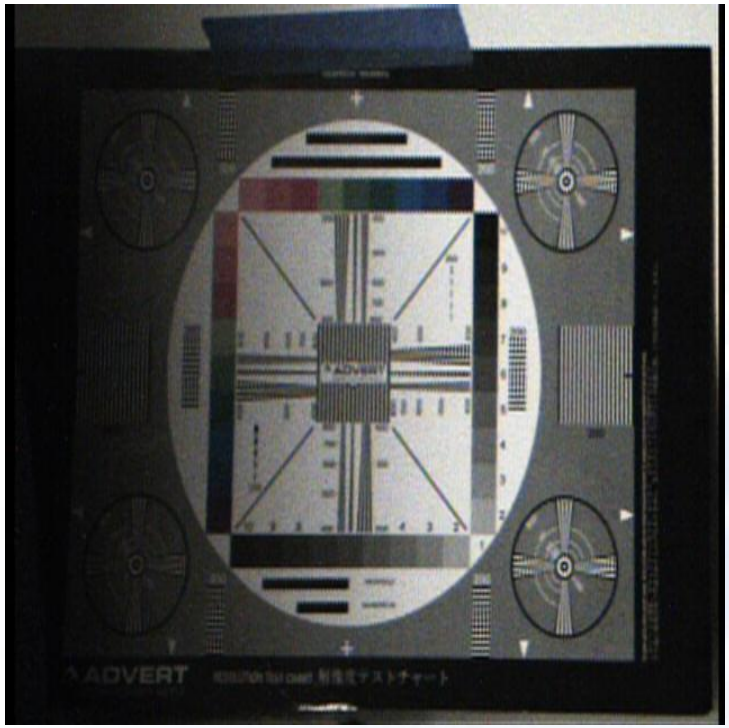
Optical throughput of lens varies with zoom

26X drop in optical throughput over zoom range

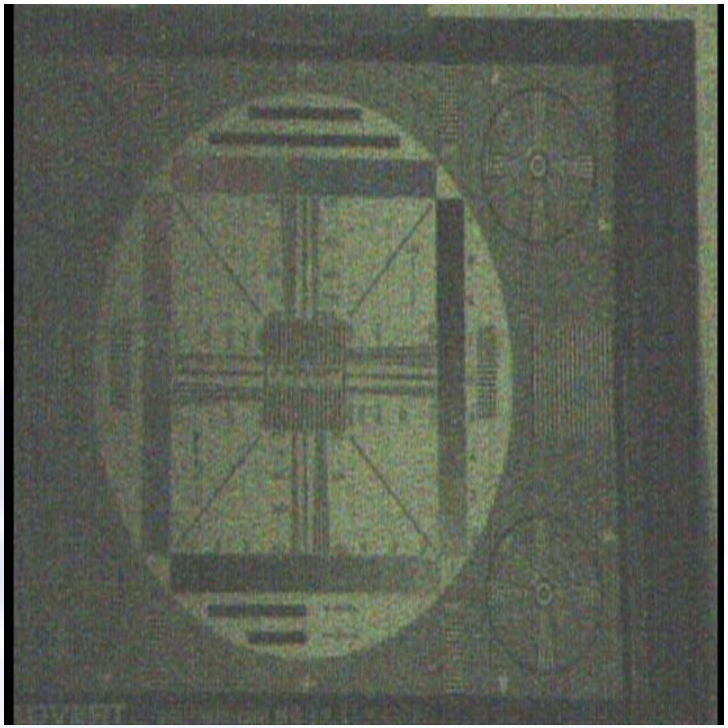


Effect of zoom on image brightness in low light

Light level is 1 lux with 6000 K color temperature
Lens iris is fully dilated



f/3.5 (135mm FL, 10m range)



f/18 (2000mm FL, 150m range)

The maximum relative aperture changes from f/3.5 to f/18 over zoom range of lens

Figure 10a. Left: Hitachi, Right Tau CNV, 4:46PM, 6 minutes before sunset. 300 Lux. Both Lenses' irises probably closed down to f/16 by cameras' auto iris circuits.

Figure 10b. Left: Hitachi, Right Tau CNV, 4:56PM, 4 minutes after sunset. 97 Lux. Note that the background has gone out of focus. This is because the lens iris has fully dilated and the f/number has decreased from f/16 to f/3.5.

Figure 10c. Left: Hitachi, Right Tau CNV, 5:11 PM, 19 minutes after sunset. 5 Lux. More detail is showing on the orange cone surface in the Tau CNV image compared to earlier Tau CNV images. The cameras' exposures are starting to drop and fixed-pattern noise is apparent in the Hitachi image.

Figure 10d. Left: Hitachi, Right Tau CNV, 5:19 PM, 27 minutes after sunset. 0.8 Lux. The signal level is dropping rapidly and noise is now apparent in both images.

Figure 10e. Left: Hitachi, Right Tau CNV, 5:26 PM, 34 minutes after sunset. 0.2 Lux. Contrast is dropping rapidly with time.

Figure 10f. Left: Hitachi, Right: Tau CNV, 5:32 PM, 40 minutes after sunset. 0.060 Lux. The Hitachi image is dark and the license number is no longer legible.

1 Hz frame rate to get longer integration time

Figure 10h. Left: Hitachi, Right: Tau CNV, 5:49 PM, 57 minutes after sunset. 0.013 Lux. Both cameras have been set for 1Hz frame rate operation. The Tau CNV integration time is 966 msec and the Hitachi has Sens Up set to "Autox32", which means that up to 32 frames can be summed as needed.

Then Tau CNV switched to Night filter mode

1 Hz frame rate to get longer int. time

Figure 10h. Left: Hitachi, Right: Tau CNV, 5:49 PM, 57 minutes after sunset. 0.013 Lux. Both cameras have been set for 1Hz frame rate operation. The Tau CNV integration time is 966 msec and the Hitachi has Sens Up set to "Autox32", which means that up to 32 frames can be summed as needed.

Hitachi switched → to 512 frame integration, (or 17 seconds)

Tau CNV has 1 second int. time

Estimate of CNV SNR during rural tests

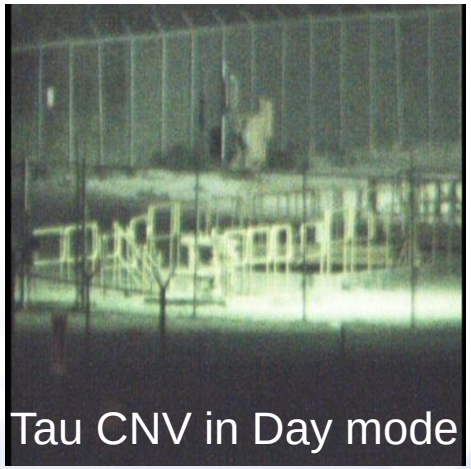
- Used photopic flux calculator to estimate in-band radiance from target
- Calculated photoelectrons through f/8.8 optics for conditions:

Illumination (lux)	Si In-Band Flux Density	SNR	CNV Int. Time (msec)
300	3e14	108	30
97	1e14	62	30
5	5e12	14	30
0.8	8e11	5	30
0.2	2e11	2.3	30
0.060	6e10	1	30
0.013	1e10	3.7	966

Recursive noise filter can pull out details even when SNR is unity.

Urban Shootout between Tau CNV and Hitachi

SBA Airport viewed from 1km. Time is 1 hour after sunset. Visible-band light level is ~1 Lux
Day mode gives better color saturation, Night mode admits more light to sensor



Reading tail numbers

Hitachi 5010

Tau CNV in Night mode

Day Versus Night Versus NIR Only

NIR radiation greatly reduces the readability of the tail number!

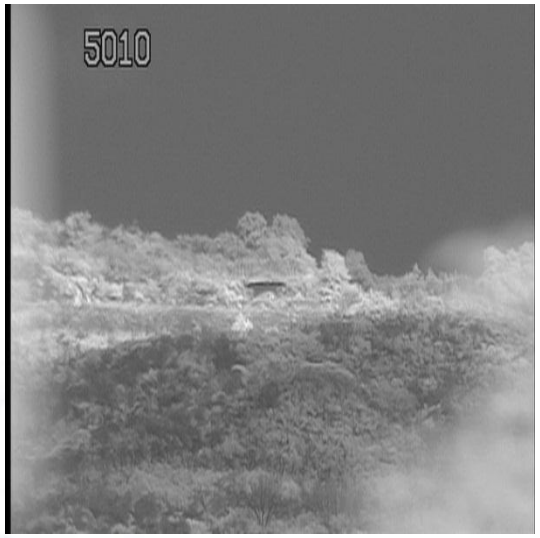
This is why we use day mode filter during the day – cuts out NIR

NIR-Only mode

7000 meter air path with light haze

Target is concrete water tank

NIR mode “cuts through” haze and gives good contrast between target and surrounding foliage



Conclusion

- Tau CNV offers about a 5X improvement in SNR in low light over Hitachi 5010 CCD camera
- Color information improves identification ability
- CNV LRV systems can image in “full moon” (~60 mlux) conditions at 30 Hz frame rates
- CNV LRV systems can image in “quarter-moon” (~10 mlux) conditions but with reduced frame rate
- CNV LRV useful in urban conditions with 24 hour illumination