# Two Types of Fusion
## RHV Electro-Optics, LLC

- Multiplicative Fusion; US10885828B1, 5 January 2021
- Resolution Enhancement of Color Images; US10726531B2,28 July 2020
- Multiplicative Fusion is computationally fast, simple to implement, and highly effective at combining thermal and reflective image features
  - It has been criticized for not performing well with “quantitative metrics”
  - When I looked into the metrics, they have not been verified in any sense
  - The most widely accepted metric is “Mutual Information” which compares the histograms of constituent and fused imagery.
    - Good name
    - If thermal and reflective images are multiplied pixel by pixel, they will share information, but they will not share a histogram.
- In my experience, Multiplicative Fusion is not at all fussy, it does combine image features, and it never produces a bad image from two decent images.
- It’s easy to try it; register the two images and multiply pixel by pixel.
- Multiplicative Fusion examples are shown on the following slides


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**Uncooled thermal with HD resolution**

**Me kneeling at Gordon street building the first time we tried MF.**


**PVS-14 viewed with camera**

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Thermal and visible pictures taken at different locations and times

- •Vehicles not precisely aligned
- •Backgrounds different

•Images illustrate that both thermal and visible details of vehicles are preserved by the fusion process.



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Pictures taken with uncooled thermal and PVS-14 with camera viewing the eyepiece.

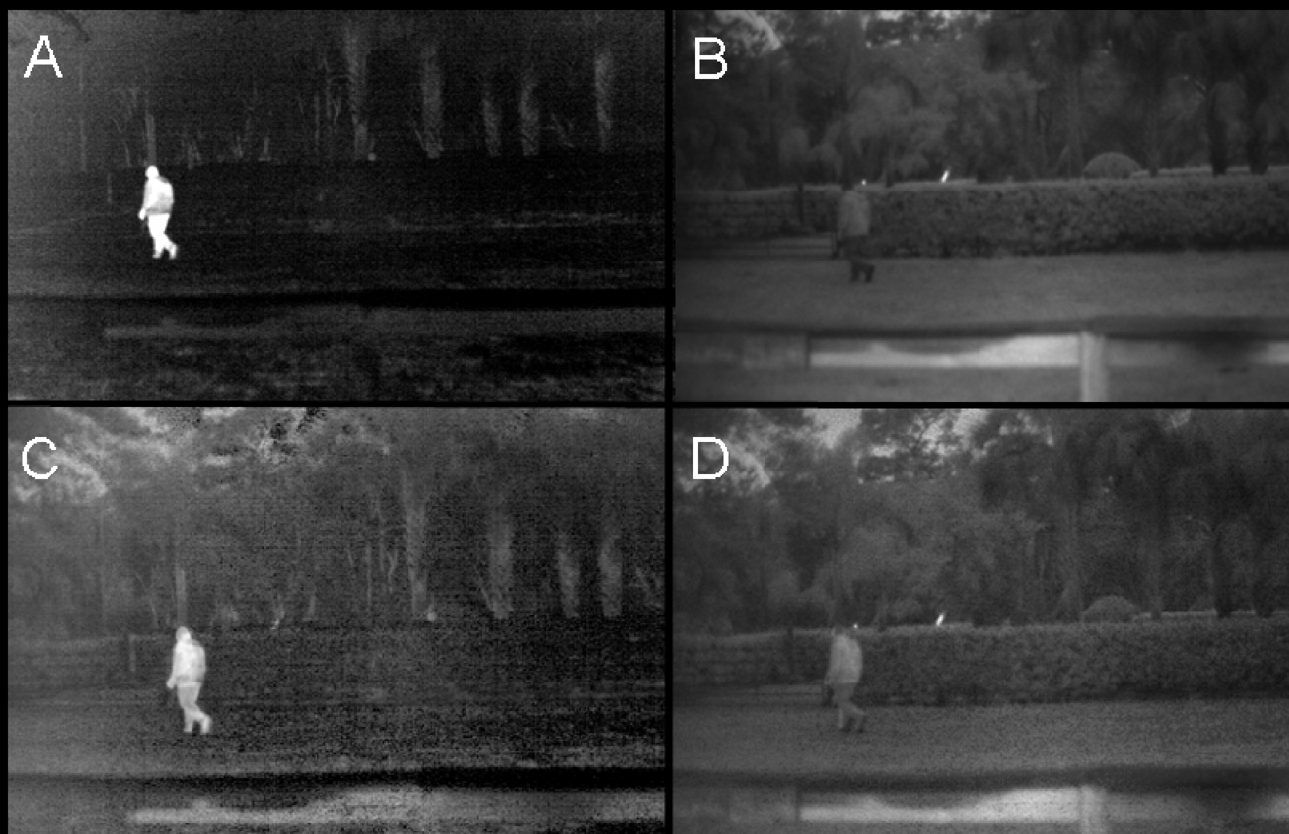
- A woman is standing behind a chair in the living room. That is a robot vacuum on the floor and sunlight on the wall.
- Hard to see, but there are two vertical lines on the wall behind the woman. Those are metal wall studs showing up from the thermal image.


The imagery fused in these figures is part of the NATO_camp_sequence from the TNO_Image_Fusion_Dataset available at https://figshare.com. Rows A, B, and C are thermal, visible, and fused images, respectively. The person is walking in front of a fence and he is hard to see in the visible imagery. The fused imagery makes the person visible and puts him and the fence into spatial perspective.

Top row shows pictures taken at night after a clear day with ample insolation. Both the I2 and thermal cameras were providing clean imagery. In the top row of pictures, I was walking near two miniature cows. Pictures A, B, and C are thermal, I2, and fused respectively. The cows and person are highlighted in the thermal image, whereas the gate lights are seen in the I2. All of those features appear in the fused picture.

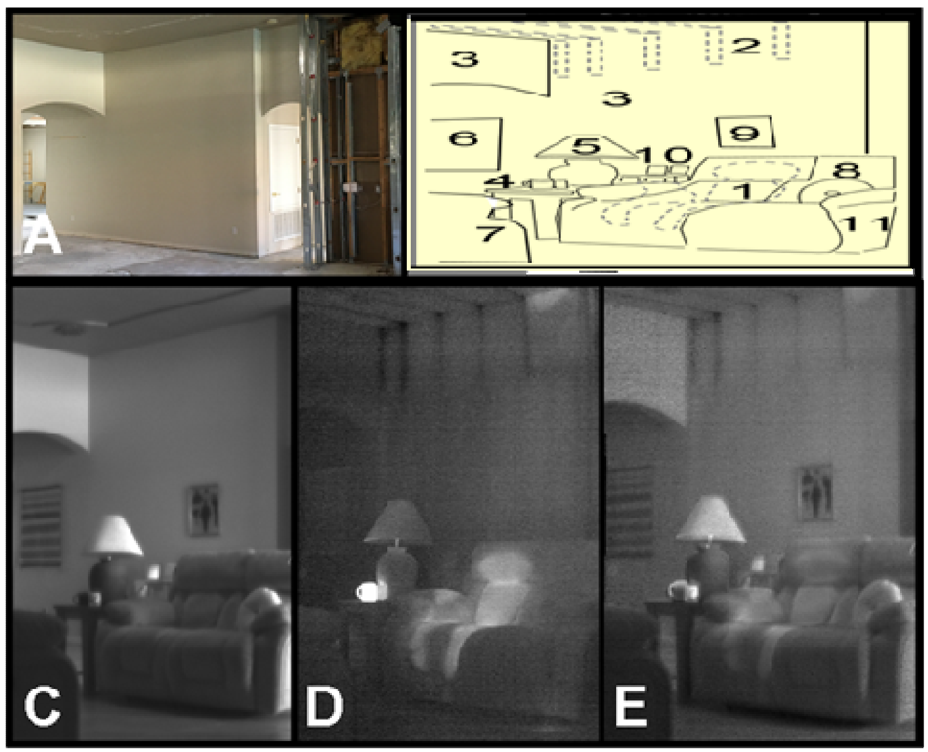
In the middle row, I have a flashlight and am examining the pasture gate. In the bottom row, the flashlight is pointed directly at the cameras. The thermal images are D and G, the I2 images are E and H, and the fused images are F and I. The lights are not visible in the thermal imagery, but shining the flashlight at the cameras clamps down the I2 gain, and that makes the people and animals hard to see in the NIR imagery. People, animals, and lights are all visible and in visual context in the fused images.

The imagery below was taken on a rainy night after a day of rain. The streetlight still provided ample illumination for the I2, but the thermal imagery was noisy. The thermal image is shown in A and the I2 in B. The fused image in C was generated ignoring the thermal noise whereas an adjusted fusion algorithm was used to generate the fused image in D. Note that the author walking through the pasture is brighter in C than in D, but the D image quality is much better than C.



The picture was taken with the house under construction and shows the metal studs used in the walls. In the summer with the air conditioner on, the studs absorb heat from the attached wall material, creating a thermal signature where the studs contact the wall. The pictures C, D, and E at the bottom are I2, thermal, and fused, respectively. B is a map of the objects in the area pictured.

The dark lines on the walls (2) in the thermal image are caused by the metal studs absorbing heat. The cartoon-like thermal signature (1) on the couch (11) resulted from the author sitting on the couch before getting up and taking the pictures. Item (4) consists of two coffee cups, one with hot water and the other filled with cold water. The rug (6) and picture (9) are visible in the I2 image but not the thermal. The fused image shows the NIR features like the rug, picture, and coffee cups along with thermal features like the body-heated area of the couch and stud signature on the wall and ceiling.

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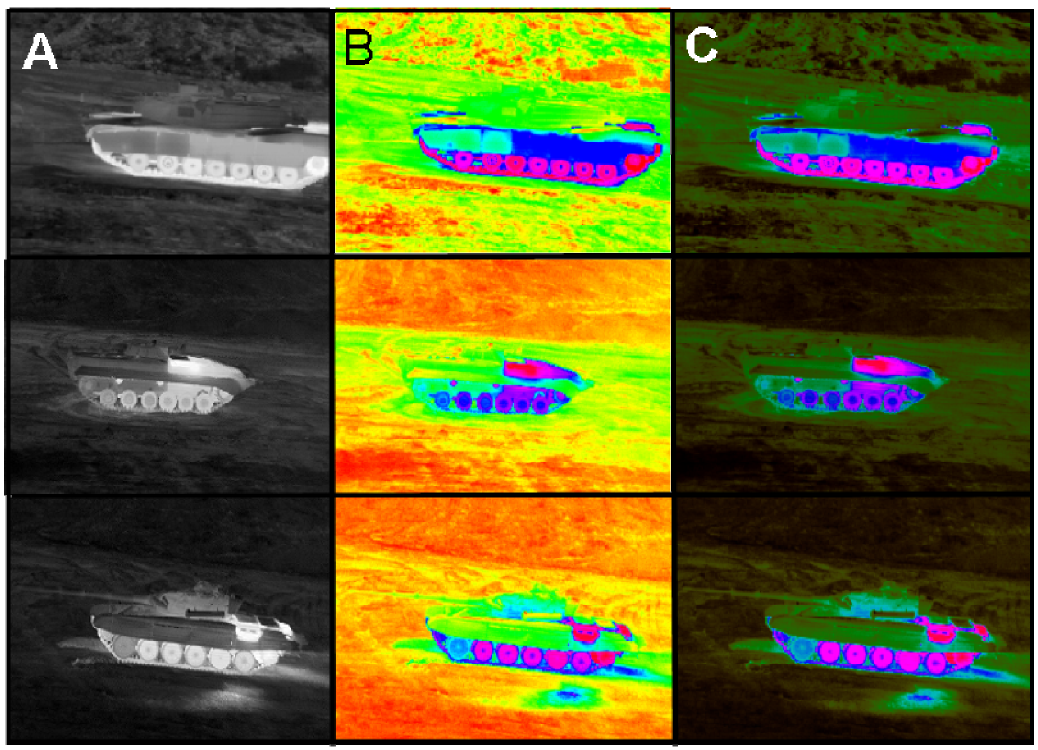
In this figure, there are three thermal images in Column A, and Column B shows color map conversions based upon hue, saturation, and value (HSV). The images in row C fuse A and B. The color mapping in B degrades image contrast and, in certain areas, makes the structure in the original image difficult to see. Figure C illustrates that fusion restores the image structure, making both the color map and object shape more visible.

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- Calculation of the Multiplicative Fusion algorithm is fast because it only involves multiplication of thermal and NIR pixel intensities.
- The examples presented in this brief illustrate that the MF algorithm effectively combines thermal and NIR image details into a single image.
- Some might argue that the numerical values for commonly used image quality metrics should be calculated and provided for reader assessment.
    - However, commonly used metrics quantify similarity between pixel intensities or histograms of the constituent and fused images.
    - For the examples presented in this paper, the histograms are not sufficiently alike to obtain a good value of the Mutual Information metric.
    - Empirical data supporting the correlation between image metric values and fusion algorithm performance has not been published. Further, an a priori postulate that image histograms quantify how well thermal and reflective features have been combined for human understanding is not warranted.
    - It does, however, seem reasonable that metrics like Mutual Information are valid for applications where the images are supposed to be alike. For example, to evaluate compression algorithms.
- Based on Shannon's definition of information capacity, the MF image combines all of the information from both the thermal and reflective constituent images.
- Whether the information is combined in a manner that is visibly cognizable cannot be quantified without a better understanding human vision or a series of perception experiments.

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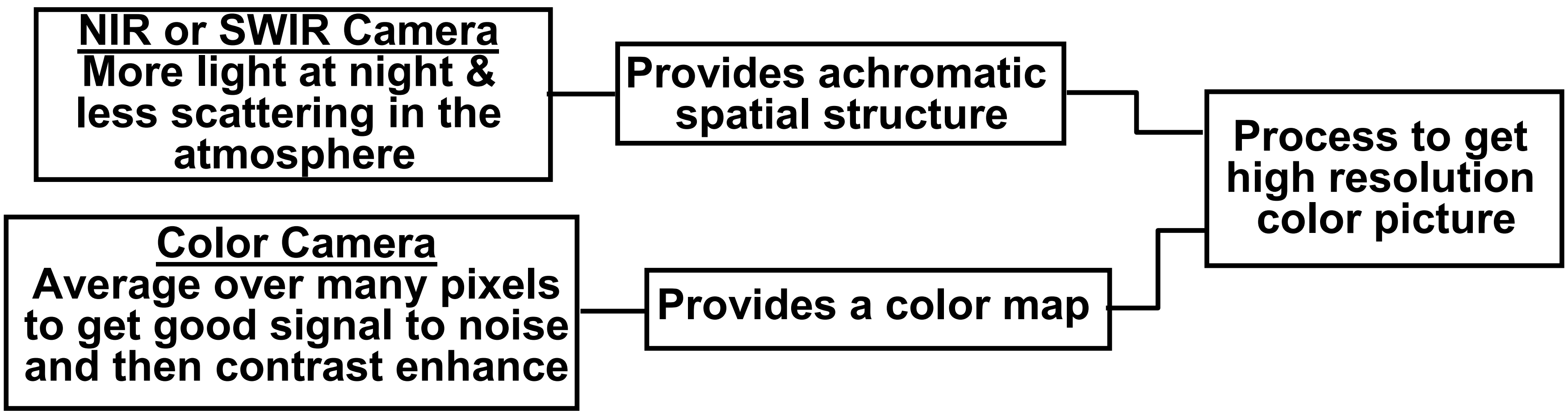
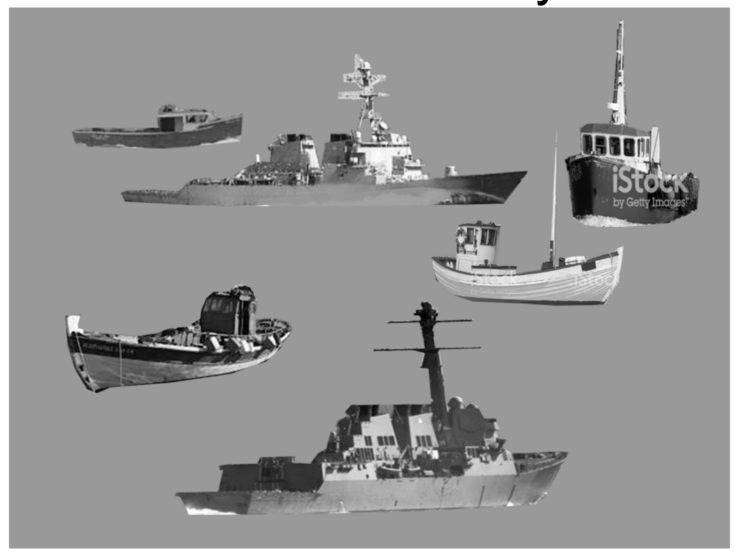
- **Color Enhancement** improves color rendition when scenes are viewed at long range through the atmosphere.
- Color enhancement also adds color to night imagery.
- The algorithm assumes that a sensor suite has both a color camera and a near infrared (NIR) or short wave infrared (SWIR) camera.
  - The cameras do not need to have the same field of view. or be pixel-to-pixel registered.



# Benefit of color is hard to quantify
# <u>but subjectively highly valued</u>

- Hard to say that the colored boats are easier to identify




- On the other hand, where's the fire?

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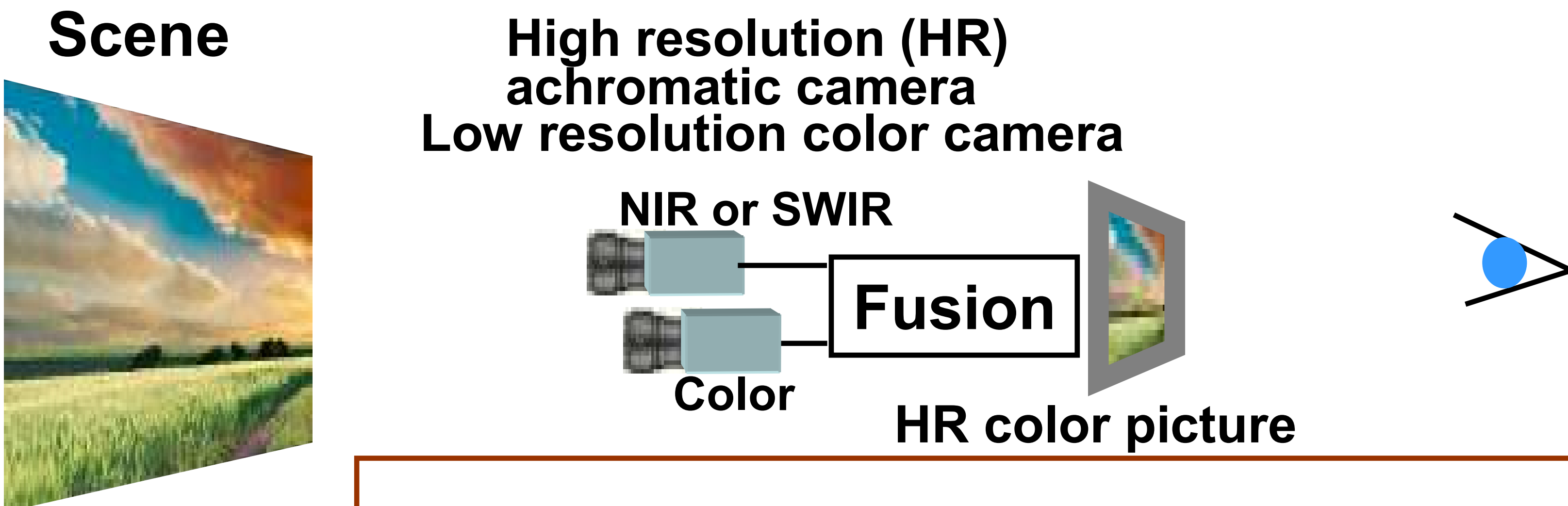
# Color restoration logic


- Do we need to sense HR color if the eye does not use it?
- Low resolution color is sensed with larger and fewer pixels, so we get better signal to noise, and that makes it easier to contrast enhance the image and restore the color.

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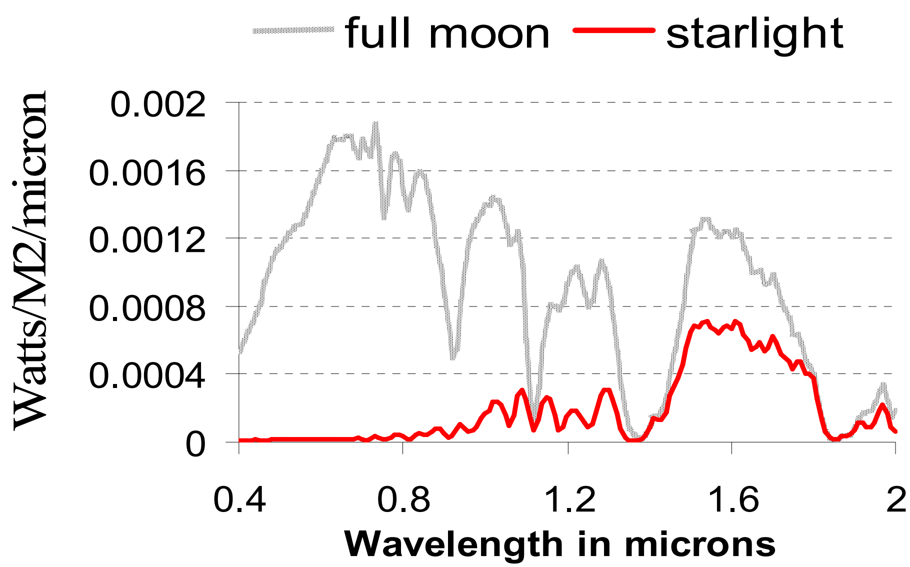
# Problem with imaging color at night




- On a dark night, there is not a lot of light in the color spectrums
- “Starlight” has strong NIR and SWIR content from airglow
- Starlight color video with good signal to noise can be achieved using large pixels or by summing many small pixels
- Can get high resolution NIR or perhaps SWIR imagery
- Fuse low resolution color with high resolution NIR or SWIR to get high resolution color at night

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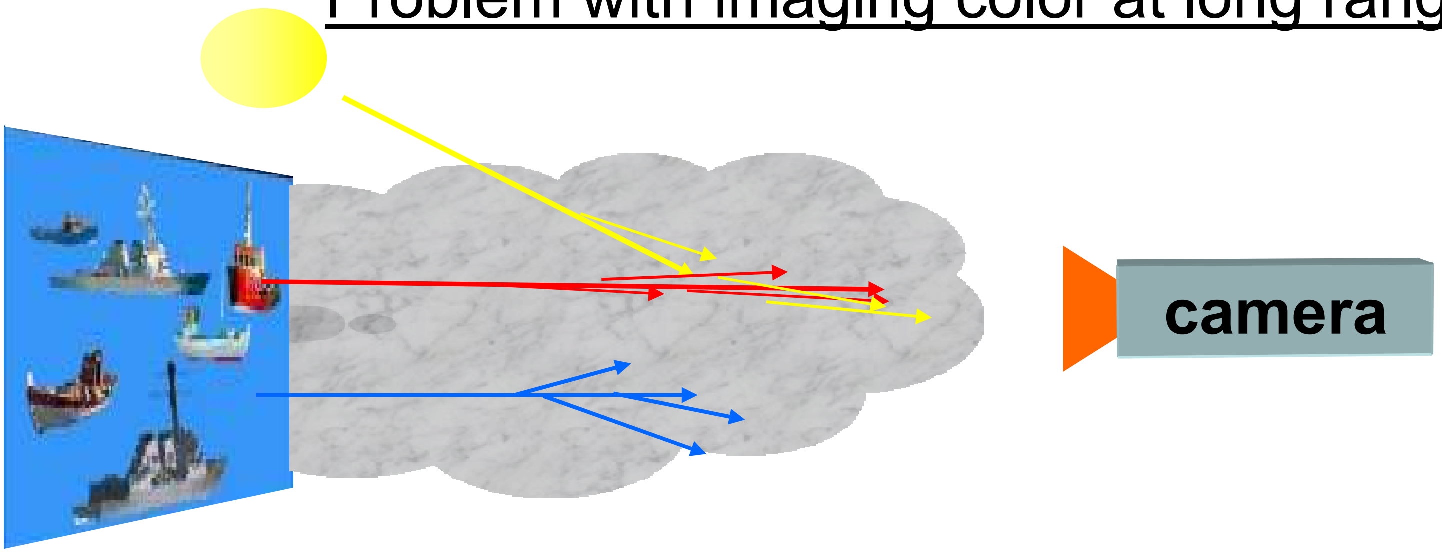
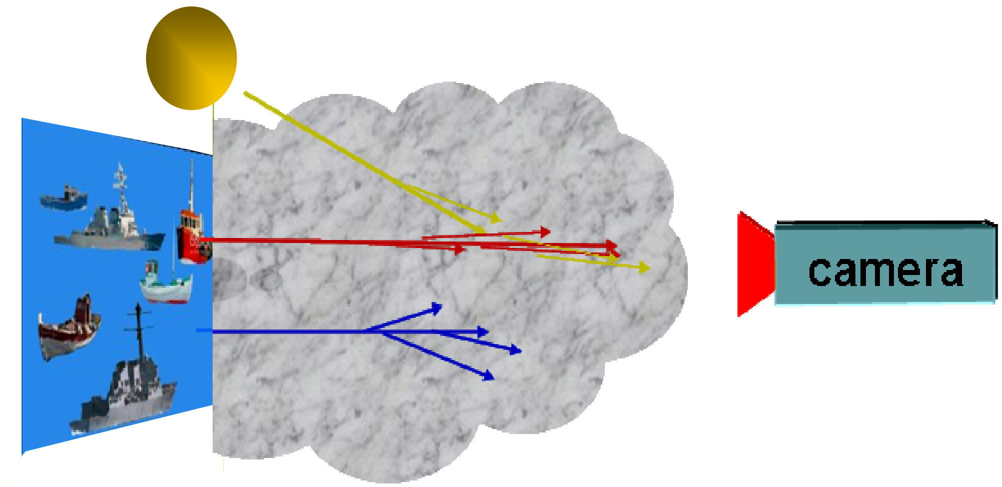
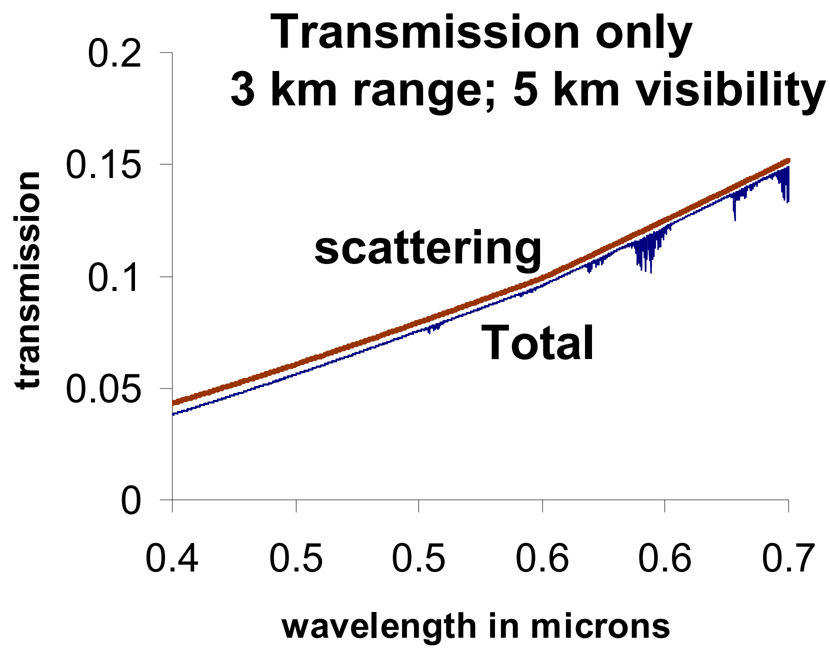
<u>Problem with imaging color at long range</u>




- In the atmosphere, blue scatters more than green which scatters more than red which scatters more than near infrared
- Scattered light is mainly scattered forward
  - Scattered light reaches the camera but at the wrong entrance angle
  - So colors mix together: contrast drops and color becomes constant
  - The bright flux creates shot noise that limits contrast enhancement

# Example of the problem with sensing color at range




- Color contrast at range is very low
  - In graph at right, absorbed is the difference between scattered and total; most visible light is scattered
  - Sunlight scattered into line of sight creates strong path radiance
  - Even at 3 km, target contrast is < 0.02 and probably 0.002.
    - Pixel signal to noise about 0.2:1 at most and might be 0.02:1 for a high resolution color camera with the sun as shown at top left.
- Getting color at long range requires dealing with very low contrast and poor signal to noise
- Many factors have a strong influence on the color signal at range

# Color fusion

- Get a “color map”  by averaging over many pixels of a high resolution color camera or by using a focal plane with large pixels
- The NIR or SWIR penetrates the atmosphere much better than color and provides the necessary spatial feature set.
- Also, there is more light at night in the NIR and SWIR and therefore a higher resolution image than possible with color
- Process the NIR/SWIR and color images to get a high spatial resolution color picture of the scene.

Original


Achromatic


Blurred 10:1


Restored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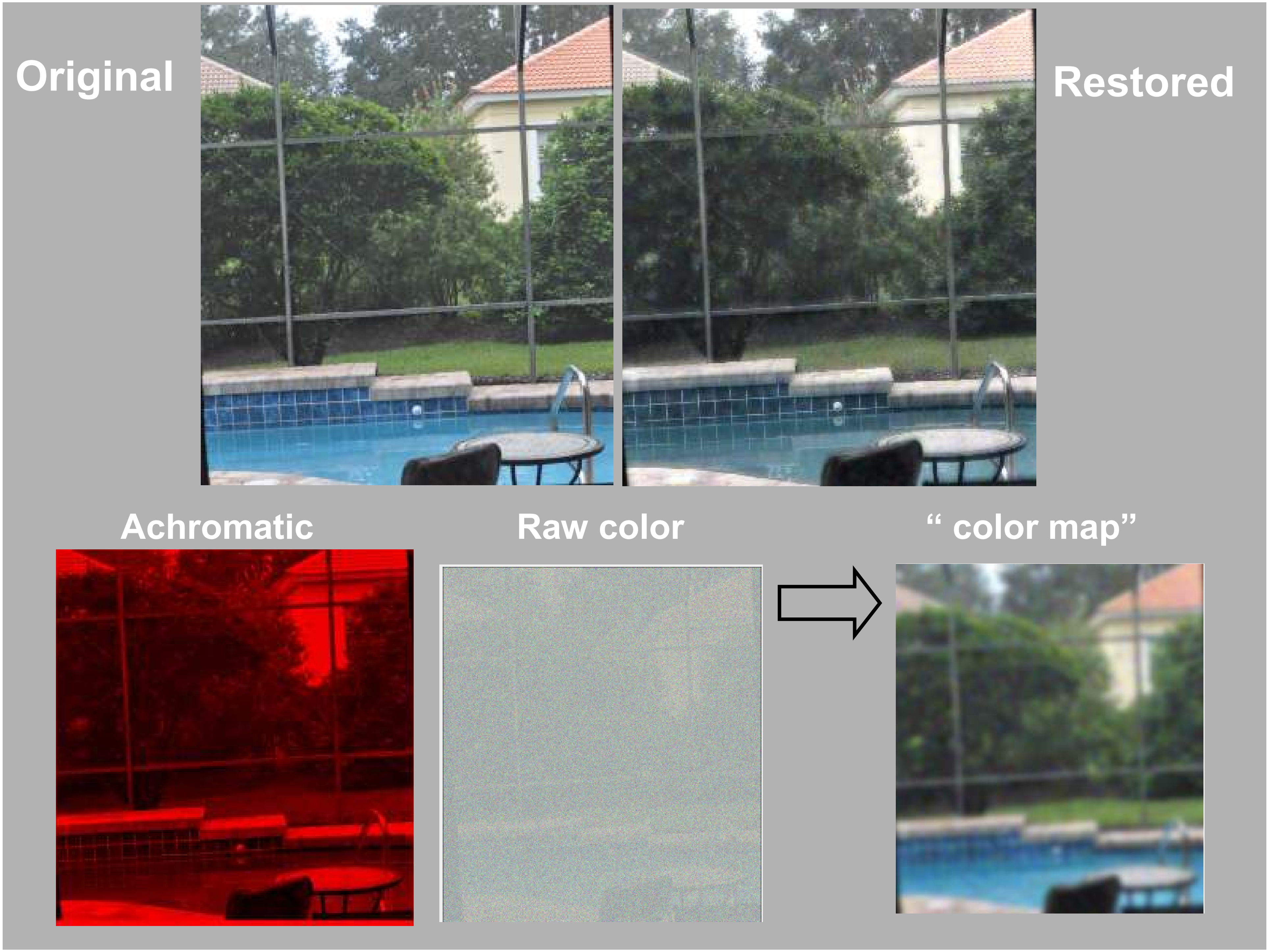
# Example Using a digital Camera

- The pictures on the following slide were taken with a digital camera.
- The achromatic picture had a NIR filter over the lens that completely blocked the color.
- The original color image was processed to reduce contrast and add noise to produce the raw color picture.
- The raw color picture was filtered (blurred) in order to get rid of the noise and enhance color contrast.
- Multiplicative Fusion produced the picture at top right.
- Slide after next illustrates that a few pixel offset between blurred color and achromatic is not important.


Original
Restored
Achromatic
Raw color
" color map"

# Effect of achromatic to color offset on restored picture

**Pictures are 440 by 800**

**Zero pixel offset each direction**

**Five pixel offset each direction**

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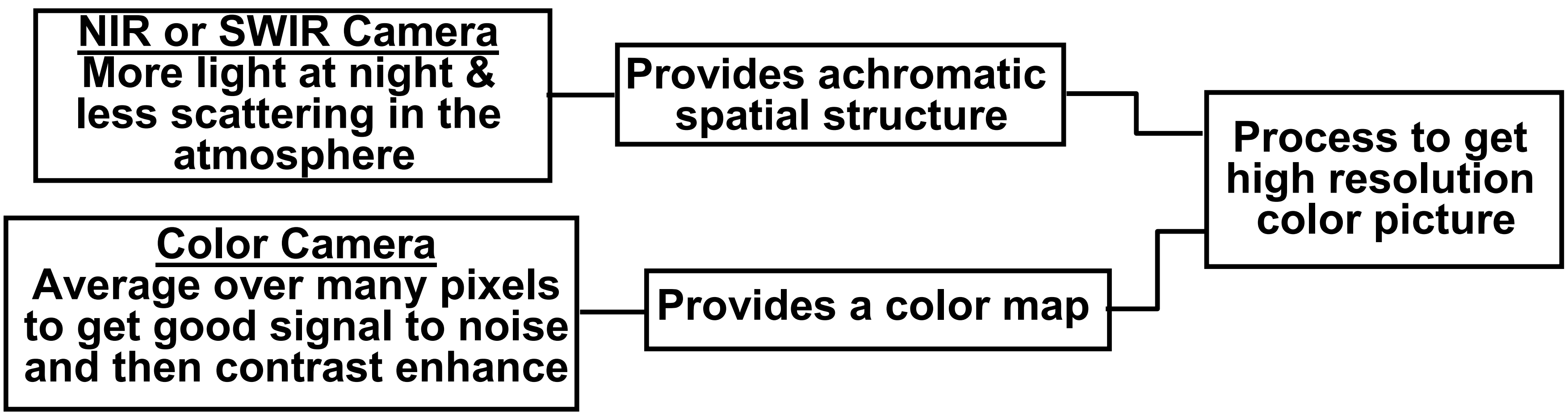
# Summary of concept

- “Panchromatic sharpening” is not a new idea and has been demonstrated
  - Also, there’s some nice technology on the market using it.
- We have a simple and effective algorithm for color sharpening,
- By combining color sharpening with NIR and SWIR imagery we are expanding both night color and long range day capabilities
- Since pixel level registration is not required, the display algorithm is easy to apply to sensor suites using separate NIR/SWIR and color cameras

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