Impacts and Mitigation Strategies of Sun Exposure on Uncooled Microbolometer Image Sensors

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Abstract

This paper provides results from testing and analysis of sun exposure effects on amorphous silicon (α-Si) microbolometers and vanadium oxide (VOX) microbolometers and cameras. Gain and offset changes on the video signal for each detector material type due to sun exposure is provided.

Results from different sun exposure levels corresponding to different geographic locations and time of year are presented. Data associated with increasing exposure duration and number of exposures is also presented. The time constants associated with the decay of the sun exposure effects are also provided. Processes and algorithms that mitigate the impact on image quality are presented and their effectiveness measured.

Introduction

Thermal imaging cameras based on uncooled microbolometers are becoming widely used in video security applications. These cameras can be deployed in fixed and pan/tilt configurations. A typical pan/tilt version is shown in Figure 1. Since the sun can enter into the field of view for these applications, it is important to understand and to mitigate the effects of solar exposure in the camera design process.

This paper quantifies the effects of sun exposure on Vanadium Oxide (VOX) and amorphous silicon (α-Si) thermal cameras. The VOX camera has an F#1.3 lens with a 14.25mm focal length, 320x240 format, and 38µm pixel pitch. The α-Si camera has the identical lens (F#1.3 with14.25mm focal length), 384x288 format, and 25 µm pixel pitch.

It is shown here that both VOX cameras and α-Si cameras exhibit similar behavior with respect to pixel gain and offset changes when pointed at the sun. Real world and controlled lab test results are presented.

Once detected, sun exposure effects can be dynamically corrected to eliminate adverse impacts on image quality. In addition to the immediate impacts on image quality, it is important to determine if any permanent damage has been done to the microbolometer which might lower the sensitivity of the microbolometer. Camera design considerations need to be made so the dynamic range of the camera needs to accept the additional offset in the microbolometer video signal due to the sun exposure.

Figure 2 schematically shows the structure of a single pixel of a microbolometer. The pixel physical configuration is similar between VOX and α-Si microbolometers. The sensing material (VOX or α-Si) is a very thin membrane (on the order of 100 nanometers thick) suspended above the readout IC structure (ROIC). These membranes are thermally isolated from the ROIC structure to improve sensitivity and decrease response time. When exposed to the sun, these pixels heat quite quickly. For both VOX and α-Si, this temporarily changes the resistivity of the material, and consequently changes the gain and offset associated with the sun exposed pixels.

Figure 3 shows a thermal camera that has had 45 consecutive days of solar exposure without any correction being applied. Similar effects are seen for both VOX and α-Si cameras (this particular example is for the α-Si camera). Figure 4 shows the resulting image quality obtained after correction based on a single shutter operation is applied. The image in Figure 4 is stretched to maximum contrast and shows no residual streaks remain after applying the correction algorithm.

Figure 1. Pan/Tilt Thermal Thermal Security Camera

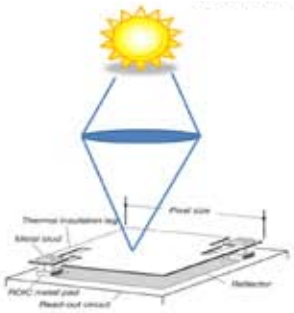

Figure 2. Pixel Physical Configuration

Figure 3. Uncorrected Image

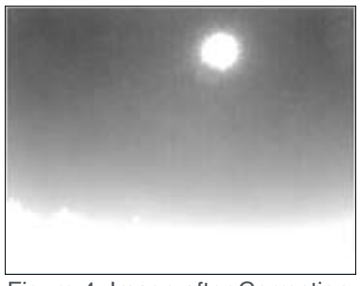

Figure 4. Image after Correction Applied

Real World Testing

A VOX camera was exposed outdoors to the winter sun on January 28th, 2011 in Colorado. Figure 5 shows an image from the VOX camera after it has been exposed to the sun twice, each for 45 days. A single shutter image taken between the sun exposures was used to correct the offset and the corresponding gain values were corrected algorithmically based on the offset values obtained. After two sun exposures, the camera was then taken back inside and setup to image two black body sources and the interior scene shown in Figure 5. The sequence of exposures and correction was as follows:

Figure 5. Effects of Two Sun Exposures on a VOX Camera

1. Expose VOX camera to sun three times for 3 hours each exposure (Represented by black streaks in the image in Figure 5.). Not allowing the camera to shutter or correct for solar exposure between exposures.

2. Shutter the camera once to allow the VOX camera to correct for solar exposure.

3. Expose VOX camera to the sun once for one hour. Not allowing the camera to shutter or correct for solar exposure.

4. Capture image. (Shown as Figure 5).

The three black streaks (one very dark, two fainter) shown in Figure 5 are from the first sun exposure events that were corrected one hour prior to the image shown. Initially after the single correction is applied, these streaks went away, but without additional correction, over time the changes in gain and offset will begin to return towards their original value and the initial correction values applied are no longer correct (too much correction is being applied leading to the black streaks).

The white streak in Figure 5 corresponds to a second sun exposed area without any correction being applied. Using the blackbodies in the scene for calibration, it is possible to convert the sun impression into an equivalent change in degrees Celsius. In this case, the intensity of the uncorrected, sun imprinted white streak corresponds to a 19°C temperature difference.

Sun Exposure Lab Testing

Sun exposure can vary dramatically as a function of latitude, time of year, weather and other atmospheric conditions. The nominal equivalent to one sun solar radiation is defined as approximately 1 kW/m^2. The range of thermal energy can vary by a factor of 4X due to the conditions mentioned above.

To quantify the effects of sun exposure and to provide a quantitative comparison between VOX and α-Si camera technologies, a laboratory light source capable of generating photon fluxes and energies comparable to the sun must be used.

For these experiments, a high intensity carbon arc source was used to mimic the effects of sun exposure. The temperature of the sun source is varied between 2200°C to 2500°C, corresponding to highest (worst case) sun illumination levels. A solar simulator temperature of 1900°C of this equates to 1.2 times the peak value of the sun over a one year period times for Southern Europe. A solar simulator temperature of 2500°C corresponds to a peak value of sun over a one year period for Colorado in the USA.

VOX Camera Artificial Sun Source Testing

Using the artificial sun source, the VOX camera test sequence is as follows:

1. Expose 3 spots on the VOX camera to sun source set at 2500°C

2. Turn VOX camera to black bodies and take images

3. Turn camera back and expose spots to sun target now set to 2200°C

4. Turn VOX camera to blackbodies and take images (shown below in Figure 6)

5. Apply sun exposure correction to end sun-exposure time for 2200°C and capture image

6. Compute the impression of the 2500°C image right after exposure

7. Compute the impression of the 2200°C image right after exposure

8. Since the 2500°C image was taken first, the “relaxed” imprint is visible in the 2200°C image. The decay of the 2500°C spot is measured 27 minutes later

There was no detectable sun impression in the image from the VOX camera immediately following shutter compensation (shown in Figure 7).

Table 1 – VOX Camera Sun Impressions - 2500°C Impressions

Time	Top Left (°C)	Top Middle (°C)	Top Right (°C)
Initial	19.1	20.8	23.6
27 Minutes After Exposure	15.1	16.1	16.8

Table 2 – VOX Camera Sun Impressions - 2200°C Impressions

	Bottom Left (°C)	Bottom Middle (°C)	Bottom Right (°C)
Initial	13.3	14.3	16.0

Figure 6. VOX Camera after 2200°C and 2500°C Exposures before Correction

Figure 7. VOX after Shutter Correction

α-Si Camera Imprint Decay versus Time Without Non-Uniformity Correction (NUC) Applied

Using the α-Si camera, this experiment is a set of 100 images of the shutter (without NUC) taken over a 9 minute time period immediately following a 2 minute exposure to a 2350°C spot exposure from the sun source. The median spot value and median background value for each image is taken over 8 minutes. The left half of Figure 8 shows the results during this 9 minute period, the solar imprint drops by 7.3°C.

α-Si Camera Imprint Decay versus Time with Non-Uniformity Correction Applied

Using the α-Si camera, this experiment is a set of is a set of 100 images of the shutter (with NUC) taken over a 9 minute time period. The median spot value and the median background value are calculated and shown in Figure 8. As shown in the right half of Figure 8 during the time period of 9 minutes to 18 minutes, the solar imprint drops 1.9°C.

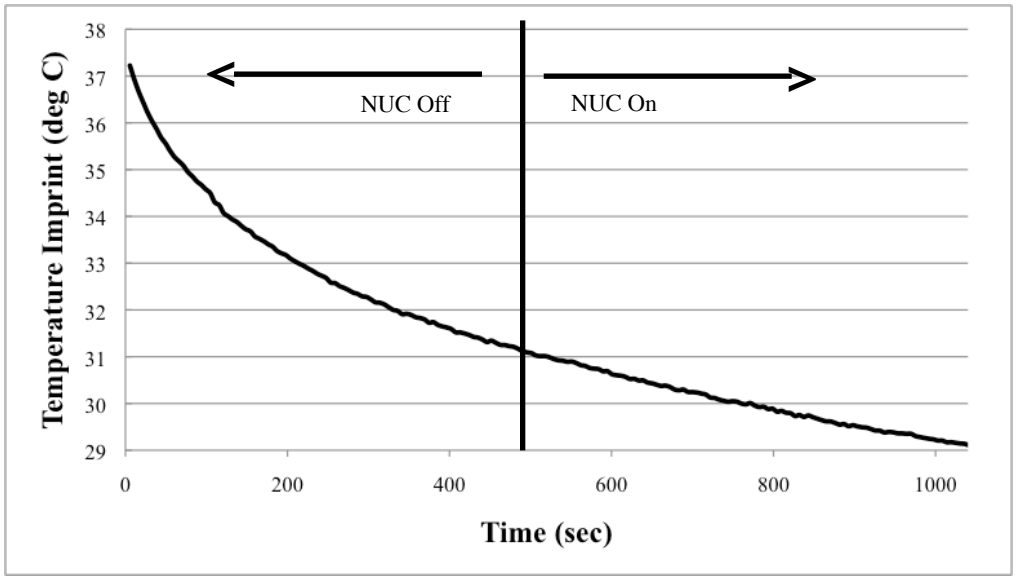

Figure 8. Imprint Decay versus Time for α-Si w/o NUC

α-Si Camera Temporal Noise with NUC but without Sun Compensation

Using the α-Si camera, this experiment is a set of 100 images of a scene with blackbodies (with non-uniformity applied, but no sun compensation) taken over a 26 second time period. The median spot value for was calculated for the first and last image and the temporal noise of the spot and the background was calculated. Figure 9 is one of the 100 images.

Figure 9. Image 2350°C with NUC but without Sun Exposure Algorithm

α-Si Camera Temporal Noise with NUC and Sun Compensation

Using the α-Si camera, this experiment is a set of 100 images of a scene with blackbodies (with NUC applied and sun compensation) taken over a 31second time period. The median spot value is calculated for the first and last image and the temporal noise of the spot and the background is calculated. The median temporal noise is calculated for the spot and areas near the spot across the 100 images.

Table 3 - Temporal Noise Measurement On and Near the Sun Spot

Location	**Temporal Noise F#1.0 Equivalent**
Spot	49mK
Left of Spot	50mK
Right of Spot	50mk
Top of Spot	51mK
Bottom of Spot	50mK

Conclusion

VOX and α-Si behave similarly with respect to effects associated with solar exposure. Time constants associated with decay extrapolate into time periods of weeks for both technologies. Algorithms substituting a new offset value obtained by post exposure shuttering and adjusting the pixel gain based on differences between pre and post exposure offset are effective at removing image artifacts. To maintain image quality for both technologies, multiple shutter operations are required to update gain and offset changes as the pixels return to pre-exposure values. For the particular a-Si and VOX cameras studied, no increase in temporal noise is noted in areas that have been exposed to high levels of solar illumination.

References

1. Biancardini, JJ., “Infrared microbolometer sensors and their application in automotive safety”, AMAA, November 2003

2. FLIR Technical Note TN-006, “Are Thermal Cameras Damaged by Solar Radiation?”

3. Liger, M., “Uncooled Carbon Microbolometer Imager”, PhD Dissertation, Caltech, 2006

4. Howell, P. A. “Infrared On-Orbit Inspection of Shuttle Orbiter Reinforced Carbon-Carbon Using Solar Heating”, SPIE Optics and Photonics 2005, 31Jul. - 4 Aug. 2005

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