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The Need for Image Processing In Infrared Camera Design

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ABSTRACT

While the value of image processing has been longly recognized, this is usually done during post-processing. For scientific application, the presence of large noise errors, data drop-out, and dead sensors would invalidate any conclusions made from the data until noise-removal and sensor calibration has been accomplished. With the growing need for ruggedized, real-time image acquisitions systems, including applications to automotive and aerospace, post processing is not an option. In some instances, the operator does not have the opportunity to view the cleaned-up image. Focal plane arrays are plagued by bad sensors, high manufacturing costs, and low yields, often forcing a six digit cost tag. Perhaps infrared camera design is too serious an issue to leave to the camera manufacturers. Alternative camera designs using a single spinning mirror can yield perfect infrared images at rates up to 12000 frames per second using a fraction of the hardware in the current focal-plane arrays. Using a 768x5 sensor array, redundant 2048x768 images are produced by each row of the sensor array. Sensor arrays with flawed sensors would no longer need to be discarded because data from dead sensors can be discarded, thus increasing manufacturing yields and reducing manufacturing costs. Furthermore, very rapid image processing chips are available, allowing for real-time morphological image processing (including real-time sensor calibration), thus significantly increasing thermal precision, making thermal imaging amenable for an increased variety of applications.

Key words: Infrared thermography, focal-plane arrays, image processing, infrared cameras.

1. INTRODUCTION

During recent years, substantial progress has been made in the development and application of infrared imaging, however, I feel that the industry has penetrated only a fraction of the potential market. Part of the difficulty is the high cost of infrared cameras. For exterior applications, thermal precision is not so much of an issue because surface temperatures can vary widely with even small convection currents and wind. The new ruggedized instruments work well for exterior applications. While the cost would probably reduce with high volume purchases, at the present time, the user is forced to pay up to \$100,000 for an instrument with low visual resolution and now thermal resolution. For scientific application, the choices become more limited. Part of the problem seems to be the heavy investment in focal plane arrays, most of which are plagued by dead sensors, and non-uniform sensor response. One should point out that the presence of a single bad sensor can make the entire system useless for automated scientific applications.

The mindset of many manufacturers seems to be to produce cameras. It is only recently that some of the manufacturers have begun to incorporate noise corrections in infrared camera design to correct some of the more glaring errors. With the recent advances in integrated circuitry, there now exist chips which can correct, in real time, most of the errors which exist in many of the thermal imaging systems. Some of the chips cost as little as \$20. These chips can identify and remove snow and bad sensor data. With a few modifications to the camera hardware, the the selection of appropriate image filters the potential exists to produce *perfect* thermal images at rates in excess of 1000 frames per second, or higher if need. All of this can be done without increasing the basic cost. In some cases, the designs will simplify sensor design with potential to decrease manufacturing costs. This paper contains a methodology of these image filters and camera designs.

Because frame rate is not an issue with the new infrared camera designs, thermal resolution can be significantly improved by combining data across several frames before displaying it. Such a system would limit real-time snow in the image. I feel that the promotion of poor resolution instruments has given the entire thermography industry a

bad name. The new now-resolution automotive systems are compromised by *snow*, which contributes to eye fatigue. The snow is so bad, that I fear that most drivers will prefer to drive with the infrared system off. The incorporation of a \$20 chip in the system to remove this snow would not significantly increase the manufacturing costs.

2. AVERAGING—THE WRONG APPROACH

When offered redundant data, the first inclination is to average the data together. In particular,

$$x' = \frac{x_1 + x_2}{2} \quad (1)$$

It is obvious that this formula will reduce the error in any individual component by half. Unfortunately, if one has a dead sensor, half of the error is still intolerable. When is needed is to identify erroneous sensor data and eliminate it.

3. MORPHOLOGICAL FILTERS

A morphological filters produces a result that is derived using logic as opposed to arithmetic. Examples of morphological filters include median operators [1], erosion operators [1], WMMR filters (weighted mean of minimum range) [2], [3], and statistical filters [1]. The median operator replaces a set of pixels by their median. This operator will eliminate totally erroneous data. Unfortunately, however it also discards most of the data. A 2x2 median operator or erosion operators will discard 75% of the original data. The proposed statistical operator [1] discards only data which lies outside the statistical range specified by surrounding pixels. The statistical operator will leave up to 95% of the original image intact, and is recommended for this application. While some newer camera designs have the capability for detecting bad pixel data, the methods employed are rudimentary. Perhaps the business of designing an infrared camera is too serious a business to leave to the camera manufacturers.

4. OBTAINING REDUNDANT IMAGERY

The author has approaches for camera designs which offer completely redundant images. In real time systems successive images can be considered to be redundant, if the scan rate is high enough. Unfortunately for focal plane arrays, any given objective point will be viewed by the same sensing element. If the sensing element is either miscalibrated or dead, the redundant data is not of much use. However, the technique will work for eliminating any snow in the data. The author has an approach with a hybrid camera design using a rotating multi-sided mirror and a sensor array (5x768) (refer to Figure 1). As the mirror rotates, each row of the sensing array produces a complete image. Using a sensor technology of MgCdTe, sampling rates for individual sensors can exceed 1 megahertz. As a consequence, it is possible to achieve 1000 frames per second using this design. Maurice Bales of Bales Scientific is currently in the process of prototyping a camera using this design. The redundant data provides the ability to identify any erroneous data and completely eliminate it.

5. THE WMMR FILTER

A good morphological filter for a redundant imaging system was developed by Dr. Harold Longbotham at the University of Texas at San Antonio [1], [2]. WMMR is an abbreviation for Weighted Mean of Minimum Range. While the WMMR is usually employed for eliminating noise and enhancing edges, there is nothing to preclude its use for this application. The concept is to find subsets of the data with a minimum range. For example, three samples which agree with each other have a range of zero. With five redundant, we would probably require each subset to have at least three samples. The WMMR would then take the mean value of all subsets which exhibit this range.

Figure 1. Hybrid Camera Design

5.1 Reduced-Calculation WMMR

The author has a modification of the WMMR which greatly simplifies the calculation of the WMMR. In traditional implementations, the data is first sorted numerically. Data subsets of minimum range in the original sample are identical to data subsets of minimum range in the sorted sample. After sorting, however, one has the advantage of knowing that minimum range data points are contiguous in to each other in the sorted sample. (If they are not contiguous, then one can substitute one of the intervening points for one of the end points, and obtain a subset with a smaller range). One then scans through contiguous subsets of the sorted data to find those subsets with minimum range. The simplified calculation uses the average value of the smallest element of the smallest selected subset and the largest element of the largest subset. For combined subsets containing less than four elements, this simplified computation produces the result identical to the traditional WMMR. The algorithm is elaborated in the box below.

1. Order the pixels, yielding $o_1, o_2, \dots$
2. Let Q be the minimum number of elements in each subset ($Q=3$)
3. Initialize M , the minimum range, to a large value
4. For each i , examine the pair, successive pair, o_i, o_{i+Q-1} .
 - a. Calculate $d = o_{i+Q-1} - o_i$
 - b. If ($m > d$) then
 - Set $m = d$
 - Set $L = o_i$
 - c. If ($m \geq d$) then
 - Set $U = o_{i+Q-1}$
5. When completed with 3., the WMMR is equal to $(L+U/2)$.

6. OPPORTUNITY FOR MULTIPLE SENSOR CALIBRATION

Redundant images also provide the opportunity for multiple sensor calibration. In contrast to focal plane arrays, flawed sensor sensors and flawed sensor calibrations will appear as streaks across the image. The difference in intensity between redundant rows of the same image is easily recognized and readily calibrated. Sensor response is usually specified by a smoothly varying curve. It is simply a matter of adjusting the curve so that the resulting data agrees the best with the other (redundant data). This task is made easier if the camera has a calibration source, i.e. a calibrated hot and cold spot inside the camera which lie outside the field of view, but are scanned with each turn of the rotating mirror.

7. ACKNOWLEDGEMENTS

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8. REFERENCES AND BIBLIOGRAPHY

- [1] L. G. Allred, "Statistical techniques for noise removal from visual images", May 92, *OE/Aerospace Sensing conference*.
- [2] H. Longbotham and D. Eberly, "The WMMR Filters: A Class of Robust Edge Enhancers", Mar 94. *IEEE Transactions on Acoustics, Speech and Signal Processing*.
- [3] L. G. Allred and G.E. Kelly, "Incorporating morphological filters in infrared camera design", Feb 94. *Electronic Image Science & Technology Symposium (IS&T)*.