

Original Research Article

Novel technique for IRFPA blind pixels detection

Abstract: Infrared focal plane array (IRFPA) is a bi-dimensional infrared detector which is a matrix of micro detectors referred as pixels. Physical pixel failure (blind pixel) is a serious issue in case of utilizing IRFPA as a measuring tool or a surveillance system which monitoring hot objects. Scene-based non-uniformity correction (SBNUC) for uncooled IRFPA depends on powerful of algorithms to estimate the correction and could eliminate the need to use reference-based non- uniformity correction (RBNUC) which requires doing a lab calibration instead of self-calibration. SBNUC's have disadvantages of ghosting artifacts which be complex when new blind pixel appear. This research focuses on the electrical aspect of IRFPA detector to examine the effect of skimming reference voltage on the global image contrast and found out that exciting V_{sk} voltage in boundaries could separate blind pixels from image background which become very simple to detect and correct.

Keywords: IRFPA, IR, uncooled Thermal camera, TPC, FPGA, Blind pixel, SBNUC, Skimming, IR readout circuit, Otsu method, and global thresholding.

1. Introduction

Since replacing the Infrared (IR) scanning technology by the Infrared focal plane array (IRFPA) technology, applications demand got expanded widely. IRFPA is a two dimensional arrangement of micro infrared detectors (below than $17\mu\text{m}$ size, recently) which collect photons on a certain wavelength [1]. Old IR scanning system was consisted of a combined mechanism between a one row of micro detector (a vector of adjacent detectors) and polygon of mirrors which mounted in different angles [2]. In scanning system, each angle reflects a

horizontal stripe (single row) of IR image onto a front vector of IR micro detectors (combined in one chip) to acquire a single raw of picture matrix while polygon moves in a high speed rotating mechanism.

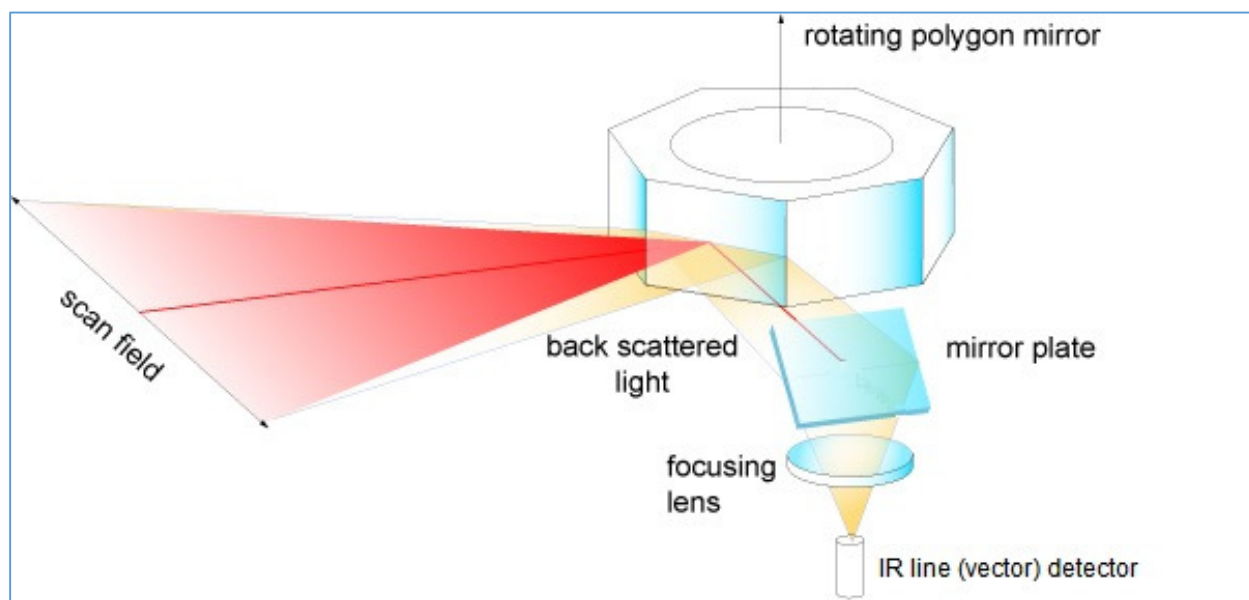


Figure 1: Traditional optical scanning mechanism.

Figure 1 illustrates that scanning system design was narrowing the chance of small, light weighted, and lower power consumption system due to its huge mechanical aspect related to IR line detector as in Figure 1. Besides eliminating scanning mechanism by the revolution of two dimensional detector (IRFPA), IRFPA extended the demand of applications beyond military and medical purposes of use [3]. Recently, a trend of very advanced automobile research projects aim to combine IRFPA with other sensing equipment's to increase the safety and reliability of modern cars [4]. In security field, a small and compact uncooled IRFPA's are in use for purpose of face recognitions [5]. The history of IRFPA passed through two major

stages and deep research and developments until they could present an uncooled IRFPA detector that has small footprint and suitable for commercial purpose applications [6].

Researches could enhance the Feasibility of depending on scene-based non-uniformity correction (SBNUC) algorithms to avoid the need for hardware calibration in labs, and to solve the issue of fast IR image drifting which came up as a disadvantage issue in uncooled IRFPA's type [6]. In conventional reference-based non-uniformity correction (RBNUC) which needs a calibration lab, the process should calibrate the response to linearize the image by modeling the output according to the first order slope (gain) and offset coefficients [7]. RBNUC priority is to generate two lookup tables for gain and offset that satisfies [6]:

$$x_{ij} = G_{ij}y_{ij} - O_{ij} \quad 1$$

Where x_{ij} is the actual radiation, y_{ij} is the pixel response, G_{ij} is the gain value for a pixel and O_{ij} is the offset value for the same pixel.

Also, RBNUC process could utilized to detect blind pixels. Blind pixels are pixels that have physical failure in their internal structures [8]. In RBNUC two point corrections (TPC) process [6], it classifies pixels whom their behavior kept unchanged or (slowly change) during the incremented change of reference temperature. Theas classified pixels shall be short listed in a blind pixels lookup table which has to be stored on the IR digital board for real time digital processing. Blind pixel referred to an over-responding, under-responding, or frail-responding micro detector. In image processing, it is so clear that blind pixels in IR could be modeled as a salt and pepper noise and can be easily removed by a 3x3 median filter. Many SBNUC's depend on lookup tables for gains and blind pixels that have been generated by the

manufacturer during RBNUC calibration process. Some other SBNUC's are not utilizing any of RBNUC's except the blind pixel lookup table which is not easy to estimate. Of course, gain and blind pixel lookup tables solve the physical failure in pixel itself, which is the easiest and most reliable technique for many reasons:

- It is a direct and fast way to retrieve and utilize within any algorithm; which makes it suitable for real time processing while data stream is running.
- Blind pixels and gain are rarely change over short period of time so that there is no need for reserving system resources for non-frequent use. Of course, the disadvantage is interrupting the operation and shut down the system for calibration and system tables update.

Due to the demand for Uncooled IRFPA, this paper propose a novel process to recognize blind pixels and update their lookup table without the need to interrupt the system and take it to the lab for RBNUC calibration to generate the desired lookup table, which is a great solution to avoid taking tens of thousands of SBNUC IRFPA to their manufacturer labs for calibration. For SBNUC IRFPA whom their video processing unit is running through a very complex algorithms to detect and recognize blind pixels, this proposed process shall offer them a great savings in system resources, processes, time, and space.

2. Background.

Although many literatures call it dead pixel instead of blind pixel [9], researcher in this paper think that many pixels which have frail response should classified as a blind pixel, also. Researchers in this paper call this third type of blind pixels as bad pixels because of they still have a response which means they still active, but they may cost the system extra resources to linearize their response instead of just consider them as a blind pixels and treat them with blind pixels without a core change in the system architecture of digital processing. For example, a bad pixel (which has frail response) may needs a gain value higher than the fixed integer part of the fixed point number representation, which is easier to consider it as a blind pixel and

force a median filter to estimate its value instead of changing the whole digital architecture for miner need.

Blind pixels could interrupt any image processing algorithm and detected as a far hot target (object). Nowadays, IRFPA system is a major part for most of military surveillance systems and has essential mission as an early warning system in aircrafts against thermal missiles which are equipped by thermal seekers instead of radar seekers.

Far objects shall appear initially as hot pixels whom their energy are higher than adjacent pixels. According to this observation, military utilize IRFPA systems as a point target surveillance systems which specifies a certain minimal geometrical resolution to classify the hot object under serious monitoring [10].

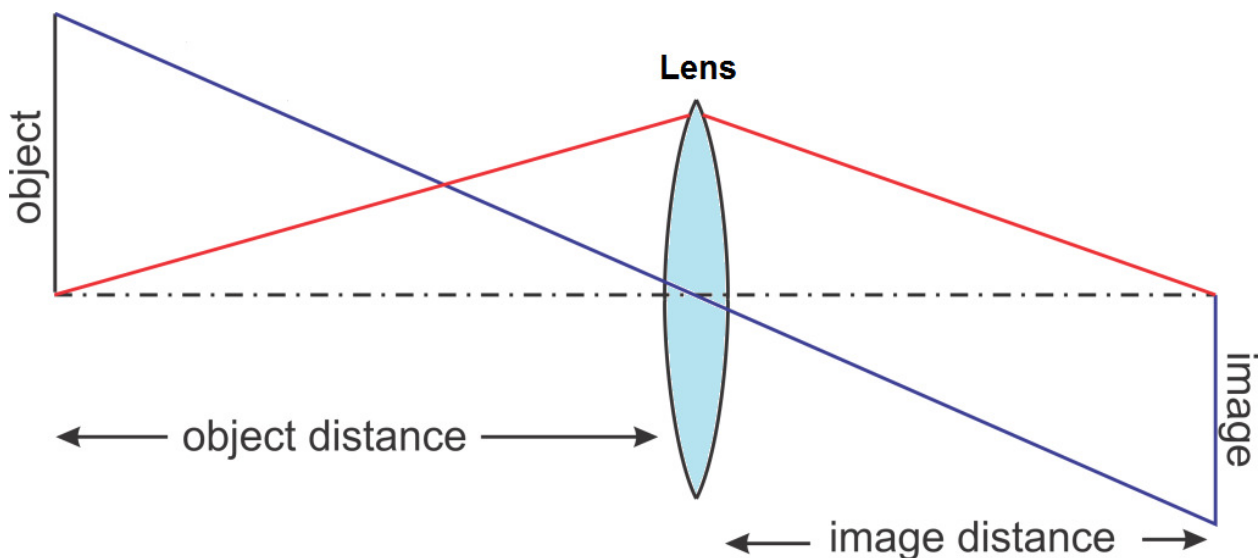


Figure 2: Instant field of view and geometrical resolution calculation principle.

Figure 2 illustrates the optical aspect of a single image pixel with respect of a far object observation. As an example: to estimate the smallest representation for a far object means to calculate the distance with respect of equivalent pixel size. Suppose that the image in Figure 2

is a 17μm height and object is a 2m height airplane, and the task is to detect and represent this object as a single pixel from 20,000m (20Km) distance; then and from the principle of triangle proportions, system design requires a 17cm focal length for optical lens as follows:

$$f = \frac{H_i}{H_o} \times d = \frac{17 \times 10^{-6}}{2} \times 20000 = 0.17m \quad (1)$$

Where: f is image distance (focal length), H_i is the pixel size, H_o is the far object size, and d is object distance from IRFPA system (see Figure 2).

Above example demonstrates how critical is when an early warning system alarmed by the surveillance unit which has to segment object signature [11] due to detecting a single hot pixel in the scene which indicates a prospective threat from 20Km distance far.

SBNUC algorithms offer great solution for uncooled IRFPA drifting issue [1]. SBNUC has two categories: algebraic algorithms which extract global image features (from frame to frame) like neural networks [12], and statistical algorithms which extract local features within the frame itself [3]. Whatever the algorithm, its complexity shall cause some disadvantages that may need extra researches to solve these side effects [13]. Ghosting artifact is one of major issues which occurs when an object did not move during the scenario for long period and then suddenly moved which will cause a ghost for that object for a while before get slowly removed [14].

Blind pixels that appear after a while of system usage are more complex to be solved by a simple SBNUC algorithm than ghosting artifact. All SBNUC's put up their algorithms on the assumption of there is no blind pixel that have to be fixed while operation and all blind pixels are mapped out from their lookup table which was calibrated by manufacturer. The reality is that new blind pixels will appear over long period of IRFPA system operation duo to an

unexpected physical failure which needs extra complex layer of algorithm(s) to detect and update the lookup table in case of algorithms that lay on gain and blind pixel lookup tables as a base input for them; or shall implement a very complex layer for real time blind pixel recognition and strip for algorithms that ignore gain and blind pixel lookup tables.

This research aimed to study the electrical and operational conditions for IRFPA detector which manufactured by Ulis company (model UL 03 26 2 size 384x288); to understand and measure detector behavior and responses against variable excitation for skimming voltage.

3. Proposed technique

Based on our previous project [6], Figure 3 and Figure 4 illustrate the whole block diagram related to the interest of research in this paper and experiment IRFPA system.

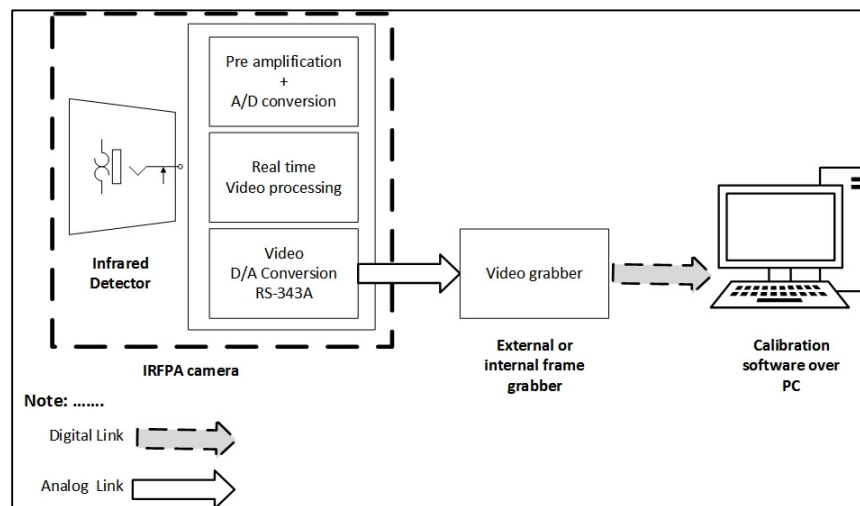


Figure 3: System basic operation modes.

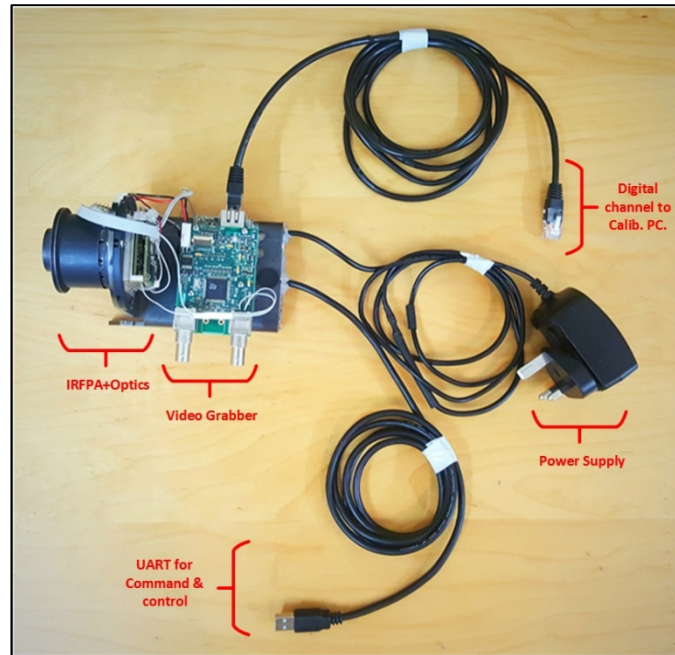


Figure 4: Experiment setup.

Each IRFPA detector must have a readout circuit to inject the desired charges which are needed for voltage conversion purposes (sampling). To have a stable and avoid saturated output, IRFPA equipped with a modeled pre-amplification and sampling circuit as in Figure 5. Manufacturers follow general model for detector manufacturing process which consists of three major parts: pixel (micro detector unit of active bolometer and n-channel enhanced MOSFET), skimming model, and sampling circuitry.

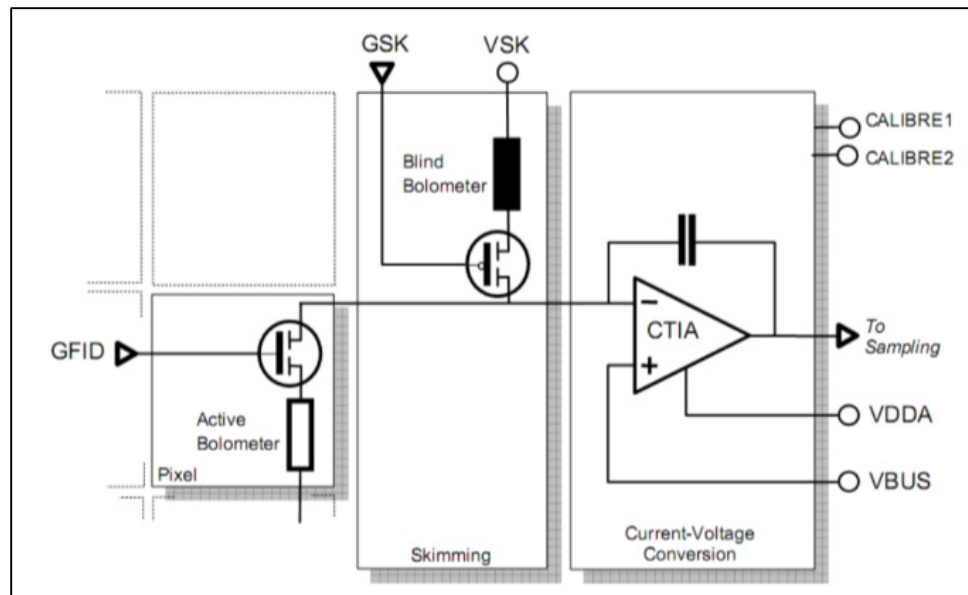


Figure 5: UliS (IRFPA manufacturer) readout circuit model.

The goal of implementing a skimming circuit inside the IRFPA is to avoid saturation while blind stage and to support having smaller pixel size which shall give a better dynamic range and signal-to-noise ratio. This research focuses on studying the behavior of skimming on the extreme boundaries of the skimming source voltage (V_{sk}). As in Figure 5, a p-channel enhanced MOSFET (in series after a blind bolometer) is shunted on the pixel signal line. However, Figure 5 illustrate the conceptual (functional) model although IR readout circuits are much more complex than that [15]. For example, there are many design and patents on how to implement high performance skimming module which in some cases have blind bolometers for each IRFPA column instead of individual pixels.

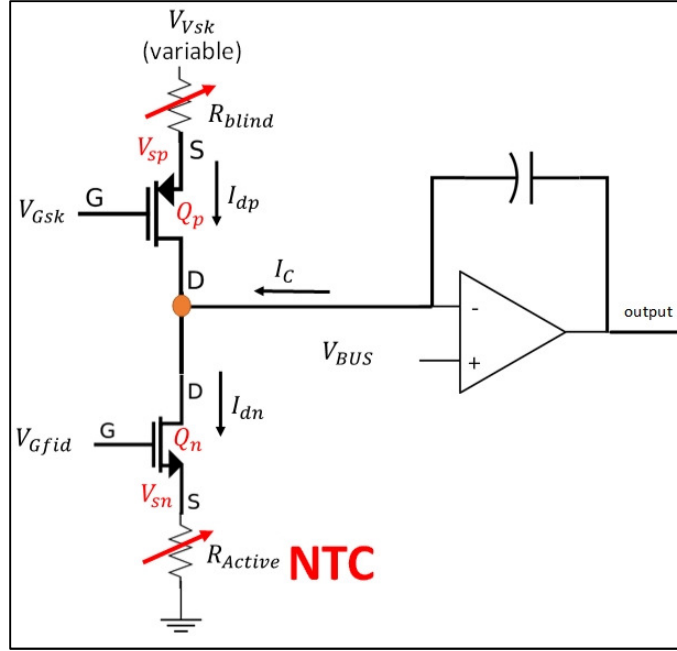


Figure 6: Readout circuit analysis.

According to Figure 5 and conventional design concepts for readout circuits [15], researchers have drawn the circuit for purpose of analysis as in Figure 6. Readout circuit designers supposed that p and n channel MOSFET's shall operate in triode mode to satisfy the circuit optimal operation requirements, thus:

From KCL:

$$I_c = |I_{dn} - I_{dp}| \quad 1$$

$$\text{Where } I_{dp} = \frac{V_{vsk} - V_{sp}}{R_{blind}} \quad 2$$

$$\text{And } I_{dn} = \frac{V_{sn}}{R_{Active}} \quad 4$$

The most important conclusion from above equation is that I_c represents the absolute difference value for current which shall charge or discharge the sampling capacitor (buffer).

This buffer holds the equivalent representation of active pixel as a voltage level instead of desired current consumption; or in other words: it acts as a current-to-volt converter.

Figure 6 and equations 2, 3, and 4 show that I_c is a function of: $I_c = |I_{dn} - I_{dp}|$

1

$$I_c = f\left(V_{vsk}, V_{Gfid}, R_{blind}, R_{Active}\right)$$

With respect to all other parameters, V_{vsk} has an inverse proportional relationship with R_{Active} due to the nature of negative temperature coefficient (NTC) of the active area (pixel sensing region) itself. In other words, the resistance decreases with increasing temperature. Increasing the voltage of V_{vsk} shall increase the absolute difference in buffered charge but due to NTC nature it shall discharge by the same amount instead of charging. Form this concept point of view and if the pixel active area has a defect like a short or open circuit then changing the V_{vsk} voltage level to the boundaries shall emerge blind pixels which are not fluctuating with same pace.

According to manufacturer specific test report (STR) which specifies the electrical aspects, it constrains the V_{vsk} voltage level between 2.5V to 5.5V with a recommendation for the optimal 5V voltage level. For experiment purpose and to proof the research concept, researchers insulate the V_{vsk} power feeding line and feed it externally by a very precise power supply to study the effect of V_{vsk} level changing and to find out the best (maximum and minimum) voltage levels on boundaries before full saturation for sampling buffer in Figure 6.

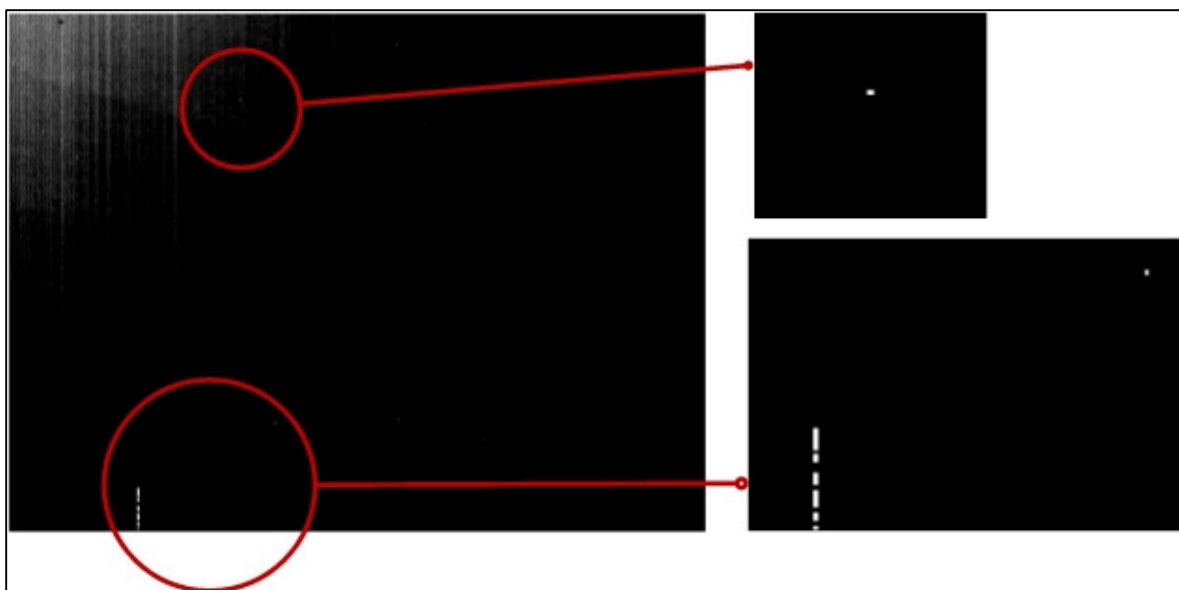


Figure 7: IRFPA response image when V_{sk} has increased to 5.276V.

Researchers found out that increasing the V_{vsk} to 5.276V is the maximum to find out most of blind (open circuit) pixels as in Figure 7; and reducing the V_{vsk} to 4.935V is the minimum to find out the most of blind (short circuit) pixels as in Figure 8.

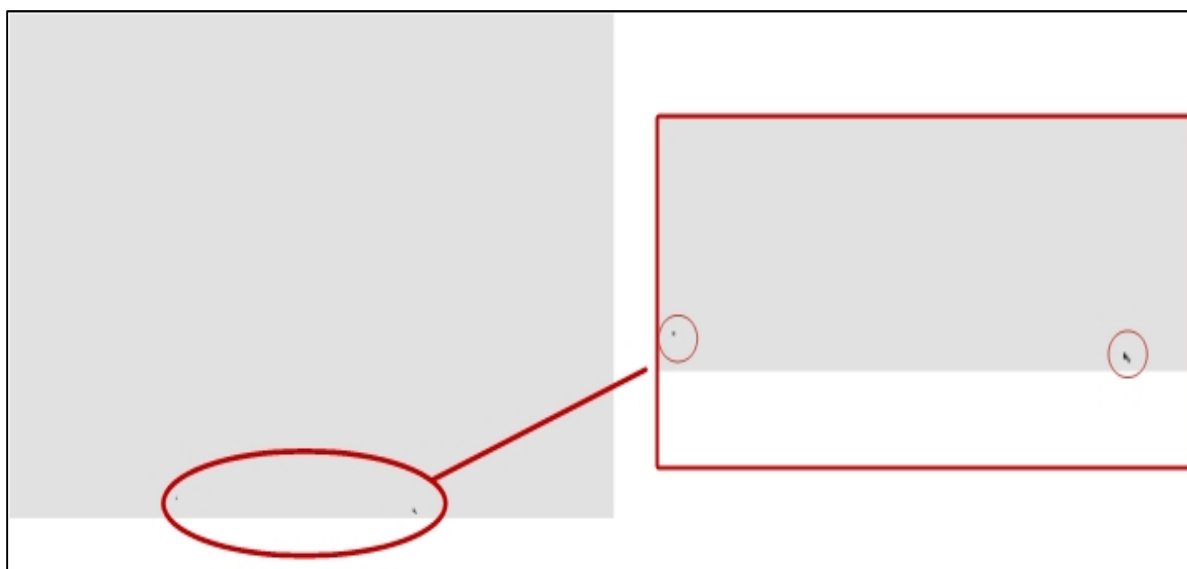


Figure 8: IRFPA response image when V_{sk} has decreased to 4.935V.

Statistically, 3D demonstration by using Matlab observes all type of blind pixels which are easy for stripping out process by a desired image processing filter like 3x3 median filler [16].

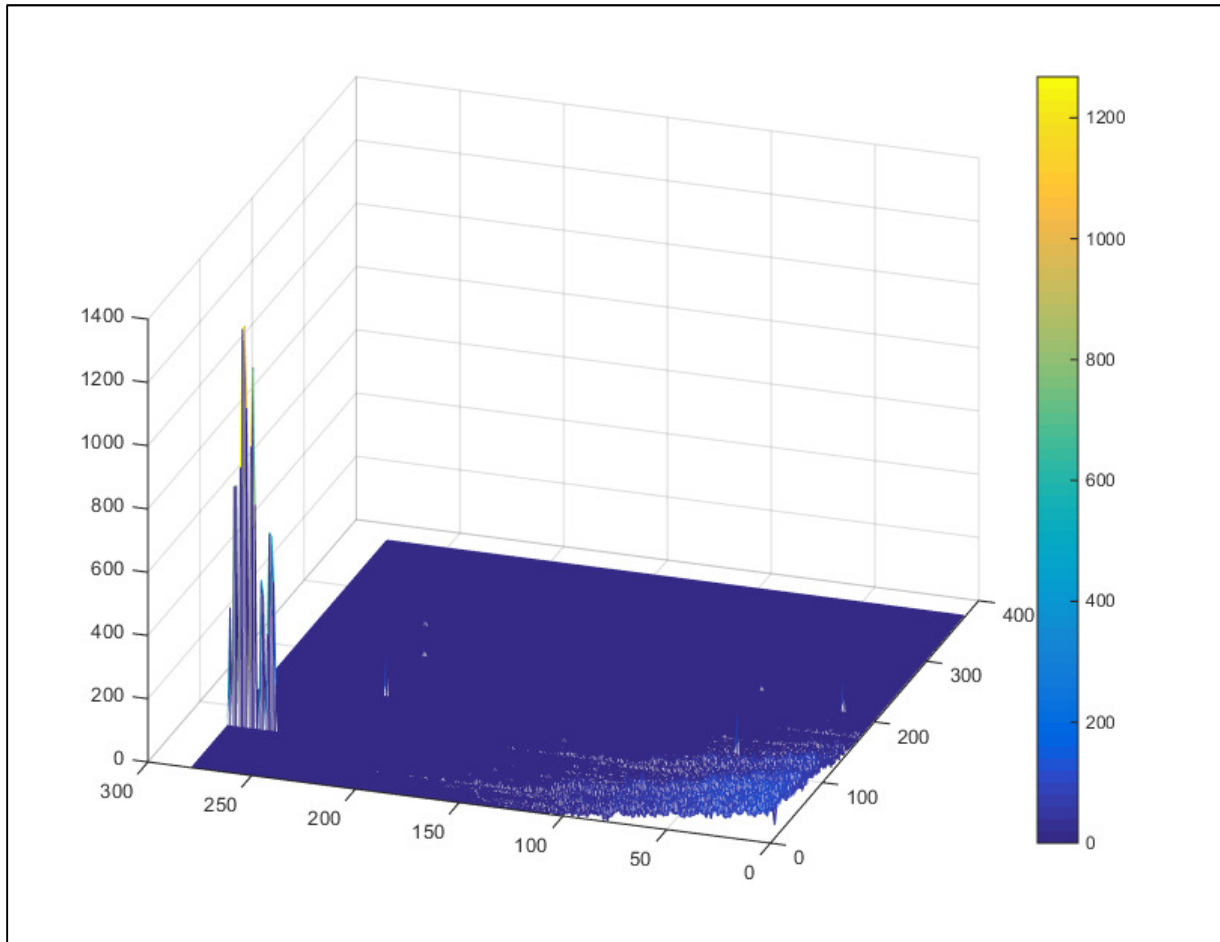


Figure 9: Matlab mesh plot representation for IRFPA when V_{sk} is 5.276V

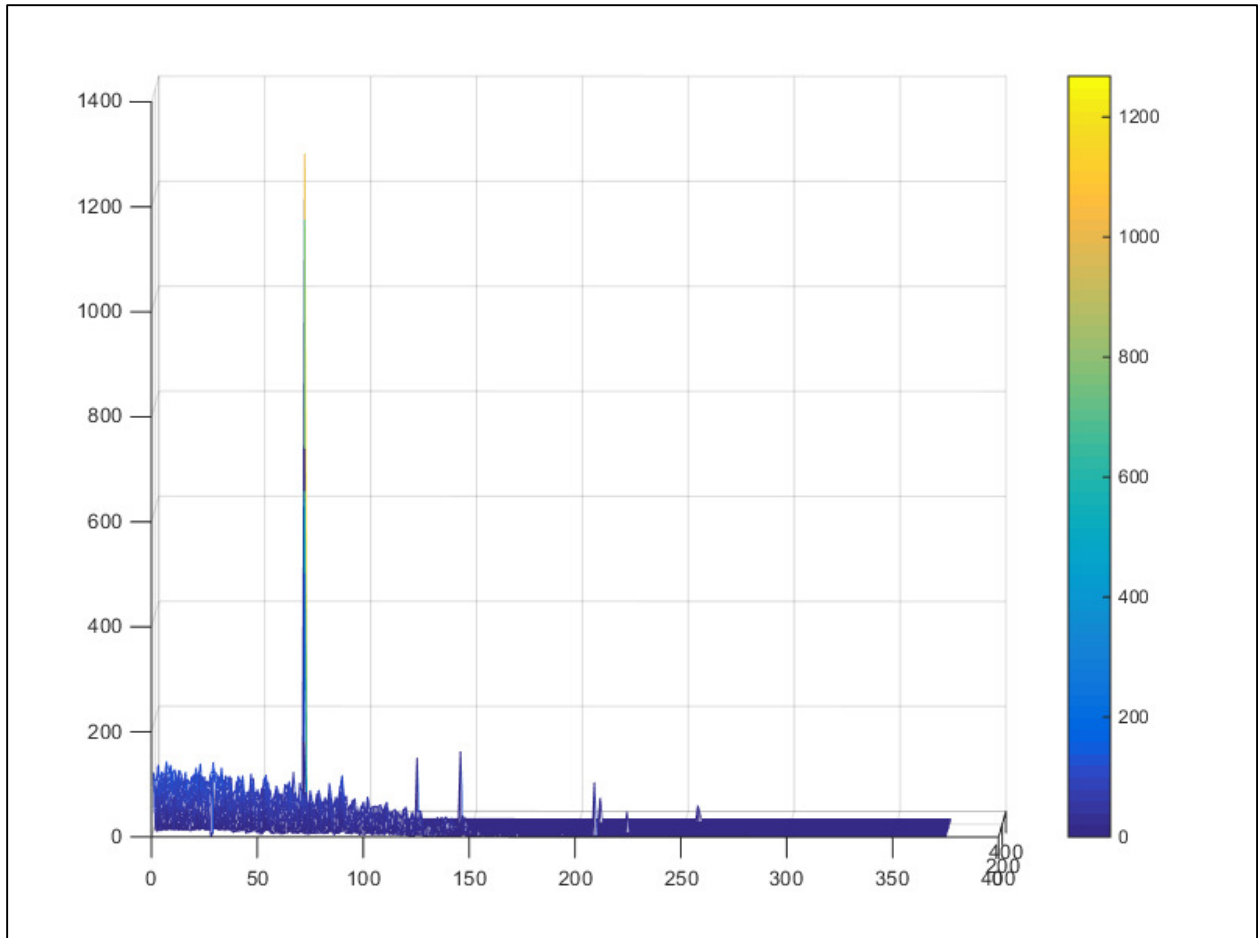


Figure 10: Side view rotation for the 3D illustration for IRFPA image response when V_{sk} is 5.276V.

Figure 9 and Figure 10 illustrates the IRFPA response image when V_{vsk} is 5.276V. Some blind pixels from the third type (bad pixels) could statistically appear clearly. Figure 11 and Figure 12 illustrates the IRFPA response image when V_{vsk} is 4.935V.

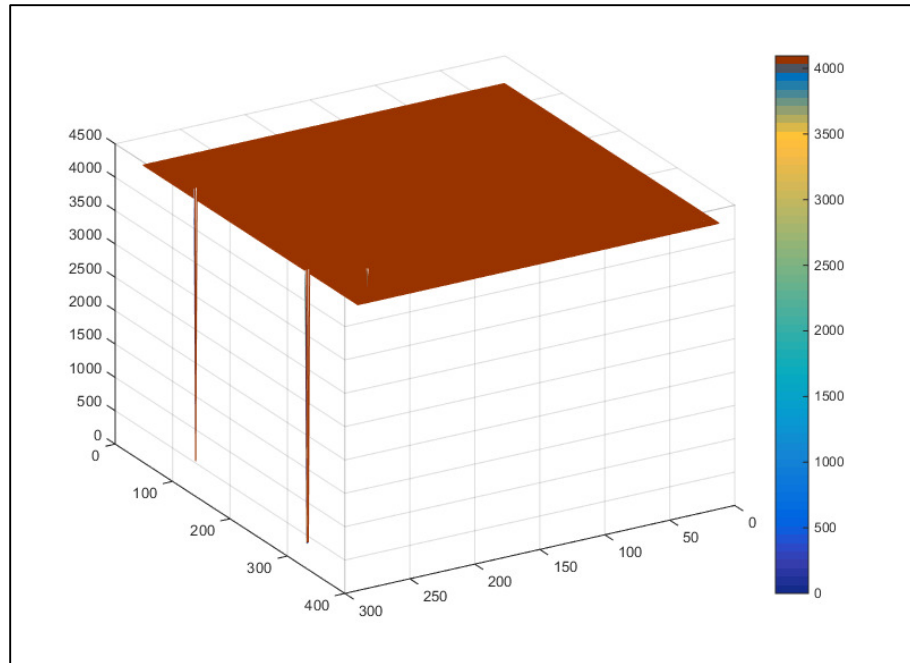


Figure 11: Matlab mesh plot representation for IRFPA when V_{sk} is 4.935V.

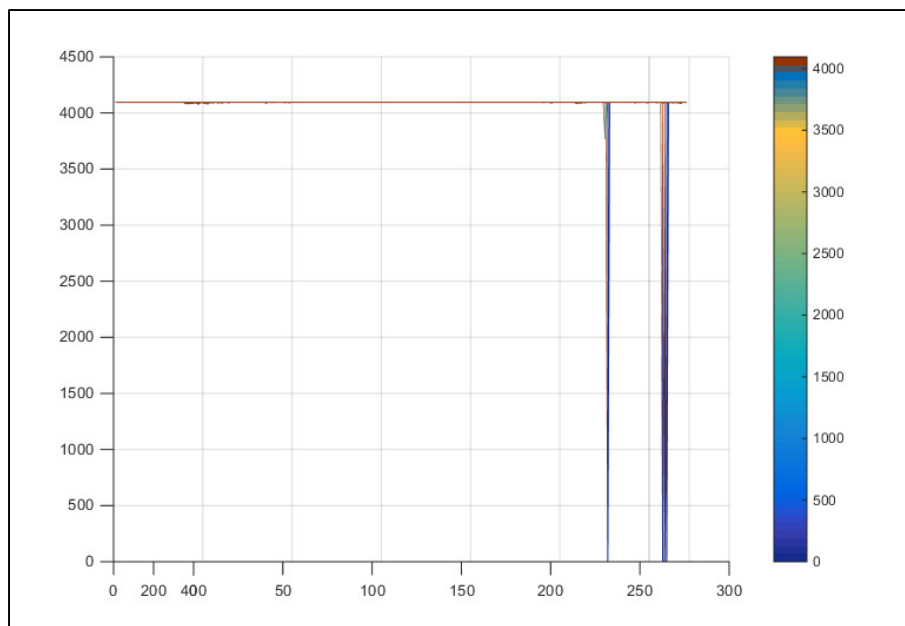


Figure 12: Side view rotation of the 3D illustration for IRFPA image response when V_{sk} is 4.935V.

Usually, image processing for detection, recognition, or identification passes through two major stages which are feature extractions and classification [17].

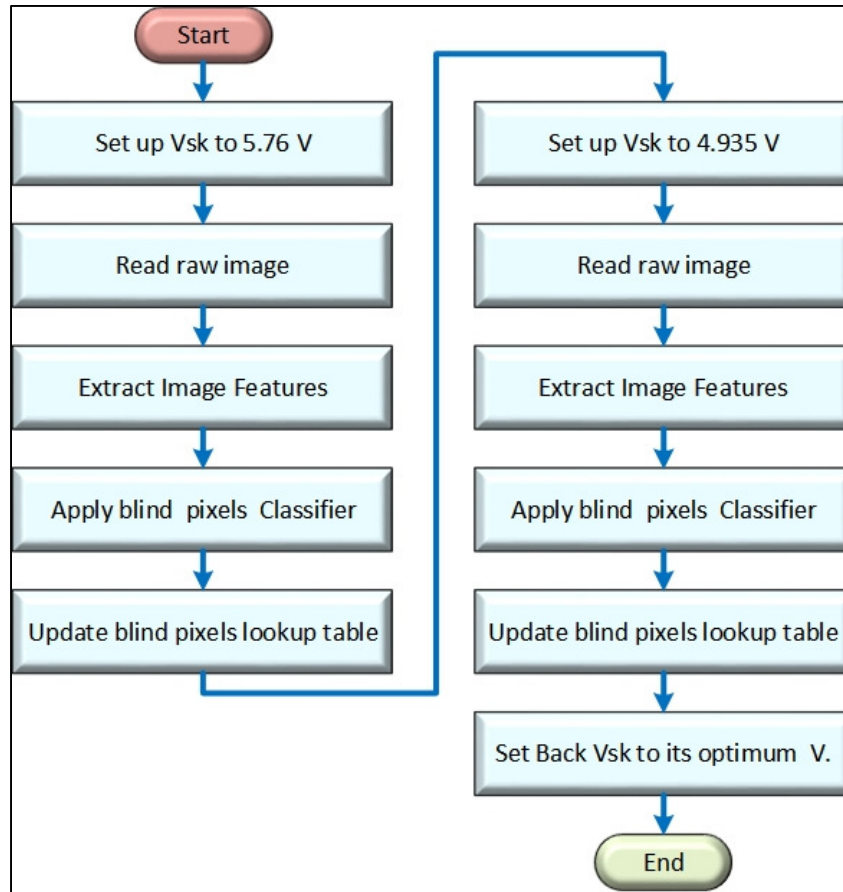


Figure 13: Flow chart for the proposed technique.

Figure 13 illustrates the flow chart for the proposed technique that it has to extracts features, detect blind pixels through classification, and update the blind pixels lookup table. This process shall applied sequentially for both voltages. The best and simplest classifier could be anyone of global thresholding techniques [18]. This paper proposes using Otsu's method due to it is simplicity for implementation and nature of problem in this study which does not requires complex classifier [19]. But, researchers apply special constrains on Otsu's method to make it sufficient for this proposed techniques as follows:

- In case of open circuit pixel detection routine when the V_{sk} is maximum, Otsu's method shall use the mean value as the minimum value and find out the image maximum as usual.
- In case of short circuit pixel detection routine when V_{sk} is minimum, Otsu's method shall use the mean value as the maximum value and find out the image minimum as usual.

4. Results

Researchers acquire images after applying desired technique for offline evaluation and feed them to the same analyzing tool (Matlab software) to compare the result with images accouired by traditional referenced-Based calibration process which also needs two images for two different temperatures on opposite boundaries of the region of interest.

Technique	Blind pixels			total
	Open circuit pixels	Short circuit pixels	Bad pixel	
Referenced Based	19	9	45	73
Proposed technique	19	9	53	81

Table 1: Blide pixles estimation result

Table 1 shows that both techniques could exactly detect the same blind pixels that (physically) have an internal electrical failure, but this proposed technique could highlight more bad pixels than referenced-based technique. The reason is because of the difference in boundaries selection. Images that acquired by referenced-based technique were from certain region but the proposed technique were experimenting the extreme boundaries that may IRFPA could reach.

5. Conclusion

This paper introduces a novel technique for blind pixels detection which offers great enhancement for SBNUC algorithms. Proposed technique is simple, fast to implement, and saves the memory and process resources by applying straightforward rules during system

initialization time (when the system turned on) and suggests a hardware modification to excite Vsk through programmable (variable) power supply and control the Vsk automatically through the DSP or FPGA according to the core technology used in image processing card.

6. Future work

To Expand the research to study GFID in Figure 5 and modify the processing card design by adding programmable power supply like DAC8831 and connect it to the DSP.

7. References

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