HIGH RESOLUTION IMAGE ACQUISITION MODE USING PANCHROMATIC REDUNDANT CHANNEL

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ABSTRACT: The Space-borne electro-optical camera system, like KOMPSAT has panchromatic redundant image channel as well as primary channel in order to increase reliability of satellite system. In most case redundant channel never been used during the whole mission period. Staggered array configuration using redundant image channel and new operation mode proposed which operates primary and redundant channel simultaneously. Without new hardware design, fast electronics and system complexity, we can get 1.414 times more fine GSD image of original system and aliasing effect which corrupt high frequency information of image can be minimized. To get the more efficiency from staggered array configuration, we introduce masked pixel CCD.

KEY WORDS: KOMPSAT, MTF, CCD, ARRAY

1. INTRODUCTION

The Space-borne electro-optical camera system, like KOMPSAT (KOrea-Multi-Purpose-SATellite) has panchromatic redundant image channel as well as primary channel in order to cope with single point failure and increase reliability of satellite system. In most case redundant channel never been used during the whole mission period, because redundant channel has only one purpose of replacing failed primary channel and each channel has no more than 1~2% failure rate for mission time. Additional weight and mass burden are in vain only to satisfy reliability number. In order to increase efficiency and utilize potential of whole system we propose staggered array configuration using redundant image channel and new operation mode which operates primary and redundant channel simultaneously.

2. SPATIAL RESOLUTION BASICS

2.1 Spatial resolution of satellite camera

The sharpness of imaging system is characterized by a parameter called modulation transfer function (MTF). MTF is the most important and the most often used characteristics of the imaging system. Besides the definition of the MTF as the magnitude of the optical transfer function (OTF), we can define MTF as the ratio of the spatial sine wave modulation depth in the image and object planes. In satellite camera system, MTF can be cascaded in order to combine all the different influence elements.

$$MTF_{system} = MTF_{Optics} \cdot MTF_{Detector} \cdot MTF_{Jitter} \qquad (1)$$

MTF_{Optics} represents the diffraction, aberration and defocus degradation effect of optical system. Figure 1 shows Richey-Chretien type telescope MTF. As we can see, typical space-borne optical system may be considered near diffraction limited.

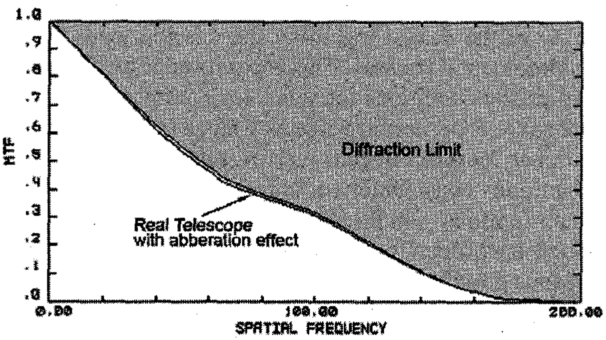

Figure 1. Richey-Chretien type telescope MTF

$MTF_{Detector}$ is image sensor ability to resolve spatial variations in the incoming signal. In case of conventional CCD, MTF degradation comes from geometrical features of the pixels, non-ideal charge transfer and mis-diffusion of electron. Considering only geometrical effect, fill factor 100% CCD's MTF value at Nyquist frequency is 0.65 and practical experiments show about 0.5.

Another MTF degradation effect term caused by satellite jitter is MTF_{Jitter}. Altitude and orbit control system (AOCS) makes some random vibration and it contributes image blurring. This effect can be minimized by using sensitive image sensor which requires short integration time (ex. CCD which has short time delay integration (TDI) stage) and stable satellite platform.

2.2 Pixel geometric MTF

General CCD pixel geometry structure is rectangular. The detector light response function p(x,y) is

$$p(x,y)=\begin{cases}\dfrac{1}{AB} & \left(|x|\le\dfrac{A}{2},|y|\le\dfrac{B}{2}\right)\\ 0 & (elsewhere)\end{cases} \quad (2)$$

The detector OTF is obtained by Fourier transform of the point spread function p(x,y).

$$\begin{aligned} OTF(u,v) &= \mathrm{sinc}(Au)\cdot\mathrm{sinc}(Bv)\\ MTF(u,v) &= |\mathrm{sinc}(Au)\cdot\mathrm{sinc}(Bv)| \end{aligned} \quad (3)$$

Equation (3) shows that the transfer function is wider for small detector area in proportion to pixel pitch. Modern CCD cameras it is possible that a portion of the camera surface is not sensitive to light and is instead used for the CCD electronics or to prevent blooming. Blooming occurs when a CCD well is filled and additional photoelectrons spill over into adjacent CCD wells. Anti-blooming regions between the active CCD sites can be used to prevent this. This means, of course, that a fraction of the incoming photons are lost as they strike the non-sensitive portion of the CCD chip. The larger the fill factor the more light will be captured by the chip up to the maximum of 100%. This helps improve the SNR. As a trade off, however, larger values of the fill factor mean more spatial smoothing due to the aperture effect.

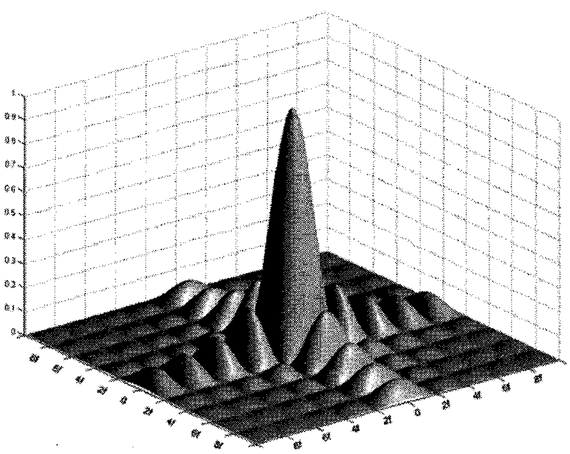

Figure 2. 2D MTF of sensor with rectangular pixel

3. STAGGERED ARRAY CHARACTERISIC

3.1 Staggered Array performance

High MTF values at Nyquist frequency mean aliasing artefacts corrupting high frequency patterns and edges. Shannon sampling theorem shows information above Nyquist cut off frequency inducing moiré pattern and jagged edge. This effect may not be apparent to the sense of human eye but causes image processing difficulties for resampling and fine deconvolution. Above all, such a system is not optimized since the instrument catches high frequency components that are lost during sampling.

This problem arises with sampling imager when the sampling cut off frequency is equal to the elementary detector size inverse, which unfortunately happens to be the sampling frequency. In order to decouple cut-off frequency and sampling frequency, we propose staggered array configuration which using both primary and redundant image channel.

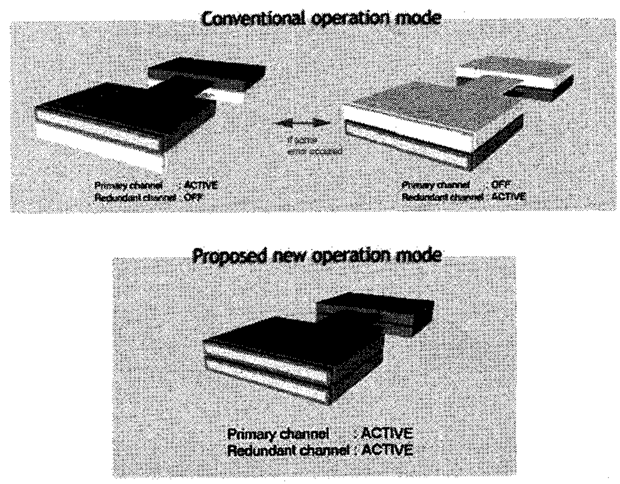

Figure 3. Proposed operation concept

Using a two lines detector, each line being shifted by 0.5 pixel along the CCD direction and (n+0.5) pixel along scanning direction. Each CCD line thus produces conventional images with a 0.5 pixel offset along both row and column directions. Interleaving the two images yields a quincunx sampling which has the twice dense sampling grid.

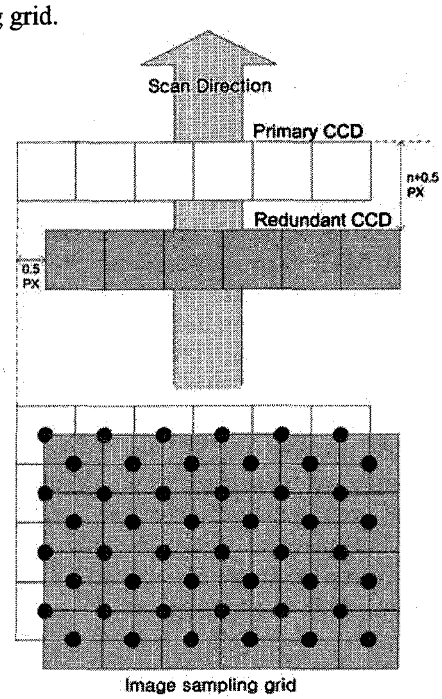

Figure 4. Proposed operation concept

The quincunx grid generated by two 0.5pixel shifted CCD arrays has sampling frequency 1.414 times higher than original sampling grid and its unit pixel geometry form is rhombic structure rather than rectangular. Figure 5 shows general optical system MTF with conventional sampling and quincunx sampling. In each case pixel MTF is almost same but 1.414 times faster Nyquist frequency makes maximum MTF value outside from the Nyquist frequency 0.22 to 0.12 and aliasing effect is dramatically reduced.

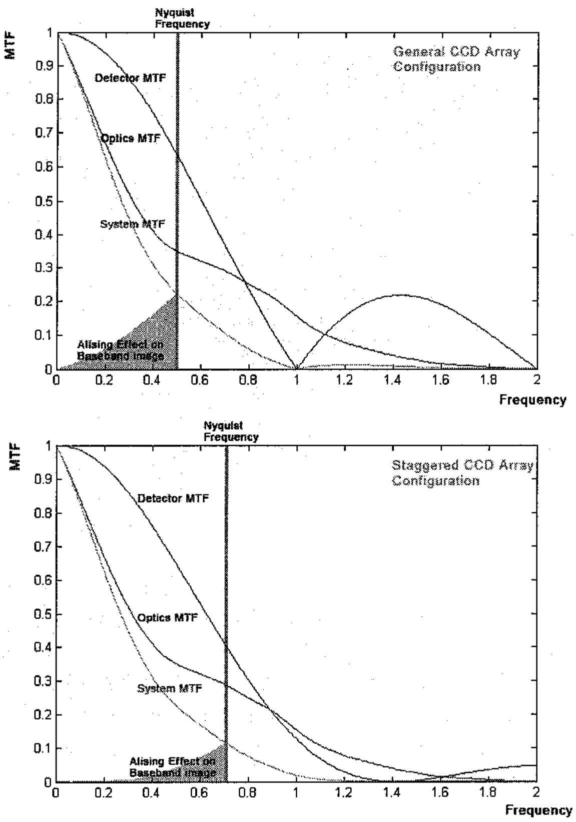

Figure 5. MTF and aliasing comparison

3.2 Masked CCD

Using pixel masked CCD we can get more spacial information from acquired image. Masked CCD has higher pixel MTF than conventional fill factor 100% CCD and whole system MTF is increased. This technique is not unusual because reducing photon sensitive area makes masked CCD has low light sensitivity than unmasked CCD. Besides, increased pixel MTF induces aliasing effect more severely. But in staggered CCD array configuration, masked CCD has some advantages. Staggered array has more margins on aliasing effect than conventional configuration. We can get more high frequency component of image at same aliasing level. Figure 6 shows one example of masked CCD and its MTF characteristic. Non-overlapping mask is chosen for criterion.

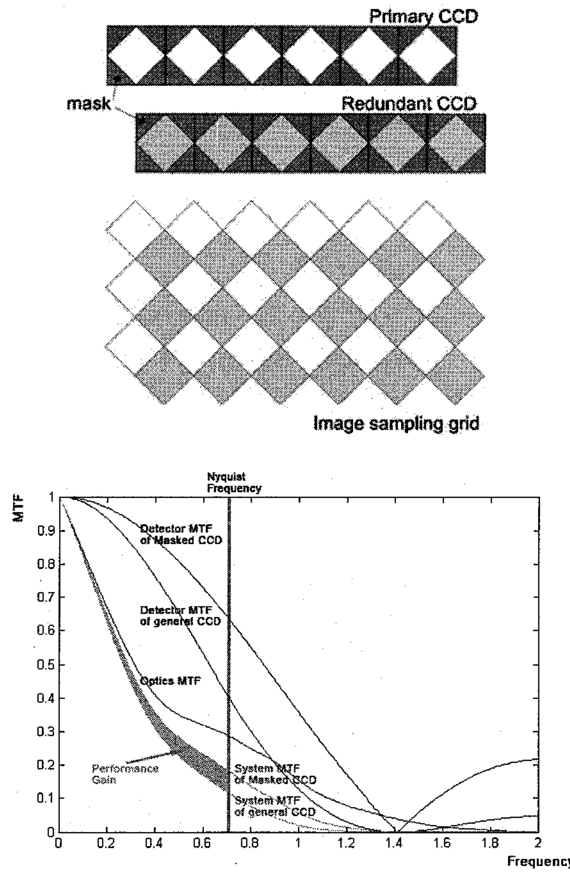

Figure 6. Masked CCD and its MTF performance

Using this masked CCD, we can get more sharp image has 0.707 times smaller ground sample distance (GSD). Compare to unmasked CCD, it has 0.18 system MTF at Nyquist frequency than 0.12. Only drawback is SNR degradation caused by 50% obscuration layer on CCD focal plane. By half reducing photo-sensitive area, sensitivity lowed to 0.707 of original value. We can select optimal screening ratio trading off system SNR and MTF.

4. CONCLUSION

One hardware burden to get the additional gain of image quality using staggered array approach is redundant CCD alignment. Other changes, like operation software revision, accommodating to additional peak power consumption and doubled image data size are not big deal. Without new hardware design, fast electronics and system complexity, we can get 0.707 GSD image of original system and aliasing effect can be minimized. These advantages make ground image correction process more accurate and efficient. To maximize resolution information from staggered array configuration, we need masked CCD which can be realized by ordering customized CCD. On CCD design phase, masked CCD needs only one additional layer for the fabrication. Its extra price is not so high.

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