Renewal Design Concept of Mechanical Scanning Imager

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ABSTRACT:

This paper deals with a new concept of electromechanical scanning imager to realize a reduced size, high resolution with wide swath optical imager. Principle of operation as well as key components characteristics, and design limit are described.
Some experimental design by using commercial electronics components are also introduced.

1. Introduction

Recent increase of the demands on Earth observation by optical imagers are high resolution and wide swath achievement. At the early history of space borne remote sensing, LANDSAT MSS realized the wide swath of hundred and eighty five kilometer with eighty meter resolution. This number is important to have repeated observations with the frequency of half a month. TM on LANDSAT 4 and 5 had realized thirty meter resolution with the same swath. To achieve this performance, TM optics has a large aperture compared with refraction limit of the optics to realize the IFOV and high sensitive detectors. Both MSS and TM adopted mechanical scanning to look through the swath. One design evolution was the introduction of linear CCD. This reduced the sensor size significantly due to the increased optical integration time which eventually decreased optical aperture size. SPOT, INSAT, ASTER and other imagers of recent satellite mostly adopt this approach. In the case of SPOT, which achieved twenty meter multi spectral bands resolution and ten meter in panchromatic resolution, size of optics still exceed the refraction limit. To achieve further high resolution, there is needs of larger optics and longer integration time. These will increase design and manufacturing cost significantly in both sensor system itself and required large bus system to carry this large size sensor. Besides, linear CCD approach to realize wide swath requires wide field of view optics which will also increase the design and manufacturing cost significantly.

This paper deals with an new approach of optical sensor design to solve this kind of problem.

2. Electromechanical scanning imager

2.1 Principle of operation

Basic idea of the newly proposed imager is to introduce area CCD to observe subarea of full swath width. To perform such observation scheme instant hopping of IFOV which consists of area CCD pixels is required. Fig. 1 shows the schematic view of the system. Path of the platform which carries this imager is assumed perpendicular to the drawing. In Fig. 1, scan mirror scans object in continuous motion. Primary optics makes image of objects on its main focus. After the main focus there exist a set of relay optics which finally reconstruct image of objects on the secondary focus where an area CCD is located to convert optical intensity into electric signals. In the path of relay optics, there is a staring mirror which rotates as saw wave angle change with time. Fig. 2 shows the scan sequence, in which line A represents the scan mirror rotation angle versus time, line B represents staring mirror rotation angle versus time, and line C represents over all performance of scan. Due to the saw wave rotation of small staring mirror, step scan and staring is achieved. If the ratio of focal length of the main optics to that of relay optics is larger than unity, staring mirror rotation speed must increase by the ratio to the rotation speed of scan mirror.

2.2 Foot print

The foot print of the sub area looks like in Fig. 3. Due to the platform motion, sub area of view scans progressively along the subtrack of the platform. In a subframe acquisition time frame, along track image motion also happens. To eliminate this motion, one example approach is to tilt staring mirror rotation axis to the scan mirror rotation angle with the value shown in Fig. 3. The value is calculated on the assumption of commercial video camera specification. The specification are assumed as;

Area CCD pixel number: 600x400,
Frame rate :30 frames per second (non interlaced).

2.3 Design limitations

The basic idea is to obtain enough incident light from a small performances. To achieve saw wave motion of staring mirror with thirty frames per second rate, natural vibration frequency of the staring mirror should enough high compared with the frame frequency in any vibration mode. Thus the staring mirror must be stiff, small seiz and light weight. This will limit the scale of the system. For very high resolution system, one meter resolution for example, this may restrict the swath width, because the staring mirror rotation angle with the rotation ratio factor, which is the ratio of main focal length to relay focal length, increases in higher resolution ranges, which eventually requires higher rotation speed. From these consideration, around ten meter resolution or more (lower resolution) is most preferable to realize.

2.4 Swath width of the system

On the assumption to use commercial video cameras which has three CCDs for full color, one system design was performed. The pixel number of each CCD is also assumed to be 600 bt 400 pixels and frame scan rate is thirty frames per second (non interlaced or one frame of two intrlaced scans). Fig. 6 shows the achievable swath width versus required ground resolution. A hundred kilimeter swath width is achieved for ten meter resolution. If 1024 by 1024 pixel CCD which operates with the same frame rate, swath is four times wider.

3. Components

3.1 Optical design

For all of the previous space borne high resolution optical imager, optics unts are designed under the light intensity limit rather than refraction limit. This is due to the insufficient detector sensitivity and the small integration time to achieve required along track MTF under the image sway inthe integration time duration which corresponds to satellite motion. In the present approach, integration time is around thirty milli second independent of the required resolution. So the light intensity is enough high compared with the previous space borne sensors. For example, AVNIR which was launched on ADEOS achieved eight meter resolution in panchromatic band and its integration time is 1.7 milli seconds. This sensor adopts optics with tewnty six centimeters in diameter. To achieve the same performance, optics diameter requires 5.9 centimeters in proposed design on the assumption that the both CCD has the identical sensitivity. In addition, the sensor uses only near optical axis region so that optical design does not requires wide angle performances. Only the diffration limit should be considered to achieve required resolution. The limit is shown in Fig. 5.

3.2 Staring mirror unit

Staring mirror vibrates with saw wave manner. Rotation angle of peak to peak of the vibration is less than 0.1 degrees in most cases with thirty vibrations per second. To consider rotation speed magnification, the angle limit can be designed not to exceed one degree. This small vibration angle can be easily achieved by electromechanical actuators like piezo-crystal device.

3.3 Area CCD

In consideration of integration time of each detector cell, frame rate of a component area is around thirty. From the basic calculation on the assumption of commercial video camera system, it is feasible to realize more than ten meter resolution and more than hundred kilometer swath coverage is achievable with regular video CCDs. To realize higher resolution for example to realize five meter resolution with hundred kilometer swath, 1044 by 1024 pixel CCD with thirty frames per second operation is required. Present state of the art technology well covers this request.

4. An idea of system verification by using commercial components

Presently, the idea is only the concept level. To verify the system performance, one simple approach is to use commercial video camera system which has DV channel (IEEE1394 interface). These kind of video camera is already sold in market.
To use this unit as a after relay optics system, all the scan timing signal will be provided from the DV channel.

5. Conclusion

An idea to reduce optical imager weight and size is introduced. Principle of operation as well as main performance. Idea for simple performance test with commercial components is also introduced. This idea can be applicable to small or medium satellite to perform high resolution with the order of ten meter resolution.

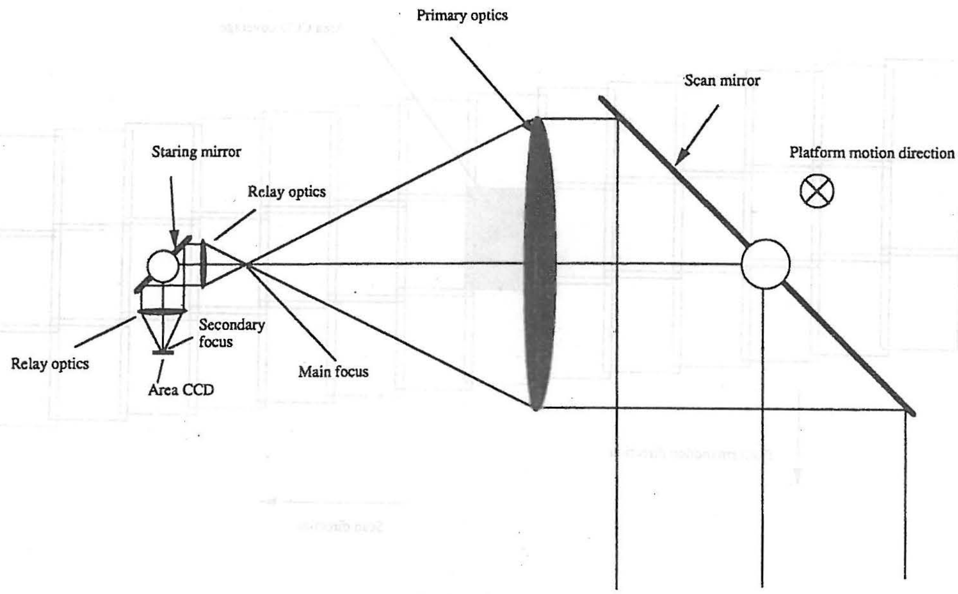

Fig. 1 Configuration of the optical imager.

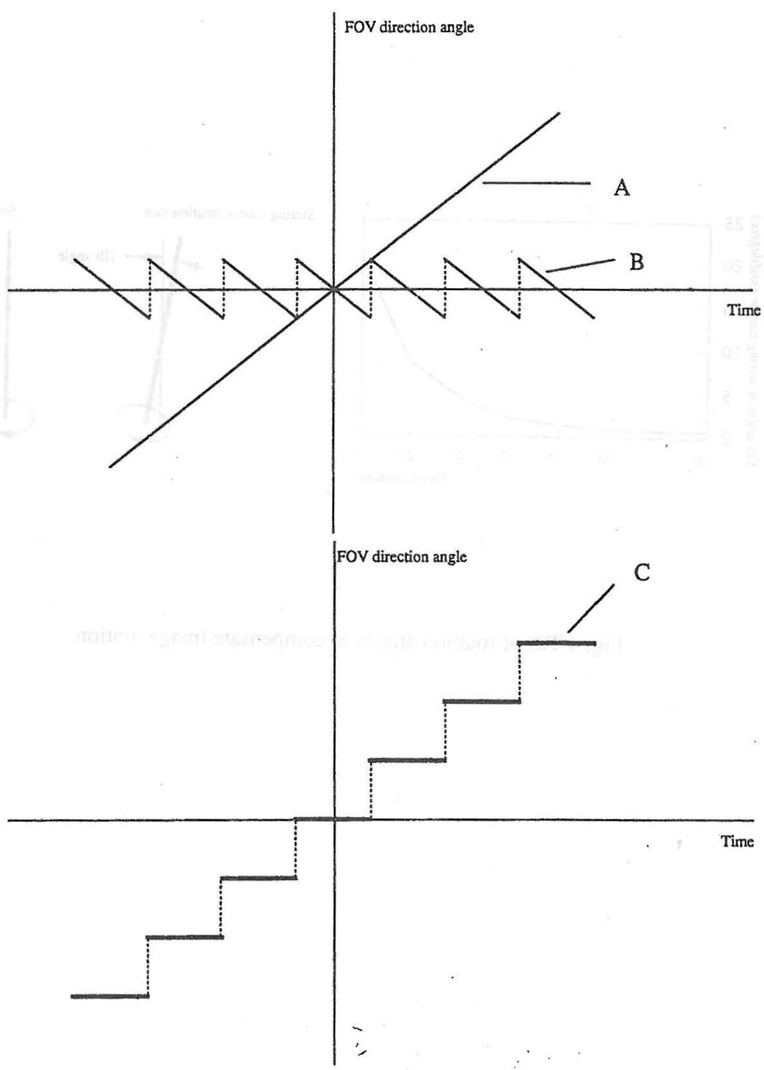

Fig. 2 Mirror scan timing.

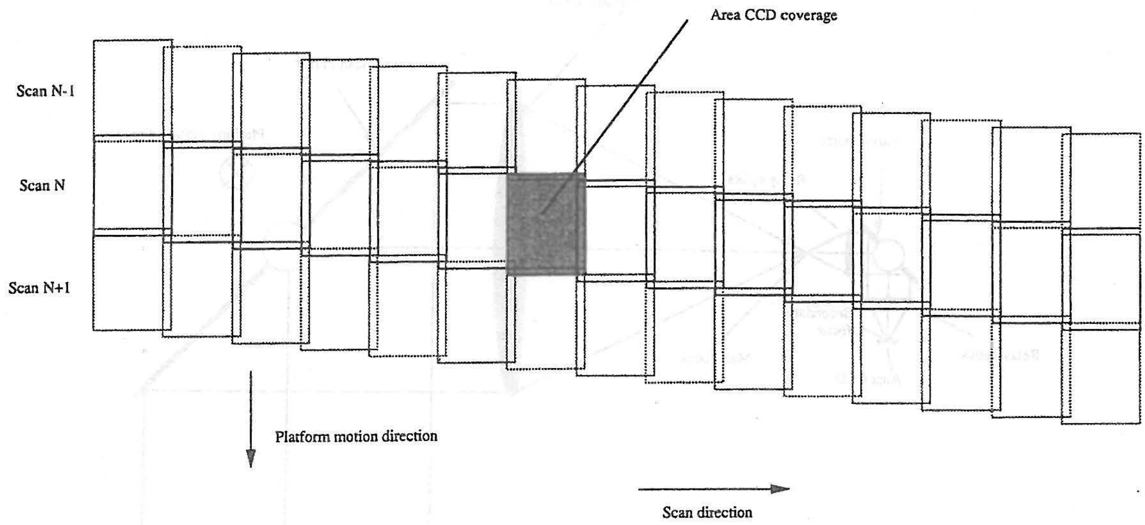

Fig.3 Foot print of sub areas.

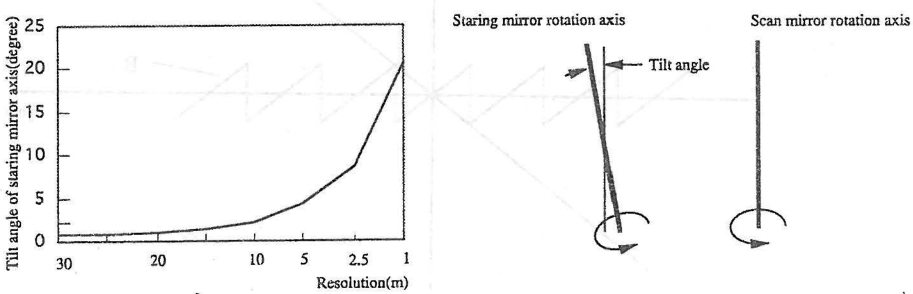

Fig. 4 Tilt of rotation angles to compensate image motion.

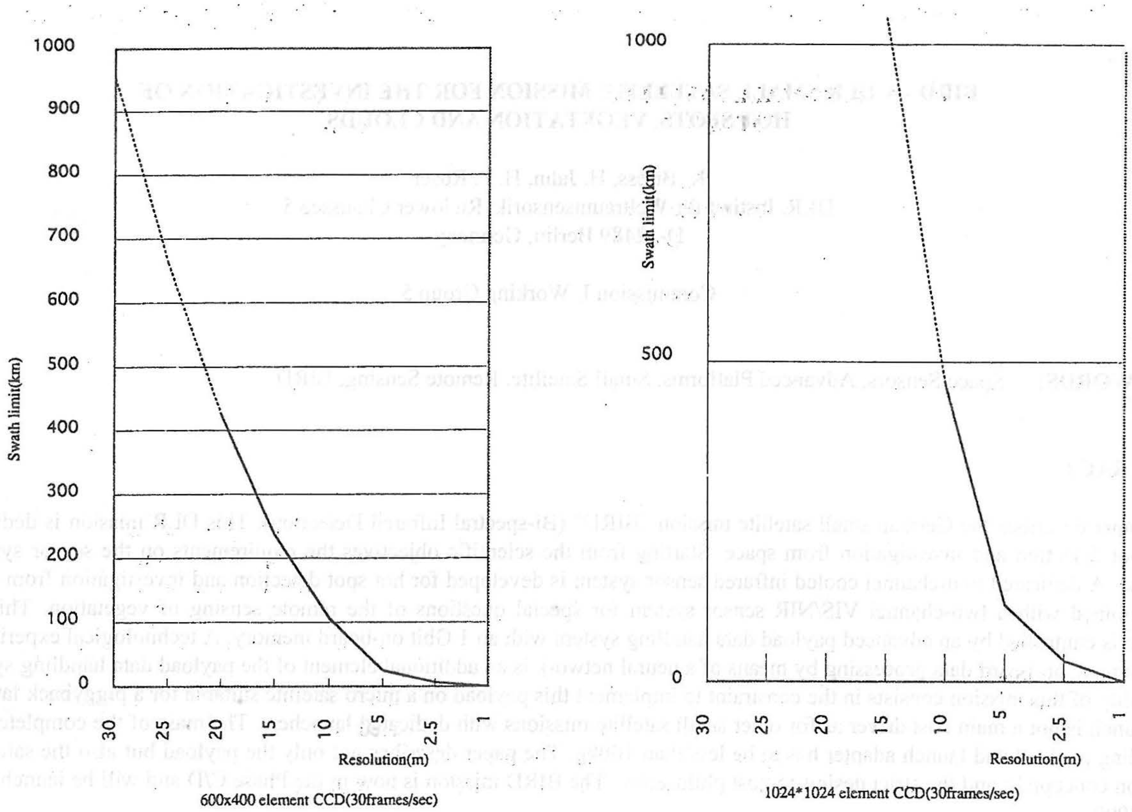

Fig. 5 Achievable swath width.

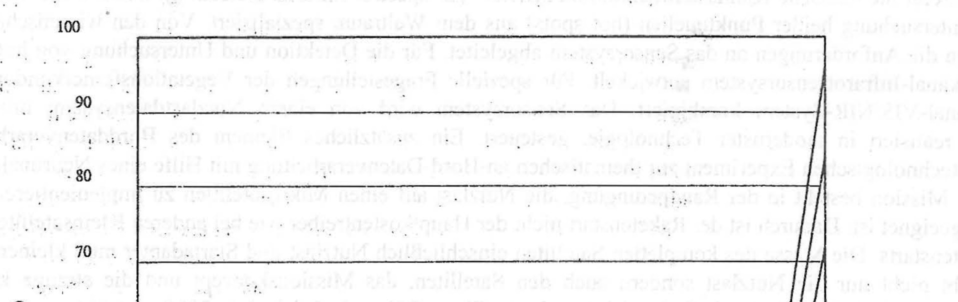

Fig. 6 Refraction limit of the optical aperture diameter.