New Optical Modalities Utilizing Curved Focal Plane Imaging Detector Devices and Large Arrays for Terrestrial and Spaceborne Telescopes

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Throughout the history of astronomy, developments in the structures with which light signals are retrieved within telescopes, incorporating advancing sensor design, have ushered in new eras of astronomical research and discovery**.** In more recent times, the ability to fabricate imaging detector devices, including CCD and CMOS devices, into user selectable curved shapes has allowed the telescope designer the opportunity to further optimize the telescope's optical system by contouring the imaging detector surfaces to the telescope's intrinsic Petzval curvature, or curved focal plane, for a variety of imaging configurations and tasks. In so doing, several immediate optical benefits become achievable, including the removal of field flattening optics, the expansion of telescope's aperture for greater light sensitivity, the capability of undistorted and instantaneous wide field mapping of star data onto a curved surface, real-time multi-perspective 3D image data streaming, and simultaneous multi-wavelength spectroscopy. These sets of improved functions enable the telescope to perform more efficiently in all areas of astronomical research, and further addresses the need for attaining greater spectral resolutions at various wavelengths, while at the same time reducing the size and number of the telescope's optical elements and surfaces, crucial for spaceborne astronomy missions. In addition to this, simplification of a telescope's optical system increases the amount of interior optical space for other astronomy experiments, increasing the telescope's multi-function capacity, which has become another requisite for space based astronomy missions. For earth-based astronomy, the increasing size of telescopes necessitates the use of faster, more thorough adaptive optics to compensate for the larger telescope's wider region of atmospheric turbulence in its viewing zone. Using conformable curved detectors, segmented for the large array needed to cover the curved focal plane converging zone of the large telescope and linked dynamically to the conformable mirrors of the telescope, a new and faster method of adaptive optics is realizable for this class of telescopes.

3D Stereoscopic Imaging with Satellites Equipped with Curved Focal Plane Sensors

Remote sensing satellites equipped with cameras that make use of curved focal plane detection devices, including curved CCD's and CMOS devices, have distinct advantages over their flat detector counterparts in both geosynchronous and non-geosynchronous tracking modes. Any camera or telescope designed with curved focal plane detectors benefits universally over flat detectors by optimizing its optical system to converge an image over a preferred Petzval curvature surface established by the camera or telescope. The result of this optimization process yields a wider aperture for greater sensitivity, 75% fewer optical components due the elimination of field flattening optics, lower mass of the complete imaging system due to miniaturization and size reduction of the optical system, and greater resolution, depth of focus, and field of view of the image area through the expansion of the imaging field. In light of these fundamental improvements, additional features are enabled for orbiting satellites. In the case of the non-geosynchronous tracking satellite, curved focal plane detection optics provide real time, multi-perspective scanning abilities from a single camera device, utilizing the high speed curved imager, which in turn captures and processes 3 dimensional data taken from a rapidly shifting surface environment at the speed of light and at higher resolution, rather than in computerized post processing with conventional orbiting imaging satellites. This attribute of the high resolution curved focal plane imager renders it unique among all other imagers due to the simplification of its primary optical structure, creating a lens system that is omnivergent as well as completely solid state, with no moving parts, to achieve the multi-perspective and multi-spectral acquisition of images with a single moving camera in remote sensing mode. In such a case, the pivoting of the camera's optical axis, performed at high speed and in synchronicity with the image capturing frame rate of the curved focal plane high speed imager, runs in solid state mode with no mechanical parts as it scans over its target, sending a sequence of very high resolution, multi-perspective images directly to the receiver in real-time without the need for 3 dimensional image reconstruction. Consequently, such a remote sensing moving camera will possess a wider field of view than a flat detector camera due to its optimized curved focal plane optics, thereby transmitting additional three dimensional data sets over a larger area to the receiver in the same sequence of the scanned imaging region. This eliminates the need for additional orbiting passes of the respective region to be imaged by the satellite, making the satellite more efficient in the recording of 3D images, as well as expanding its 3 dimensional data set far beyond what an equally orbiting flat detector satellite camera could accomplish in the same time space. Furthermore, its time base for imaging in 3D will be denser in multi-dimensional detail due to the curved focal plane benefits just described, and can be enhanced to an even greater extent by coupling additional curved focal plane cameras along an axis aboard the satellite. In the case of the geosynchronous satellite utilizing a curved focal plane detector camera, the same benefits would apply as described previously, enabling these satellites to harness omnivergent imaging from a single fixed location in space, acquiring wider 3 dimensional fields of view for different imaged altitudes at higher resolutions and greater sensitivity, all in real-time, even as the satellite pivots its angle of view during a scanned sequence. Such satellites would also be able to perform real-time twin mode stereoscopic tracking over much wider fields of view and at higher resolutions for greater detailed 3D analysis of rapidly changing atmospheric phenomena or shifting land environmental activity over shorter time sequences.

The attributes of a satellite system containing curved focal plane sensors and adjoining optics would provide a real time remote sensing 3D imaging system capable of streaming high resolution, multi-spectral images from either a non-geosynchronous or geosynchronous satellite to an earth-based 3D display device, designed to receive and project such 3D images within seconds of retrieving the images. Such an imaging system would possess near instantaneous interactivity between ground controllers and the satellite to selectively process multiple perspective images from motion captured objects in 3D, at various scales, utilizing the new curved focal plane detection system. Such a 3D imaging system presently does not exist, and is not equipped with these abilities, although its usage has been sought in the scientific community, including the NOAA for high speed, rapidly changing weather conditions observed from space.

The stereoscopic characteristics of this 3D imaging system harnessing curved focal plane detection can take on several different forms, though yielding the same real time 3D capturing results. A tracking non-geosynchronous camera containing a curved focal plane sensor at 2K X 2K resolution will possess the beneficial feature of pivoting its central optical axis, accomplished at high speed and with no moving parts, reproducing the effect of having many cameras recording multiple points of view simultaneously over a single point source within the optical system. Furthermore, the optical system will be simplified, having a reduced number of optical components, and physically condensed in size and mass through an optimization technique in matching to the native Petzval curvature of the chosen optical design. The speed and trajectory of the satellite will act as its stereo base, due to the fact that multiple axes will time sequentially be grouped and paired to retrieve the streaming 3D high resolution images. No such space imaging system has achieved this objective.

Another embodiment of this 3D remote sensing curved focal plane detection system is with twin satellites that remain in geosynchronous orbit near the earth's equator. In this example, the probing satellites whose imagers are curved focal plane enabled possess all the same benefits as described above, but with the added feature of locking in a preferred stereo convergence, changeable over high speed due to rapidly adjusting moving apertures and optical axes, with no mechanical moving parts, with both cameras situated several kilometers apart in space to produce sufficient 3D optical depth for orbits several hundred miles above the earth. For lower earth satellites, an extended boom could be designed into the twin camera array to capture ground based or atmospheric phenomena in real time 3D in reference to other large scale stereo imaging instruments such as those used by NASA in Project Stereo with the sun. In this instance, the cameras' curved focal plane detectors provide multiple and rapidly adjustable convergence angles as in the previous examples, introducing an imaging feature in capturing real time 3D volumetric data at high resolution for highly turbulent atmospheric phenomena, which is presently beyond the scope of current remote sensing orbiting systems.

The generalized capture and transmission of real time stereoscopic images from terrestrial sources, or from space, represents a new technology paradigm, and has only recently been demonstrated in practice, as in the case of NASA's Project Stereo. In the specialization category of simultaneous multi-axial optical imaging used in conjunction with curved focal plane technology is a new technology that can adapt previous stereo imaging algorithms that have been demonstrated for use, while also combining additional new technologies never before tested in this format. Typically, tracking satellites record their imagery from a fixed central optical axis, transmit data to a home base, where the imagery is recompiled and reconstructed three dimensionally, with no interactive earth-based control enabled instantaneously. In this new format, multiple perspective views recorded at high resolution from differing optical axes from the same camera are streamed back to earth and reassembled sequentially, without the need for computer driven 3D reconstruction. This particular step will require the introduction of a new algorithm tailored for space based real time autostereoscopic imaging with co-functional real time manipulation of the angles of the 3D camera system utilizing curved focal plane technology. The chip design of the curved focal plane imager will be dependent upon the need for very high speed and very high resolution multi-spectral imaging, and the shortfalls of previous flat imagers will be overcome in the construction of the new chip, including radiation hardening and other factors for a space environment. Other recent radio telemetry improvements, both technological and scientific, specifically enable data bandwidth expansion that addresses the wider signal signature transmitted back to earth to achieve real time 3D imaging capabilities on earth, and the necessary synchronization methodology brought into play by this new technique.

In researching space borne satellite camera systems currently in operation, none to date have the capability of producing real time multi-optical-axial, and consequently, multi-perspective views of an imaged region of the earth during the satellite's orbital tracking mode, and thereby cannot furnish real time 3D imaging of the earth's surface, or oceanic, or atmospheric phenomena as well. Continuous real time 3D imaging with real time multiple perspective views captured and observed from space and viewed as streaming 3D images sent to ground-based laboratories of such phenomena is crucial to advancing the science of those groups who design and operate such satellites.