Physical Sciences

Photon Counting Using Edge-Detection Algorithm

Improved optical communications links can be used in building-to-building networks in high-attenuation conditions such as rain or fog.

NASA's Jet Propulsion Laboratory, Pasadena, California

New applications such as high-data-rate, photon-starved, free-space optical communications require photon counting at flux rates into gigaphoton-per-second regimes coupled with subnanosecond timing accuracy. Current single-photon detectors that are capable of handling such operating conditions are designed in an array format and produce output pulses that span multiple sample times. In order to discern one pulse from another and not to overcount the number of incoming photons, a detection algorithm must be applied to the sampled detector output pulses. As flux rates increase, the ability to implement such a detection algorithm becomes difficult within a digital processor that may reside within a field-programmable gate array (FPGA).

Systems have been developed and implemented to both characterize gigahertz bandwidth single-photon detectors, as well as process photon count signals at rates into gigaphotons per second in order to implement communications links at SCPPM (serial concatenated pulse position modulation) encoded data rates exceeding 100 megabits per second with efficiencies greater than two bits per detected photon.

A hardware edge-detection algorithm and corresponding signal combining and deserialization hardware were developed to meet these requirements at sample rates up to 10 GHz. The photon discriminator deserializer hardware board accepts four inputs, which allows for the ability to take inputs from a quadphoton counting detector, to support requirements for optical tracking with a reduced number of hardware components. The four inputs are hardware leading-edge detected independently. After leading-edge detection, the resultant samples are "ORed" together prior to deserialization. The deserialization is performed to reduce the rate at which data is passed to a digital signal processor, perhaps residing within an FPGA.

The hardware implements four separate analog inputs that are connected through RF connectors. Each analog input is fed to a high-speed 1-bit comparator, which digitizes the input referenced to an adjustable threshold value. This results in four independent serial sample streams of binary 1s and 0s, which are ORed together at rates up to 10 GHz. This single serial stream is then deserialized by a factor of 16 to create 16 signal lines at a rate of 622.5 MHz or lower for input to a high-speed digital processor assembly.

The new design and corresponding hardware can be employed with a quad-photon counting detector capable of handling photon rates on the order of multi-gigaphotons per second, whereas prior art was only capable of handling a single input at 1/4 the flux rate. Additionally, the hardware edge-detection algorithm has provided the ability to process 3–10× higher photon flux rates than previously possible by removing the limitation that photon-counting detector output pulses on multiple channels being ORed not overlap. Now, only the leading edges of the pulses are required to not overlap. This new photon counting digitizer hardware architecture supports a universal front end for an optical communications receiver operating at data rates from kilobits to over one gigabit per second to meet increased mission data volume requirements.

This work was done by Jonathan W. Gin, Danh H. Nguyen, and William H. Farr of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.
NPO-47046

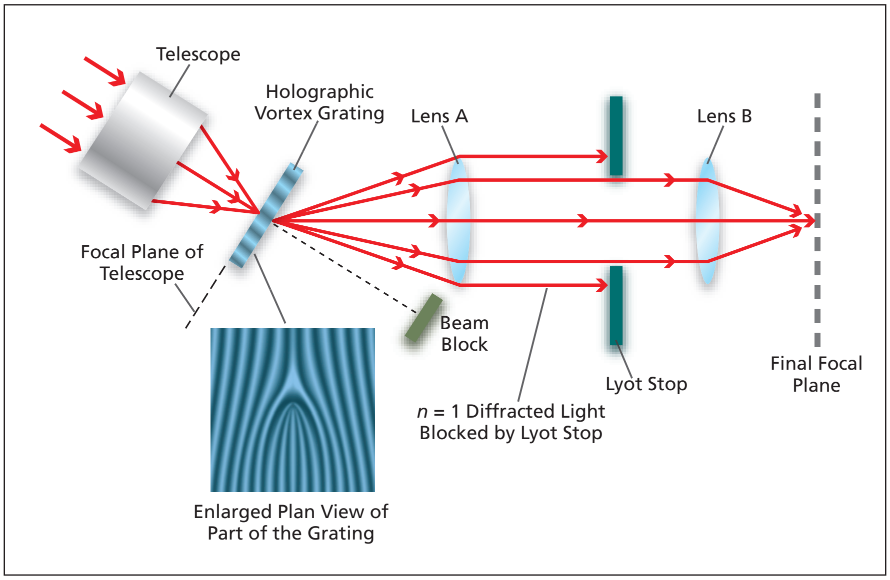
Holographic Vortex Coronagraph

This apparatus offers potential advantages of performance and manufacturability over conventional coronagraphs.

NASA's Jet Propulsion Laboratory, Pasadena, California

A holographic vortex coronagraph (HVC) has been proposed as an improvement over conventional coronagraphs for use in high-contrast astronomical imaging for detecting planets, dust disks, and other broadband light scatterers in the vicinities of stars other than the Sun. Because such light scatterers are so faint relative to their parent stars, in order to be able to detect them, it is necessary to effect ultra-high-contrast (typically by a factor of the order of 10^{10}) suppression of broadband light from the stars. Unfortunately, the performances of conventional coronagraphs are limited by low throughput, dispersion, and difficulty of satisfying challenging manufacturing requirements. The HVC concept offers the potential to overcome these limitations.

A key feature of any coronagraph is an occulting mask in the image plane of a telescope, centered on the optical axis of the telescope. In a conventional coronagraph, the occulting mask is an opaque amplitude mask that obstructs the central starlight when the optical axis points toward the star in question. In the HVC, the occulting mask is a holographic vortex grating, which may be created by etching or otherwise forming the interference pattern of a helical phase ramp and a plane wave beam into



In a **Holographic Vortex Coronagraph**, a telescope would focus light onto a blazed first-order vortex grating. A beam block would absorb residual undiffracted light. Lens A would collimate the first-order-diffracted light, forming an exit pupil wherein a Lyot stop would be placed. Lens B would re-image the light transmitted through the Lyot stop to the final focal plane.

an optical surface. As shown in the figure, the interference pattern has a forked appearance.

Light incident perpendicular to the grating is diffracted into discrete orders at angles given by $\theta_n = \sin^{-1}(n\lambda/d)$, where n is the diffraction order, λ is the wavelength of the diffracted light, and d is the lateral distance between adjacent grooves in the grating. In addition, the grating could be blazed to concentrate the diffracted light primarily into one order. If the grating is blazed to concentrate the light into the first (n = 1) order, then almost all of the light from a star or any other on-axis source will be transformed into a beam having a helical wavefront. Total destructive interference occurs along the axis of the helix over a broad wavelength band, attenuating the light from the star or other on-axis source.

The holographic vortex grating in the HVC is placed at the focus of the telescope and is designed and fabricated so as to almost completely suppress light from an on-axis star without significantly affecting images of planets or other light scatterers near the star. The starlight removed from the exit pupil appears outside exit pupil, whereas the light from scatterers near the star appears within the exit pupil. A Lyot stop — an aperture stop to block the starlight while passing the light from nearby scatterers — is placed in the exit pupil.

On the basis of previous research, it is anticipated that in comparison with a conventional coronagraph, the HVC would be less sensitive to aberrations, would yield higher throughput of light from scatterers near stars, and would offer greater planet/star contrast. On the basis of previous achievements in the fabrication of gratings similar to holographic vortex gratings, it appears that the grating for the HVC could readily be fabricated to satisfy initial requirements for imaging of extrasolar planets.

This work was done by David Palacios of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-45047

Optical Structural Health Monitoring Device

This device detects microscopic cracks and surface structural changes in components.

Dryden Flight Research Center, Edwards, California

This non-destructive, optical fatigue detection and monitoring system relies on a small and unobtrusive light-scattering sensor that is installed on a component at the beginning of its life in order to periodically scan the component *in situ*. The method involves using a laser beam to scan the surface of the monitored component. The device scans a laser spot over a metal surface to which it is attached. As the laser beam scans the surface, disruptions in the surface cause increases in scattered light intensity. As the disruptions in the surface grow, they will cause the light to scatter more. Over time, the scattering intensities over the scanned line can be compared to detect changes in the metal surface to find cracks, crack precursors, or corrosion. This periodic monitoring of the surface can be used to indicate the degree of fatigue damage on a component and allow one to predict the remaining life and/or incipient mechanical failure of the monitored component.

This wireless, compact device can operate for long periods under its own battery power and could one day use harvested power. The prototype device uses the popular open-source TinyOS operating system on an off-the-shelf Mica2 sensor mote, which allows wireless command and control through dynamically reconfigurable multi-node sensor networks. The small size and long life of this device could make it possible for the nodes to be installed and left in place over the course of years, and with wireless communication, data can be extracted from the nodes by operators without physical access to the devices.

While a prototype has been demonstrated at the time of this reporting, further work is required in the system's development to take this technology into the field, especially to improve its power management and ruggedness. It should be possible to reduce the size and sensitivity as well. Establishment of better prognostic methods based on these data is also needed. The increase of surface roughness with fatigue is closely connected to the microstructure of the metal, and ongoing research is seeking to connect this observed evidence of the fatigue state with microstructural theories of fatigue evolution to allow more accurate prognosis of remaining component life. Plans are also being discussed