Vision System Measures Motions of Robot and External Objects

Frame rates greatly exceed those of prior systems.

NASA's Jet Propulsion Laboratory, Pasadena, California

A prototype of an advanced robotic vision system both (1) measures its own motion with respect to a stationary background and (2) detects other moving objects and estimates their motions, all by use of visual cues. Like some prior robotic and other optoelectronic vision systems, this system is based partly on concepts of optical flow and visual odometry. Whereas prior optoelectronic visual-odometry systems have been limited to frame rates of no more than 1 Hz, a visual-odometry subsystem that is part of this system operates at a frame rate of 60 to 200 Hz, given optical-flow estimates. The overall system operates at an effective frame rate of 12 Hz. Moreover, unlike prior machine-vision systems for detecting motions of external objects, this system need not remain stationary: it can detect such motions while it is moving (even vibrating).

The system includes a stereoscopic pair of cameras mounted on a moving robot. The outputs of the cameras are digitized, then processed to extract positions and velocities. The initial image-data-processing functions of this system are the same as those of some prior systems: Stereoscopy is used to compute three-dimensional (3D) positions for all pixels in the camera images. For each pixel of each image, optical flow between successive image frames is used to compute the two-dimensional (2D) apparent relative translational motion of the point transverse to the line of sight of the camera.

The challenge in designing this system was to provide for utilization of the 3D information from stereoscopy in conjunction with the 2D information from optical flow to distinguish between motion of the camera pair and motions of external objects, compute the motion of the camera pair in all six degrees of translational and rotational freedom, and robustly estimate the motions of external objects, all in real time. To meet this challenge, the system is designed to perform the following image-data-processing functions:

The visual-odometry subsystem (the subsystem that estimates the motion of the camera pair relative to the stationary background) utilizes the 3D information from stereoscopy and the 2D information from optical flow. It computes the relationship between the 3D and 2D motions and uses a least-mean-squares technique to estimate motion parameters. The least-mean-squares technique is suitable for real-time implementation when the number of external-moving-object pixels is smaller than the number of stationary-background pixels.

In another subsystem, pixels representative of external transversely moving objects are detected by means of differences between (1) apparent transverse velocities computed from optical flow and (2) the corresponding relative transverse velocities estimated from visual odometry under the temporary assumption that all pixels belong to the stationary background.

In yet another subsystem, pixels representative of radially moving objects are detected by means of differences between (1) changes in radial distance estimated from changes in stereoscopic disparities between successive image frames and (2) the corresponding relative radial velocities estimated from visual odometry under the temporary assumption that all pixels belong to the stationary background. However, it is more difficult to detect radial than to detect transverse motion, especially at large distances. This difficulty is addressed by incorporating several additional processing features, including means to estimate rates of change of stereoscopic disparities, post-processing to prevent false alarms at low signal-to-noise ratios, and taking advantage of sometimes being able to distinguish between radial-motion optical flow and transverse-motion optical flow at short distances.

This work was done by Ashit Talukder and Larry Matthies of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). ***NPO-40687***

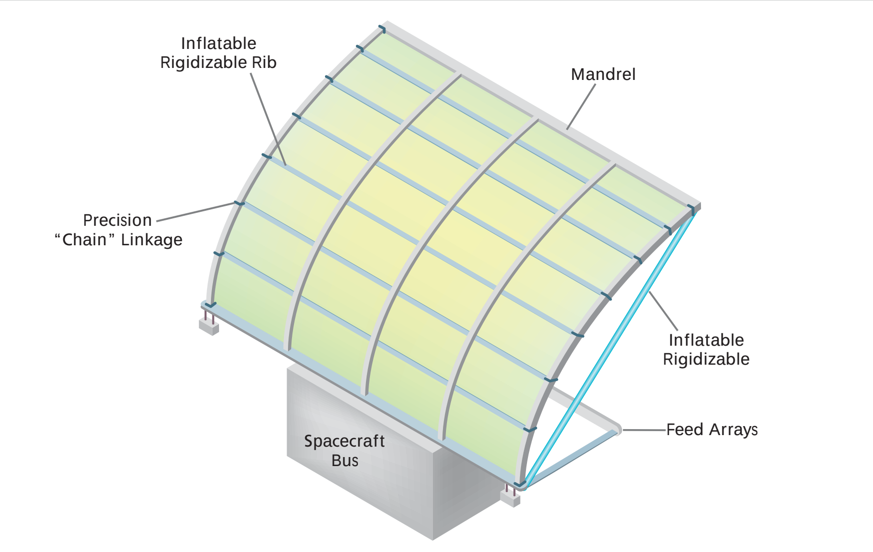
Advanced Precipitation Radar Antenna To Measure Rainfall From Space

This parabolic cylindrical reflector uses Ku and Ka bands.

NASA's Jet Propulsion Laboratory, Pasadena, California

To support NASA's planned 20-year mission to provide sustained global precipitation measurement (EOS-9 Global Precipitation Measurement (GPM)), a deployable antenna has been explored with an inflatable thin-membrane structure. This design uses a 5.3×5.3-m inflatable parabolic reflector with the electronically scanned, dual-frequency phased array feeds to provide improved rainfall measurements at 2.0-km horizontal resolution over a cross-track scan range of up to ±37°, necessary for resolving intense, isolated storm cells and for reducing the beam-filling and spatial sampling errors. The two matched radar beams at the two frequencies (Ku and Ka bands) will allow unambiguous retrieval of the parameters in raindrop size distribution.

The antenna is inflatable, using rigidizable booms, deployable chain-link supports with prescribed curvatures, a smooth, thin-membrane reflecting surface, and an offset feed technique to achieve the precision surface tolerance (0.2 mm RMS) for meeting the low-sidelobe requirement. The cylindrical parabolic offset-feed reflector augmented with two linear phased array feeds achieves dual-frequency shared-aperture with wide-angle beam scanning and very low sidelobe level of –30 dB. Very long Ku and Ka band microstrip feed arrays incorporating a combination of parallel and series power divider lines with cosine-over-pedestal distribution also augment the sidelobe level and beam scan. This design reduces antenna mass and launch



The configuration of the radar antenna features a **Chain-Link Support Structure** that is space-deployable.

vehicle stowage volume. The Ku and Ka band feed arrays are needed to achieve the required cross-track beam scanning. To demonstrate the inflatable cylindrical reflector with two linear polarizations (V and H), and two beam directions (0° and 30°), each frequency band has four individual microstrip array designs. The Ku-band array has a total of 166×2 elements and the Ka-band has 166×4 elements with both bands having element spacing about 0.65 λ_0.

The cylindrical reflector with offset linear array feeds reduces the complexity from "N×N" transmit/receive (T/R) modules of a conventional planar-phased array to just "N" T/R modules. The antenna uses T/R modules with electronic phase-shifters for beam steering. The offset reflector does not provide poor cross-polarization like a double-curved offset reflector would, and it allows the wide scan angle in one plane required by the mission. Also, the cylindrical reflector with two linear array feeds provides dual-frequency performance with a single, shared aperture. The aperture comprises a reflective surface with a focal length of 1.89 m and is made from aluminized Kapton film. The reflective surface is of uniform thickness in the range of a few thousandths of an inch and is attached to the chain-link support structure via an adjustable suspension system. The film aperture rolls up, together with the chain-link structure, for launch and can be deployed in space by the deployment of the chain-link structure.

This work was done by Yahya Rahmat-Samii of UCLA; John Lin of ILC Dover, Inc.; and John Huang, Eastwood Im, Michael Lou, Bernardo Lopez, and Stephen Durden of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-40470

Wide-Band Radar for Measuring Thickness of Sea Ice

This instrument could contribute to understanding of climate change.

NASA's Jet Propulsion Laboratory, Pasadena, California

A wide-band penetrating radar system for measuring the thickness of sea ice is under development. The need for this or a similar system arises as follows: Spatial and temporal variations in the thickness of sea ice are important indicators of heat fluxes between the ocean and atmosphere and, hence, are important indicators of climate change in polar regions. A remote-sensing system that could directly measure the thickness of sea ice over a wide thickness range from aboard an aircraft or satellite would be of great scientific value. Obtaining thickness measurements over a wide region at weekly or monthly time intervals would contribute significantly to understanding of changes in the spatial distribution and of the mass balance of sea ice.

A prototype of the system was designed on the basis of computational simulations directed toward understanding what signal frequencies are needed to satisfy partly competing requirements to detect both bottom and top ice surfaces, obtain adequate penetration despite high attenuation in the lossy sea-ice medium, and obtain adequate resolution, all over a wide thickness range. The prototype of the system is of the frequency-modulation, continuous-wave (FM-CW) type. At a given time, the prototype functions in either of two frequency-band/operational-mode combinations that correspond to two thickness ranges: a lower-frequency (50 to 250 MHz) mode for measuring thickness greater than about 1 m, and a higher-frequency (300 to 1,300 MHz) mode for measuring thickness less than about 1 m. The bandwidth in the higher-frequency (lesser-thickness) mode is adequate for a thickness resolution of 15 cm; the bandwidth in the lower-frequency (greater-thickness) mode is adequate for a thickness resolution of 75 cm. Although a thickness resolution of no more than 25 cm is desired for scientific purposes, the 75-cm resolution was deemed acceptable for the purpose of demonstrating feasibility.

The prototype was constructed as a modified version of a 500-to-2,000-MHz FM-CW radar system developed previously for mapping near-surface internal layers of the Greenland ice sheet. The prototype included two sets of antennas: one for each frequency-band/mode. For Arctic and Antarctic field tests, the prototype was mounted on a sled that was towed across the ice. The Arctic field test was performed in the lower-frequency mode on ice ranging in thickness from 1 to 4 m. In the analysis of the results of the Arctic field test, a comparison of the radar-determined ice thicknesses with actual ice thicknesses yielded an overall mean difference of 14 cm and standard deviation of 30 cm. The Antarctic field test was performed in the higher-fre-