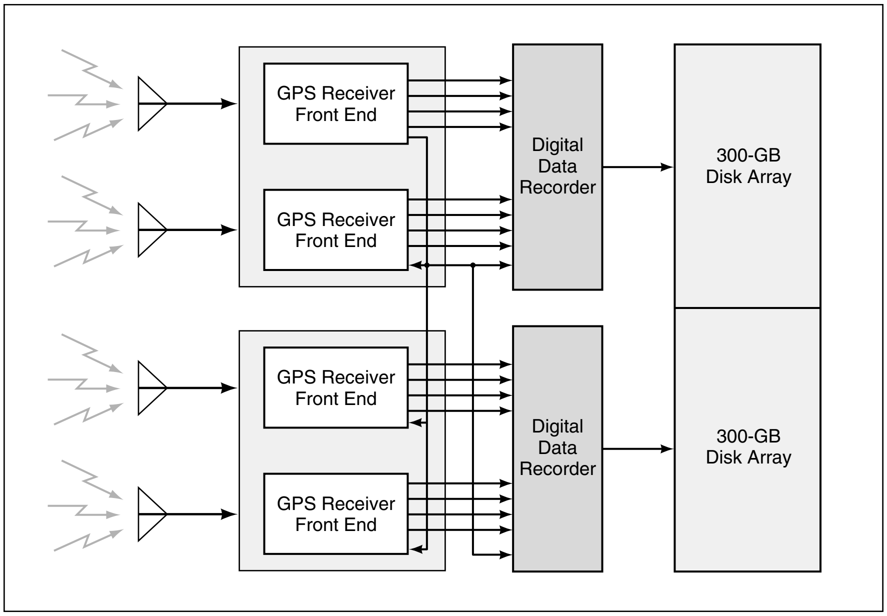


This **Airborne Subsystem** samples direct and reflected GPS signals and records the resulting data. Later, the data are uploaded to general-purpose computers for processing by software that performs a variety of standard and custom GPS receiver functions.

(GLONASS) and the proposed European Galileo system.

This remote-sensing system offers both advantages and disadvantages over traditional radar altimeters: One advantage of GPS-reflection systems is that they cost less because there is no need to transmit signals. Another advantage is that there are more simultaneous measurement opportunities — one for each GPS satellite in view. The primary disadvantage is that in comparison with radar signals, GPS signals are weaker, necessitating larger antennas and/or longer observations.

This GPS-reflection remote-sensing system was tested in aircraft and made to record and process both (1) signals coming directly from GPS satellites by means of an upward-looking antenna and (2) GPS signals reflected from the ground by means of a downward-looking antenna. In addition to performing conventional GPS processing, the system records raw signals for postprocessing as required.

The figure schematically depicts the airborne equipment part of the present system. Four synchronized GPS receiver front ends, each connected to a separate antenna, sample the complex (in-phase and quadrature) GPS L1 (1,575.42 MHz) and L2 (1,227.6) signals at a rate of 20.456 MHz. The sampling clock in one receiver front end is used as a master clock for synchronizing all four receivers and two digital data recorders. The raw samples are fed through the digital data recorders for storage on two 300-GB arrays of hard disks. Subsequently, the digitized samples are processed by software that performs functions similar to those of GPS hardware receivers, plus additional processing of the reflected signals.

Whereas prior such systems have utilized the delay information in the GPS signals, this system also utilizes the Doppler shifts of the signals to increase precision and extract additional information about the terrain or water surface under observation. The system offers 160 to 320 times the data-collection bandwidth of prior GPS-reflection remote-sensing systems. Moreover, unlike other such systems that do not have reprocessing capability, this system affords much greater flexibility because it can be made to reprocess the recorded signal data at will.

The software signal-processing functions in this system include detection of signals; tracking of phases and delays; mapping of delay, Doppler, and delay/Doppler waveforms; dual-frequency (L1 and L2) processing; coherent integrations as short as 125 µs; decoding of navigation messages; and precise time tagging of observable quantities. The software can perform these functions on all detectable satellite signals without dead time. Custom signal-processing features can easily be included: For example, in principle, data collected over the ocean by this system can be processed to extract mean sea height, wind speed and direction, and significant wave height; data collected over land can be processed to extract measures of soil moisture and biomass; and data collected over ice can be processed to obtain estimates of the ice age, thickness, and surface density.

This work was done by Stephen Lowe, Peter Kroger, Garth Franklin, John LaBrecque, Jesse Lerma, Michael Lough, Martin Marcin, Ronald Muellerschoen, Donovan Spitzmesser, and Lawrence Young of Caltech for **NASA's Jet Propulsion Laboratory***. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com****.*

NPO-30385

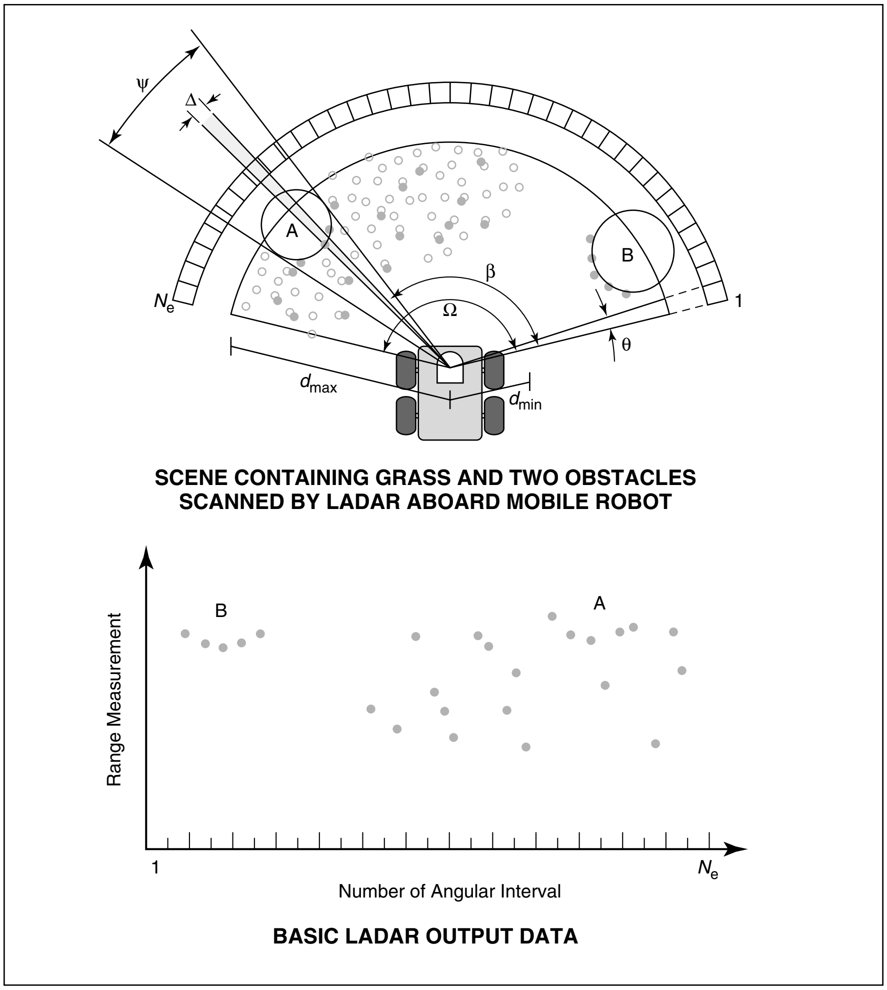
Ladar System Identifies Obstacles Partly Hidden by Grass

A robot moving cross country (e.g., an agricultural robot) could avoid obstacles.

NASA's Jet Propulsion Laboratory,
Pasadena, California

A ladar-based system now undergoing development is intended to enable an autonomous mobile robot in an outdoor environment to avoid moving toward trees, large rocks, and other obstacles that are partly hidden by tall grass. The design of the system incorporates the assumption that the robot is capable of moving through grass and provides for discrimination between grass and obstacles on the basis of geometric properties extracted from ladar readings as described below.

The system (see figure) includes a ladar system that projects a range-measuring pulsed laser beam that has a small angular width of Δ radians and is capable of measuring distances of reflective objects from a minimum of d_{min} to a maximum of d_{max}. The system is equipped with a rotating mirror that



SCENE CONTAINING GRASS AND TWO OBSTACLES SCANNED BY LADAR ABOARD MOBILE ROBOT

BASIC LADAR OUTPUT DATA

Ladar Aboard a Robotic Vehicle scans through a fan-shaped area to measure distances to nearby objects, which are represented here by circles. The small circles represent stalks of grass. Large circle A represents a tree trunk partly hidden by grass; large circle B represents a tree trunk in the clear.

scans the beam through a relatively wide angular range of Ω in a horizontal plane at a suitable small height above the ground. Successive scans are performed at time intervals of τ seconds. During each scan, the laser beam is fired at relatively small angular intervals of θ radians to make range measurements, so that the total number of range measurements acquired in a scan is $N_e = \Omega/\theta$.

The basic ladar output data for each scan consist of a range measurement for each of the N_e angular intervals. These data are processed by an algorithm that classifies objects as either foliage (that is, grass stalks) or not foliage (that is, obstacles). Objects to which the algorithm cannot assign the classification “foliage” with a sufficiently high degree of confidence are conservatively classified as “not foliage” to ensure avoidance of obstacles.

The classification is made on the basis of three locality principles that are here described by reference to object A at scan angle β in the figure. The first principle is one of locality in both space and time: If A is an obstacle and is found at angle β at time t, then it will be found at an angle near β at time $t + \tau$. The second principle is that if A is an obstacle, it must subtend a substantial angle ψ and all laser-beam directions that intersect A must lie within the angular range $\beta\pm\psi$. The third principle is one of spatial locality of the gaps between grass stalks that enable the laser beam to penetrate the foliage and reach object A: If the laser beam penetrates the foliage and hits A when aimed at angle β, then it is also likely to do so when aimed at angle $\beta\pm\Delta$. These locality principles hold for any combination of motions of the robot and the obstacles, as long as the angular sampling interval (θ) and the time between consecutive scans (τ) are sufficiently small.

This work was done by Andres Castano of Caltech for **NASA’s Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com****.*
NPO-30597

Books and Reports

Survivable Failure Data Recorders for Spacecraft

A spacecraft may be unable to communicate critical data associated with a serious or catastrophic failure. A brief report proposes a system, somewhat like a commercial aircraft “black box,” for retrieving these data. A microspacecraft attached to the prime spacecraft would continually store recent critical data from that spacecraft. If either spacecraft detected certain serious conditions of the prime spacecraft, the microspacecraft would separate from the prime spacecraft and independently transmit the stored data to Earth. Supplemental data, acquired from sensors onboard the microspacecraft, could be added to this transmission. For example, the orientation and angular rates of the prime spacecraft immediately before separation as well as pictures taken of the prime spacecraft after separation could be included. Functional enhancements over aircraft black boxes include the separation from the prime vehicle (which gains independence from the fate of that vehicle), wireless transmission of data (making physical black box recovery unnecessary), and the optional acquisition of supplemental sensor data.

This work was carried out by John Carraway and David Collins of Caltech for **NASA’s Jet Propulsion Laboratory**. *To obtain a copy of the report “Spacecraft ‘Black Box’ Flight Recorder,” access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com****. NPO-20842*