The design of the system incorporates the assumption that the robot is capable of moving through grass and 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 $d_{\text{min}}$ to a maximum of $d_{\text{max}}$. The system is equipped with a rotating mirror that

**Ladar System Identifies Obstacles Partly Hidden by Grass**

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

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 $d_{\text{min}}$ to a maximum of $d_{\text{max}}$. The system is equipped with a rotating mirror that
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 \( \beta \) 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 \( \beta \) at time \( t \), then it will be found at an angle near \( \beta \) at time \( t + \tau \). The second principle is that if A is an obstacle, it must subtend a substantial angle \( \psi \) 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 \( \beta \), 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 \( \theta \) and the time between consecutive scans \( \tau \) are sufficiently small.

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