Guest Editorial: Passive Ranging for Robotic Systems

INTRODUCTION

The understanding of the three-dimensional (3-D) world, captured in two-dimensional (2-D) images acquired using electro-optical sensors, provides an extremely important capability for the diverse applications of robotic systems. Scene understanding is possible by explicitly reconstructing the scene by obtaining

1. the range values to discrete 3-D points in the scene, and
2. segmenting and labeling 2-D images acquired where the range values to each of the parts are known.

The reconstructed scene provides sufficient information to any autonomous robotic system involved in navigation and guidance, obstacle detection, landmark identification, map updating, tracking, object recognition, manipulation, inspection, and industrial automation. It is to be noted that range or depth information is essential for any navigation system whether or not that system has domain knowledge to start with.

The range information can be obtained by using either an active sensor or a passive sensor. Although active sensors can provide dense range, they do not provide large field-of-view, high resolution, and high data rates—features that are required in many practical outdoor applications. Moreover, their active nature makes them unsuitable for some applications that require covertness. Passive sensors, for example, high-quality electro-optical sensors, can operate in outdoor environments, are less expensive than active sensors, such as laser range finders and millimeter wave radars, and allow ranging to surfaces that may not be suitable for active sensors. Although these sensors may provide very high data rates in acquiring the images, they may require special-purpose hardware for generating range values in real-time.

Passive sensors provide a means of computing the range information that does not require transmitting/receiving electromagnetic energy but uses image-based techniques such as binocular stereo, motion stereo, “shape form X,” and focusing methods. For navigation using passive ranging in unstructured outdoor environments, binocular and motion stereo make the most sense.

Passive ranging using binocular stereo method involves feature-based or field-based methods that require feature extraction (salient points, lines, contours, regions), matching (correspondence, correlation, etc.), and depth determination. Passive ranging using motion stereo involves gradient-based optical
flow or feature-based optical flow measurements from which the range and the sensor platform motion are derived. More recently, an integration of binocular and motion stereo has become a popular approach. Several algorithms have been developed in the last two decades under the sponsorship of NASA and DARPA to compute the depth using binocular stereo and optical flow-based motion stereo. However, until recently, research in this area has not stressed the verification of the algorithms using image data of outdoor scenes, especially for motion stereo-based methods. This is necessary for the user community in guidance and navigation who can now have some confidence in the application of computer vision algorithms to real-world problems.

The objective of this special issue of the *Journal of Robotic Systems* is to bring together the state-of-the-art techniques that are useful for passive ranging for navigation and guidance in outdoor scenarios.

**SPECIAL ISSUE**

To provide an opportunity to discuss some of the issues involved in passive ranging, NASA conducted a Helicopter Obstacle Detection Workshop July 10–11, 1990. This workshop was followed by the IEEE Special Workshop on Passive Ranging held at Princeton, New Jersey, October 10, 1991. Some of the issues discussed in these workshops were accuracy of range maps for near-term navigation, range sensitivity, error variation over the field of view, density of estimates, quantization and calibration errors, robustness of algorithms to varying environmental conditions, speed of algorithms, stabilization of the imaging system, criteria for evaluating algorithms, use of multiple sensors for robust navigation, standardized image sequences, and data collection. The seven articles in this special issue address some of these questions and were presented at the IEEE Special Workshop. All articles have been reviewed by two or three reviewers and have been revised.

The article by Sridhar, Suorsa, Smith, and Hussien describes the use of passive sensors for obstacle detection and avoidance during helicopter low-altitude flight. The helicopter flight presents natural scenery, maneuvering vehicle motion, objects at varying ranges, and the challenges of real-time computation. The authors give an overview of their approach and present range estimation results for both laboratory and flight data. The flight data were collected by NASA using a CH-47 helicopter and consist of imagery, helicopter motion parameters, camera parameters, and ground truth range measurements. The results show for the first time the feasibility of using vision-based algorithms for computing range information during helicopter flight.

Roberts and Bhanu describe an approach that computes range using passive sensors while taking advantage of the availability of inertial sensors. The meth-
odology used in this article consists of selecting interest points followed by feature matching to compute the optical flow. The optical flow together with the INS information is used to estimate range to objects. The sparse range measurements are interpolated to compute a dense range map. The method is applied to both indoor and outdoor images and the results are compared with the ground truth available for a small number of points.

Harris, Stephens, Sparks, and Pike describe an approach that derives range and camera motion information from a sequence of images. The method is applied to the helicopter sequence described by Sridhar and colleagues. The authors compute range by initializing the helicopter motion to be very close to the true motion information. Sparse range measurements are interpolated by Delaunay triangulation to produce a dense range map.

The article by Shekhar and Chellappa provides the description of a recursive method of passive range estimation given an image sequence and motion information. Feature points are extracted from the image using Gabor wavelets. Their formulation differs from the previous three articles by imposing the camera motion model to constrain the behavior of all the feature points. In practice, an image may contain hundreds or even thousands of features and the use of a single Kalman filter for all of the features in an image may require the solution of a large number of Kalman filter equations. The authors demonstrate their algorithm by tracking four features in a sample image set.

Kumar and Hanson use a sequence of images and a partial model of the 3-D world to compute a more complete and refined 3-D model of the world. Both modeled and unmodeled features of the object are tracked over the image sequence by using an optical flow-based line tracking algorithm.

Matthies describes the use of binocular stereo for land navigation. The article reviews the main algorithmic paradigms for stereo vision, describes a near real-time stereo vision system developed at the Jet Propulsion Laboratory, and presents experimental results that demonstrate the emerging practicality of stereo vision for obstacle detection in semiautonomous land navigation.

In the last article, Aloimonos presents some interesting and provocative ideas. The main thesis of the article is that navigation can be done without the knowledge of range. The author claims that, although passive ranging is sufficient for performing some tasks, it does not appear to be necessary. The key point of the approach is the determination of the time of contact based on normal optical flow. However, this information, available at isolated pixels that may be sparsely located, does not define an obstacle. Thus, one cannot rely on this approach for autonomous vehicle navigation in practical situations without additional constraints and scene information.

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Bir Bhanu and Banavar Sridhar

Vision-Based Obstacle Detection for Rotorcraft Flight
Banavar Sridhar, Ray Soursa, Phillip Smith, and Bassam Hussien

Passive Ranging Using a Moving Camera
Chandra Shekhar and Rama Chellappa

Model Extension and Refinement Using Pose Recovery Techniques
Rakesh Kumar and Allen R. Hanson

DROID Analysis of the NASA Helicopter Images
Chris Harris, Mike Stephens, Ed Sparks, and Mary Pike

Passive Stereo Range Imaging for Semi-Autonomous Land Navigation
Larry Matthies

Inertial Navigation Sensor Integrated Motion Analysis for Autonomous Vehicle Navigation
Barry Roberts and Bir Bhanu

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