Section 7: Sensing and Perception

The level of decisional autonomy, of adaptation and reactivity to the environment is directly related to the sensing capacities of the robot and its ability to build the correct representations. The papers in this section deal with several aspects of sensing.

The paper by E. Krotkov addresses sensing for the Ambler, a walking robot. In order to plan its motion, such a robot needs models of rugged terrain. The basic representation is an elevation map, i.e., a numerical description, built from laser range-finder data. It is hence important to have a good experimental model of the sensor.

A different aspect of perception is identification and localization of an object in a scene. A structured description is necessary for the object (planes, edges in this case). The problem is furthermore complicated if the object has a variable shape. M. Devy and J. Colly present an approach and results for the localization of an articulated object with a mobile multisensory system, using a laser range-finder and vision, with observations from several viewpoints.

M. Accordino, F. Gandolfo, G. Sandini and M. Tistarelli present a system integrating visual perception with manipulation. Indeed, object manipulation requires perception to close the loop. Hand-eye calibration is then the first necessary step, wich is performed by observing the end effector through the stereovision system. The approach adopted by the authors relies on the analysis of the optical flow for extracting qualitative information (e.g., equilibrium) or object motion estimation.

The paper by N. Andersen, O. Ravn and A. Sorensen reports on the use of vision for real-time motion control. Image processing being usually time consuming, they reduce it by dynamical selection of windows in the image. Furthermore, in order to cope with lighting constraints, an adaptative thresholding is used. Three different experimentations validate the work.

Mapping Rugged Terrain for a Walking Robot

Eric Krotkov
Robotics Institute, Carnegie Mellon University
Pittsburgh, PA 15213 USA

Abstract

This paper briefly reports on progress in the design and performance of a mapping system that uses laser rangefinder input to construct elevation maps of rugged, natural terrain. The paper emphasizes performance; the rationale for the design is presented elsewhere. The performance of two rangefinders is considered, and found to be the most significant limitation on the constructed maps. In addition, the accuracy and precision of the maps are quantified.

1 Introduction

The primary function of the currently implemented perception system for the Ambler walking robot (Figure 1) is to build maps of rugged terrain from sequences of range images. Planning modules use these maps to select footholds and to plan collision-free leg and body trajectories over the terrain. This paper outlines the current state of the perception system, focusing on *performance* rather than rationale, which is presented elsewhere [4, 6].

We have divided the perception system into modules that communicate via a central node. The implemented perception modules, slightly simplified for clarity of presentation, are the following.

Local Terrain Mapper— Builds elevation maps in a specified polygonal region of a specified reference frame. The module uses as many range images as necessary to build the requested map, processing the most recent images first. The maps are not stored between body moves.

Global Terrain Mapper— Builds elevation maps in a specified region of the global coordinate system. For convenience during indoor experiments, this reference frame is attached to the building.

Sensor Interface Manager— Each time the body moves an appreciable amount, this module acquires images from laser scanners and cameras and stamps them with the pose of the Ambler at the time of image acquisition. It then sends the images to the Image Queue Manager for storage.

Image Queue Manager— Maintains a doubly-linked list whose nodes are images tagged with properties. Handles insertion and deletion of records, plus traversal.

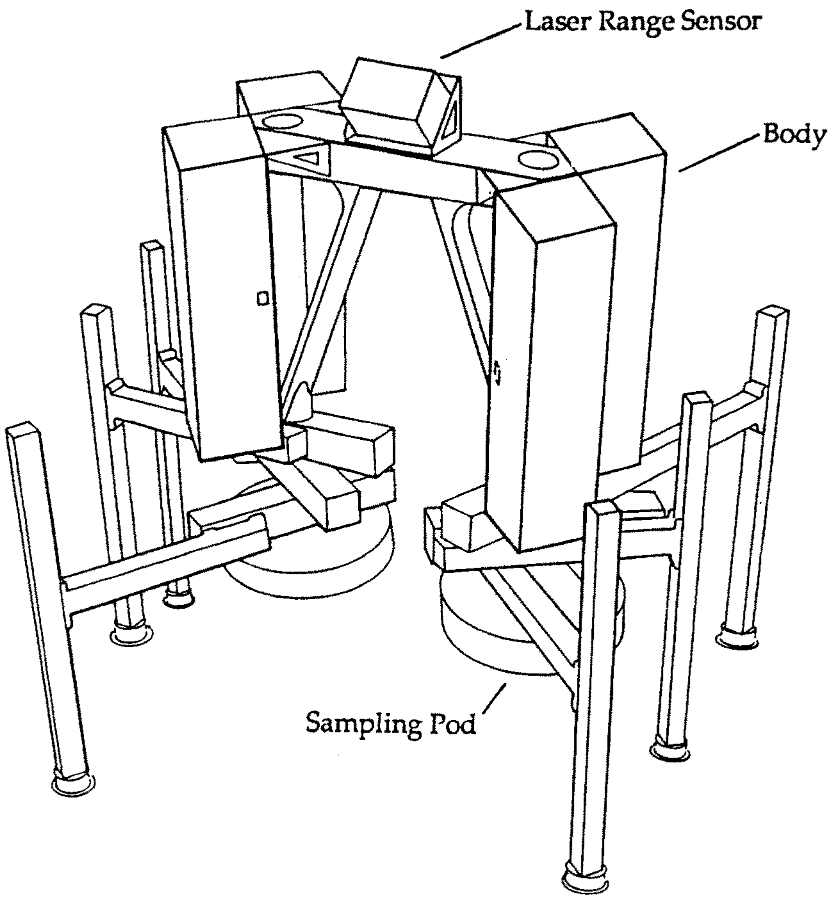
Laser Range Sensor
Body
Sampling Pod

Figure 1: Ambler walking robot
The figure shows the six-legged Ambler, and the Perceptron laser scanner mounted on the bridge between the two leg stacks.

Visual Position Estimation— Determines the pose of the Ambler from a single image and a pre-defined map marking locations of landmarks. This module employs the interpretation tree approach described in [2].

User Interface— Allows the user to communicate with external modules, view debugging information, select graphic displays, and control the flow of processing.

These modules have been implemented in C, and have been tested extensively during walking experiments. They are imperfect, but their performance—accuracy and precision—in constructing maps has proven to be sufficient for the Ambler to negotiate rugged, boulder-strewn, sloping terrain.

2 Scanning Laser Rangefinders

During walking experiments, we have employed two scanning laser rangefinder sensors, one manufactured by Erim, the other manufactured by Perceptron. In both cases, we have found the most significant limitations on the performance of the mapping system to be imposed by the sensors. Both exhibit some very desirable properties (high bandwidth and accuracy compared

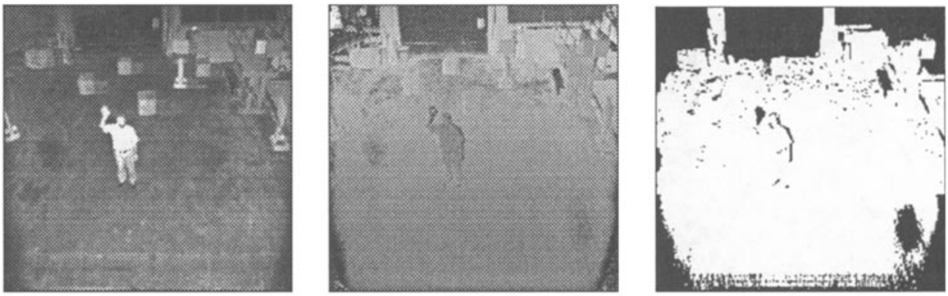

Figure 2: Perceptron images: reflectance (left), range (center), filtered

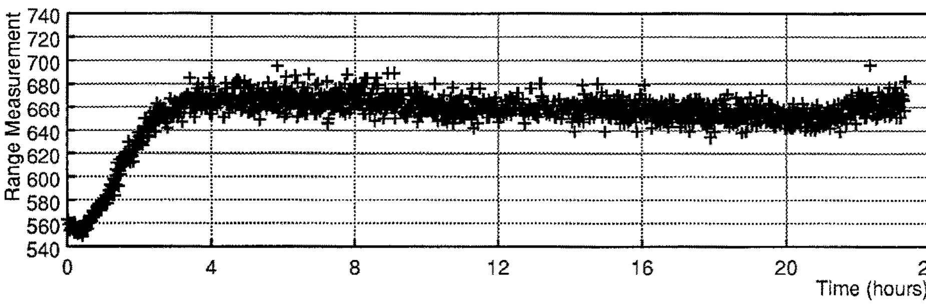

Figure 3: Range drift over 24 hours
The units of the ordinate are grey-levels, which correspond approximately to 1 cm. One measurement was acquired per minute with the Perceptron scanner. The target was a planar cardboard construction lying 6 m from the scanner.

to standard computer vision techniques, ability to function outdoors and in rugged, unknown terrain), and both suffer from some significant practical deficiencies requiring compensation.

We have systematically explored those drawbacks, and have experimentally characterized them [5]. There are more than a dozen known problems revealed in Figure 2. To illustrate one of them, consider the top central portion of the images, which correspond to a wooden garage door painted a dark green color. In the range image, grey-level is proportional to range; therefore, more distant objects should appear to be brighter. But the garage door appears to be darker than closer objects, contrary to our expectations. We have determined that the cause of this anomaly is the low infrared reflectivity of the dark wooden surface coupled with sensor processing artifacts. We have analyzed a number of similar problems with the range images, and have developed reasonably robust methods for handling them. Figure 2 illustrates the results of applying these methods.

Another problem is drift over time. Figure 3 illustrates the variations of the range measurements to a stationary target over a full day of observations. We compensate for this by changing the coefficients of the mapping from grey-levels to metric units.

3 Mapping Rugged Terrain

The mapping modules take as input the processed range images, and construct elevation maps from them using the *locus method* [1]. Figure 4 illustrates examples.

We determined the performance of the mapping modules by investigating the results of executing a calibration procedure that identifies the rigid transformation relating the sensor and body (or world) reference frames [3]. For both Erim and Perceptron sensors, the relative accuracy (accuracy in computing the dimensions of an object) is 5–10 cm, and the absolute accuracy (accuracy in computing the position of an object in an external reference frame) is 10–20 cm. The precision (repeatability) is 2–5 cm for both sensors. These figures do not take into account the inaccuracy of the Ambler navigation module, which consisted only of dead reckoning at the time of testing.

The achieved mapping performance has proven to be sufficient for the walking experiments conducted to date [6]. One reason for the success is that the errors are inferior to the size of the Ambler feet (30 cm diameter). For a more petite vehicle, the achieved performance may not have been adequate.

Acknowledgements

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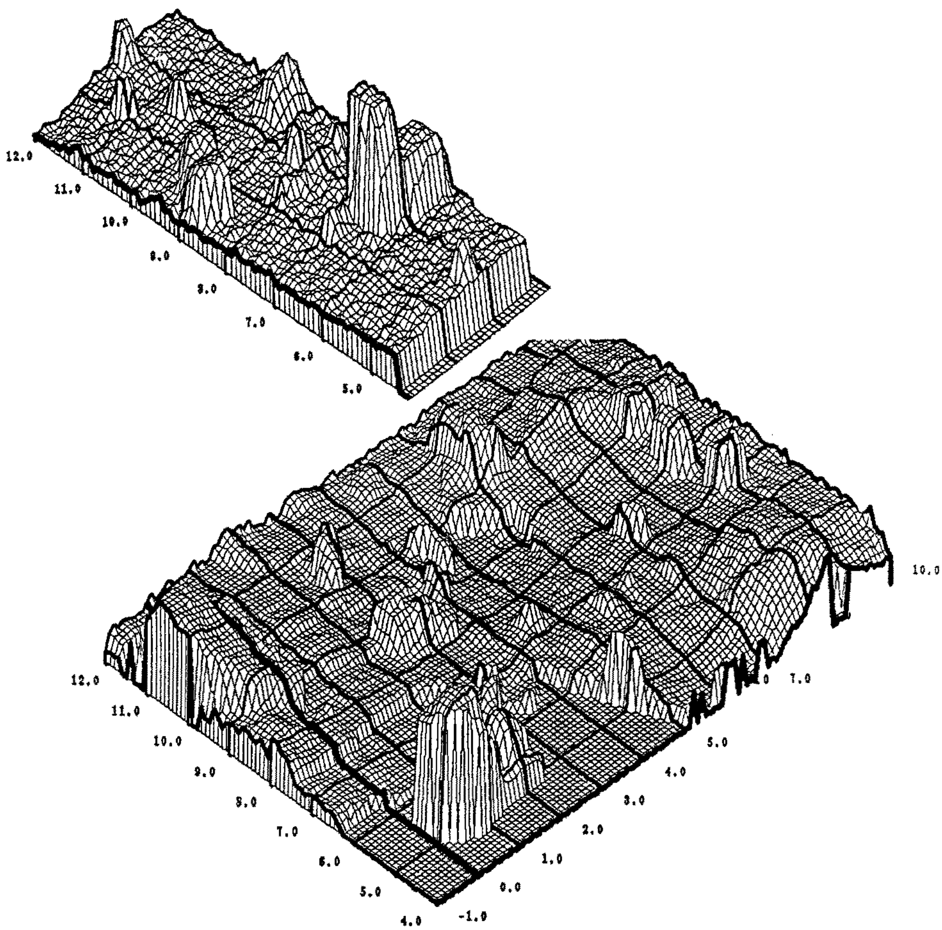

Figure 4: Maps constructed from Erim (left) and Perceptron imagery
The units are meters. The map resolution is 10 cm.