Computer Vision Techniques for Rotorcraft Low-Altitude Flight
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ABSTRACT: The automation of navigation and guidance in a rotorcraft performing low-altitude maneuvers poses challenging problems in computer vision and image understanding. This presentation gives a brief description of research in this area at NASA Ames Research Center.

Introduction

Rotorcraft operating in a high-threat environment fly close to the earth's surface to utilize surrounding terrain, vegetation, or man-made objects to minimize the risk of being detected by an enemy. Increasing levels of concealment are achieved by adopting different tactics during low-altitude flight. Figure 1 shows three tactics used during low-altitude flight: low-level mode, contour mode, and nap-of-the-earth (NOE) mode. The key feature distinguishing the NOE mode from the other two modes is that the whole rotorcraft, including the main rotor, is below tree-top whenever possible. This leads to the use of lateral maneuvers for avoiding obstacles, which, in fact, constitutes the means for concealment. The piloting of the rotorcraft is, at best, a very demanding task and the pilot will need help from on-board automation tools in order to devote more time to mission-related activities. The development of an automation tool that has the potential to detect obstacles in the rotorcraft flight path, warn the crew, and interact with the guidance system to avoid detected obstacles presents challenging problems.

This presentation describes research that applies techniques from computer vision to the automation of rotorcraft navigation. The effort emphasizes the development of a methodology for detecting the ranges to obstacles in the region of interest based on the maximum utilization of passive sensors. The range map derived from the obstacle detection approach can be used as obstacle data for the obstacle avoidance in an automatic guidance system and as advisory display to the pilot. The lack of suitable flight imagery data presents a problem in the verification of concepts for obstacle detection. This problem is being addressed by the development of an adequate flight data base and by processing of currently available flight imagery. The presentation concludes with some comments on future work and how research in this area relates to the guidance of other autonomous vehicles.

Obstacle Detection

The planning of rotorcraft low-altitude missions can be divided into far-field planning and near-field planning. Far-field planning involves the selection of goals and a nominal trajectory between the goals. Far-field planning is based on a priori information and requires a detailed map of the local terrain. However, the data base for even the best surveyed landscape will not have adequate resolution to indicate objects such as trees, buildings, wires, and transmission towers. This information has to be acquired using an on-board sensor and integrated into the navigation/guidance system to modify the nominal trajectory of the rotorcraft. Initially, passive imaging sensors like forward-looking infrared and low-light-level television will be considered for detection to assess the limitation of passive methods. The two basic requirements for obstacle avoidance are detection and range estimation of the objects from the current rotorcraft position.

There are many approaches to the estimation of range using a sequence of images. However, they can be divided into two categories depending on whether the analysis is based on optical flow techniques or feature considerations.

The optical flow approach [1] computes at each point in the image the velocity of the brightness pattern. The optical flow is similar to motion cues people use to estimate distance and relative velocity. The computation of optical flow for real scenes is extremely difficult and highly sensitive to noise.

The features in an image can be points, lines, contours, or any other clearly distinguishable part of the image. The extraction of features [2] in an image involves several considerations. A fundamental assumption of this approach is that correspondence between features in two images can be established prior to computation of range.

The extraction of range information and the simultaneous estimation of the observer (rotorcraft) motion parameters (translational and rotational velocity), using only image

Fig. 1. Typical tactics during low-altitude flight.
data, lead to ill-conditioned computations [3]. In the case of the rotorcraft, the motion parameters can be measured independently using an on-board navigation system; consequently, the use of image data only to locate obstacles results in more stable computations. Some of the requirements imposed by NOE flight on the selection of image sensors and on the processing of images are described in [4].

**Range-Estimation Algorithms**

Consider a scene as viewed from a sensor mounted at the center of gravity of the rotorcraft and with the viewing axis along the rotorcraft's longitudinal axis. Let the image plane be perpendicular to the viewing axis. The image-object geometry is shown in Fig. 2. Let p be the image corresponding to a stationary object P on the ground. Assume that the rotorcraft moves with a known translational and rotational velocity between two successive frames. As the rotorcraft moves, the coordinates of the object P change in the sensor axes and a new image \( p' \) is formed in the image plane. Given the rotorcraft position, orientation, and translational and rotational velocities at the two views of the scene, the apparent shift of the image \( pp' \) in two successive frames can be related to the distance of the object P from the rotorcraft.

However, the presence of pixel noise and other uncertainties in the image measurements leads to errors in the estimation of distance. The estimation accuracy can be improved by using a sequence of many images. Three different recursive position estimators based on a Kalman filter approach are discussed in [5].

**Concept of Safety Zone**

An application of the range estimation for advisory display is the concept of safety zone [6]. Consider a rotorcraft flying along a straight line. A safety zone can be defined by an imaginary tunnel ahead of the rotorcraft with the rotorcraft velocity as the axis of the tunnel. For the purpose of illustration, we assume the tunnel to have a circular cross section, although some other shape of cross section may be more appropriate for NOE flight. Based on this assumption, equally spaced cross sections of the tunnel appear as concentric circles in the image plane. The center, C, of the circles in the image plane corresponds to the direction of flight. As shown in Fig. 3, sections closer to the rotorcraft will appear as larger circles than sections farther away from the rotorcraft. In any given direction different from the direction of flight, an obstacle within the safety zone causes a reduction in the range when compared to the range of the tunnel wall. Since the shift in the image corresponding to an object in the scene is inversely proportional to the range, reduced range results in a larger than predicted shift. Thus, threatening objects along the flight corridor can be displayed on the image by comparing actual shift with the shift predicted based on the range to the tunnel wall.
Evaluation of Algorithms

The evaluation of rotorcraft obstacle detection algorithms can be done using imagery data acquired during rotorcraft flight. However, a data base containing rotorcraft low-altitude imagery together with rotorcraft and sensor parameters is not easily available. NASA Ames is in the process of developing such a data base [7]. In the mean time, we are evaluating algorithms using simulated data from the tests on Vertical Motion Simulator and, in the case of real flight imagery, by computing the rotorcraft parameters off-line [3] before processing the imagery for obstacles.

Future Work

Research is continuing at NASA Ames in the application of computer vision and image understanding to autonomous navigation of rotorcraft in low-altitude flight. The obstacle detection algorithms are quite general and can be used in the autonomous guidance of mobile robots operating on the Earth, Moon, Mars, and other planets. We are developing a rotorcraft automation simulation tool that can be used to examine different automation concepts and to study the inter-relationship between rotorcraft dynamics, obstacle detection, and obstacle avoidance methods.

References


Opportunities for Research on Electric Power Systems Problems

Robert J. Thomas

ABSTRACT: Long-term high-risk investigations into topics related to future planning and operation functions of large-scale electric utilities by university researchers encompass a wide range of issues. Many of these issues are captured by the following topics: computer applications, modeling, security assessment, control under uncertainty, distribution systems, protection, reliability, economics/pricing, and knowledge-based systems. These topics and others were discussed at a recent National Science Foundation workshop on university research for electric power systems engineering held in Tempe, Arizona, and attended by 70 researchers. This paper discusses the origins of the topics, their relation to future large-scale nonlinear systems problems, and conclusions reached based on the discussions held at the workshop.

Introduction

The National Science Foundation Engineering Directorate, through its Division of Electrical, Communications, and Systems Engineering, established a program in April 1987 entitled the Large-Scale Nonlinear Systems Program. The intent was to promote a renewed interest in serious, long-term high-risk university-based research on problems that exhibit phenomena attributable to system size and/or nonlinear behavior, with emphasis on specific issues in the field of electric energy systems. Most engineering systems encountered in practice exhibit significant nonlinear behavior. Complete models of physical systems are seldom known and, if known, are seldom linear. When complexity is added to the problem in the form of large numbers of variables, parameters, interconnections, or design choices, solutions become more difficult to obtain. "Large," as used here, is meant to indicate size relative to the tools available for design and analysis. Largeness, in this sense, is a rather recent concept that has emerged because of our ability to construct systems of extraordinary size.

In most cases, conventional design practice has relied on a linear system analysis together with simulation and "engineering judgment." The subtle ways in which nonlinearity and largeness affect system response or design can often be understood only with experience and for a specific system since generic systems frequently do not exhibit these subtleties. Future system nonlinearities will include a mixture of discrete and continuous events as well as symbolic and numeric subsystems. These systems will be expected to satisfy extraordinary performance and reliability requirements and to tolerate pronounced dynamic behavior while remaining amenable to diagnostics and maintenance. For these reasons, basic research is needed that will provide the engineering science base methodologies, theories, and algorithms that will enable engineers to plan, manage, and control future systems of unprecedented complexity. Generic areas of research associated with problems of this type include:

• Real-time control, computation, analysis, and event recognition;
• High-speed diagnostics, protection, and enhanced off-line decision aids;
• Theories, models, and advanced concepts for planning and operation of future systems; and

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