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Kalman Filter Based Range Estimation for Autonomous Navigation Using Imaging Sensors

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Rotorcraft operating in high-threat environments fly close to the Earth's surface to utilize surrounding terrain, vegetation, or man-made objects to minimize the risk of being detected by the enemy. 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, which 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 in control, computer vision and image understanding.

The planning of rotorcraft low-altitude missions can be divided into far-field planning and near-field planning (Cheng and Sridhar, 1988). 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 database 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 onboard sensor and integrated into the navigation/guidance system to modify the nominal trajectory of the rotorcraft. Initially, passive imaging sensors such as forward looking infrared (FLIR) and low-light-level-television (LLLTV) 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. The approach used in this analysis differs from previous methods in two significant ways: (i) we do not attempt to estimate the rotorcraft's motion from the images, and (ii) our interest lies in recursive algorithms. The rotorcraft parameters (position, translational velocity, rotational velocity and attitude) are assumed to be computed using an onboard inertial navigation system. Given a sequence of images, using image-object differential equations, a Kalman filter (Sridhar and Phatak, 1988) can be used to estimate both the relative coordinates and the Earth coordinates of objects on the ground. The Kalman filter can also be used in a predictive mode to track features in the images, leading to a significant reduction of search effort in the feature extraction step of the algorithm. The performance of three different Kalman filters for different rotorcraft maneuvers were examined in Sridhar and Phatak, 1988. This previous study did not, however, include the processing of real images. The purpose of this paper is to summarize early results obtained in extending the Kalman filter for use with actual image sequences. These tests were restricted to linear motion in order to reduce the image processing requirements. The experience gained from the application of this algorithm to real images is very valuable and is a necessary step before proceeding to the estimation of range during low-altitude curvilinear flight.

We have presented a simple recursive method to estimate range to objects using a sequence of images. The method produces good range estimates using real images in a laboratory set up and needs to be evaluated further using several different image sequences to test its robustness. The feature generation part of the algorithm requires further refinement on the strategies to limit the number of features (Sridhar and Phatak, 1989). The extension of the work reported here to curvilinear flight may require the use of the extended Kalman filter.

The research reported in this paper is part of an ongoing effort at NASA Ames to develop technologies for the automation of rotorcraft low-altitude flight. The object detection and range estimation algorithms discussed are quite general and have potential applications in robotics and autonomous navigation of vehicles. In addition to these feature-based algorithms, there are parallel efforts to investigate field-based techniques for the same range estimation applications (Menon and Sridhar, 1989; Kendall and Jacobi, 1989).

References

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