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A Strongly Goal-Directed Close-Range Vision System for Spacecraft Docking

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Abstract

In this presentation we will propose a strongly goal-oriented stereo vision system to establish proper docking approach motions for automated rendezvous and capture (AR&C). From an input sequence of stereo video image pairs, the system produces a current best estimate of:

- Contact position
- Contact vector
- Contact velocity
- Contact orientation

The processing demands imposed by this particular problem and its environment dictate a special case solution; such a system should necessarily be, in some sense, minimalist. By this we mean the system should construct a scene description just sufficiently rich to solve the problem at hand and should do no more processing than is absolutely necessary. In addition, the imaging resolution should be just sufficient. Extracting additional information and constructing higher level scene representations wastes energy and computational resources and injects an unnecessary degree of complexity, increasing the likelihood of malfunction. We therefore take a departure from most prior stereopsis work, including our own, and propose a system based on associative memory. The purpose of the memory is to immediately associate a set of motor commands with a set of input visual patterns in the two cameras. That is, rather than explicitly computing point correspondences and object positions in world coordinates and trying to reason forward from this information to a plan of action, we are trying to capture the essence of *reflex behavior* through the action of associative memory. The explicit construction of point correspondences and 3D scene descriptions, followed by online velocity and point of impact calculations, is prohibitively expensive from a computational point of view for the problem at hand. Learned patterns on the four image planes, left and right at two discrete but closely spaced instants in time, will be used directly to infer the spacecraft reaction. This will be a continuing online process as the docking collar approaches.

The essential concept behind an associative memory implementation of reflexive behavior is this. We will store some sizeable set of reference patterns derived from possible input image

foursomes. Each of these patterns will describe a physical configuration of the domain of responsibility for the memory. For our purposes, the description of the configuration of this domain should include whether or not a viable docking position is present and, if so, what its current relative position and velocity vectors are. This does not mean that we need to compute position and velocity explicitly. Rather, it means that the patterns we extract should implicitly contain that information. The set of patterns we store should effectively cover the domain of responsibility; holes in the coverage will correspond to windows of vulnerability for the spacecraft; appropriate action is impossible if the physical configuration of the domain of responsibility is not recognized. Associated with each pattern is information specifying the appropriate reflexive action based on the current state of the environment.

The presentation will discuss the following issues:

- System Design Criteria and Assumptions
- System Design Specifics (an example)
  - Pattern Construction and Imaging Resolution
  - Selecting the Reference Patterns: General Principles
  - Selecting the Reference Patterns: Specifics
  - Physical Constraints: Limiting the Choices
  - Accuracy Considerations
  - Counting the Reference Pattern Set
  - Total Memory Size and Topological Structure

The background for this work is the extensive prior work of the first and second authors in computer vision and robotics, respectively. We have conducted a design feasibility study for the related problem of robotic avoidance, retreat, or resistance to an incoming airborne projectile. In that particular example, we were able to design a system storing 100,000 patterns, each having 44 bits for the reference pattern and 20 bits to specify the necessary action. The resulting associative memory capacity requirement was about 800KBytes, which is certainly reasonable. Of course, that problem is different in many respects than the AR&C problem, but the result is encouraging.

Finally, we offer a few comments about topological structuring. Since the image foursomes are built from overlapping pairs (the second pair of one foursome is the first pair of the next) we can immeidately restrict our attention to that portion of the memory containing reference patterns whose "heads" approximate the current "tail." Additionally, we can restrict the search within this region to that subregion containing those patterns whose tails are possible (or most likely) given physical constraints on motion and disparity changes. The memory should be organized to take advantage of this natural structure. This is an area of ongoing study, as are the crucial accuracy issues.

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