Natural Feature Image Recognition Enables Docking

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The Johnson Space Center (JSC) Natural Feature Image Recognition (NFIR) (figure 1) is a model-based approach to relative navigation that matches the image features of a target vehicle, as seen from a camera on a chase vehicle, to the corresponding features in a three-dimensional (3D) model. NFIR can use any high-contrast features on a target vehicle for which a 3D model exists; no special targets or reflectors are required. A computer running NFIR receives an image from a camera, searches that image for the target vehicle, locates the high-contrast image features of the target vehicle, and matches those features to the corresponding features of the 3D model. A pose (position and orientation of the target vehicle) (figure 2) is computed relative to the camera using the two-dimensional image to 3D model feature matches and the internal camera calibration. A Kalman filter is employed to determine the relative pose for the next image; this next image, in turn, is used to compute a search area in that image for each target vehicle feature being tracked.

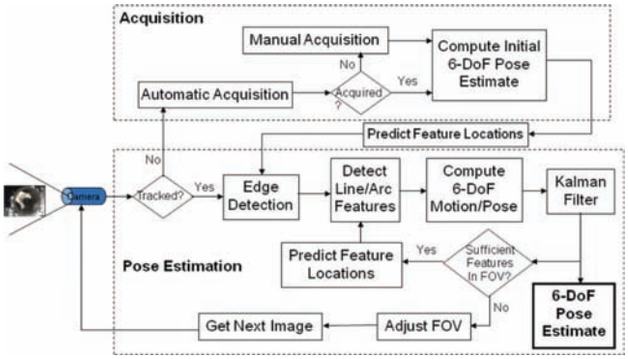

Fig. 1. *A high-level flow diagram shows how the NFIR tracker works.*

The development of NFIR began in 2003. In 2006, NASA selected NFIR as a pathfinder sensor to be characterized and tested as part of the automated rendezvous and docking (AR&D) Sensor Technology Project (STP). The NASA Marshall Space Flight Center (MSFC) flight robotics laboratory (FRL) completed an initial test that showed good performance in laboratory lighting using a full-scale pressurized module adapter mock-up that included the standard docking target. Using the planned Crew Exploration Vehicle (CEV) centerline camera and video processing unit (VPU), NFIR software could provide a software-only backup capability to the selected CEV visual navigation sensor and reduce the risk associated with relative navigation. In 2008, JSC integrated NFIR into the six-degree-of-freedom test system for use in the development of the docking closed-loop testing environment of a guidance, navigation, and control system. The major objective for NFIR in 2009 was to increase its technology readiness level (TRL) to TRL 6 and showcase its ability to use planned CEV hardware.

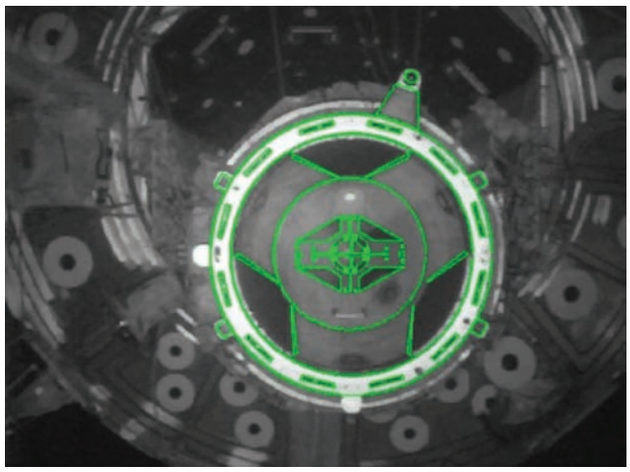

Fig. 2. *A projection of the NFIR pose estimate on a frame of the STS-118 docking camera.*

Recent upgrades to the NFIR include the following:

An automatic target vehicle acquisition/reacquisition capability

This allows NFIR to initiate tracking and pose estimates of the target vehicle automatically, and to reacquire the target vehicle if tracking is lost. Reference images of the target vehicle from the MSFC/FRL test were used to train the classifier to recognize high-contrast vehicle features. Points from the real-time image are matched to those extracted from training images.

An improved robustness to illumination variability

On-orbit lighting conditions are hard to mimic in a laboratory setting, and we are concerned with how well NFIR would work under these conditions. NFIR became

more adaptable to the dynamic lighting conditions seen on orbit when we added a contrast enhancement step at the front end of the process. This increased its capability to track and provide pose estimates of the target vehicle. Performance was improved with measures such as the overweighting premium features, the stand-off cross on the docking target, and dynamic computation of thresholds for feature detection. We tested the software modification using recorded video from the shuttle Orbiter Docking System camera during the final approach to docking with the International Space Station (ISS) on STS-116 and STS-118.

Robustness to image motion

Evaluation of the NFIR tracker using laboratory test videos showed that loss of track during nominal approach to ISS-type trajectories was minimal, and that when this loss occurred the target vehicle was successfully reacquired. This relaxes the NFIR constraints on relative motion between chase and target vehicles.

A port NFIR to an embedded processor with a clear path to flight

We developed a modular architecture for NFIR that can be compiled for embedded computers as well as for standard laptops. The existing NFIR tracking algorithm, the acquisition module, and lighting robustness improvements were implemented in the modular architecture.

Results from MSFC/FRL tests indicate that the NFIR performed well using video recordings in laboratory lighting. In general, root-mean-square pose estimation errors are less than 1% in depth and 0.75 deg in attitude (with smaller errors at closer ranges). After removal of the bias (probably due to errors in calibration of the pose of the camera relative to the truth sensor), the error standard deviations were less than 1% in depth and 0.5 deg in attitude.

The goal of the AR&D STP is to produce an NFIR brassboard for direct insertion into the mainline Orion (CEV) Project by the Orion critical design review. During 2009, we adapted NFIR to use cameras and computers similar to those selected for Orion, and to evaluate its functionality and performance for a new target vehicle. Future goals include

Converting the NFIR code to field programmable gate array architecture in preparation for porting to the CEV VPU.

Upgrading the NFIR to handle video from the Orion planned docking camera – a 2K×2K camera with a 512×512 region of interest in the center of the image that allows switching the field of view between 40 to 10 deg.

Expanding the automatic acquisition/reacquisition module to work with on-orbit video.

Developing a 3D feature model of the CEV docking adapter on the ISS for NFIR testing using simulated video of this model for a range of approach trajectories and lighting.

Testing of the NFIR with the above upgrades on real video acquired in the laboratory, and on video recorded during orbiter to ISS approach to docking.

This approach to relative navigation could be adapted to other target vehicles given a boresighted docking camera and an image processor on the chase vehicle plus high contrast features and a 3D model for the chase vehicle.

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