19 Spacecraft Subsystems II—Control Systems

19.2 Space Mission Verification and Validation

19.2.4.1 Navigation Systems

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Ground-station tracking performed by the spacecraft operator requires transponder and telemetry equipment on board the spacecraft. Note that this type of navigation data is available only when the spacecraft is visible to the operator's ground tracking station. Even if the tracking stations are geographically distributed, like the SSN or DSN, resource sharing/allocation constraints will limit the update rate of navigation data. It is possible for a satellite operator to acquire navigation data without any on-board equipage by accessing publicly available tracking data from the US Space Surveillance Network. Two-line element sets are available to users at no cost, but they are updated only twice a day and the accuracy of the data will likely be less than that achievable by transponder signals. However, this may be acceptable for some low-cost nanosatellites.

A space-based tracking system such as TDRSS can provide high-accuracy navigation data to the spacecraft operator; this requires a specific type of transponder on board the user spacecraft. With some additional on-board equipage, the TONS system can use TRDSS signals to provide autonomous navigation capability. Another autonomous navigation option for spacecraft in LEO is to install commercially available GPS receivers on board the spacecraft. For interplanetary flight, autonomous navigation is available with optical stellar navigation. Autonomous navigation relative to a celestial body such as an asteroid can be performed using optical landmark navigation. Space-based and autonomous systems can generally provide navigation data at any desired update rate, whereas ground-based systems can provide navigation data only at times when the spacecraft is visible to the ground tracking station(s).

Note that all navigation systems requiring on-board equipment have varying amounts of direct (acquisition) costs as well as indirect costs associated with mass and power usage.

Table 19web-1. Typical Onboard Relative Navigation Sensors.

Sensor	Measurement Type	Description	Mission Heritage	Applicable Range of Op
		Passive Camera-Based Systems		
Optical Camera	Long Range Bearing	Similar to star tracker, but instead of ignoring objects that move relative to the stars, it ignores the stars and reports bearing angles to the object	OE, XSS-11, Shuttle	100's of km to a few km*
Optical Camera	Mid Range Bearing	Centroiding on a distended target image		10s of km to 100s of m*
Optical Camera	6DOF relative position and attitude (aka pose)	Natural feature tracking, i.e., of edge or corner features, by comparison in real time of image with stored internal model	OE, HST RNS	100s of m to contact*
Optical Camera	Stereo pose	Uses multiple cameras separated by a baseline to generate relative attitude and position information by comparing the position of features in each of two camera frames		meters to contact
IR Camera	Bearing	Similar to optical camera-based centroiding, but with a detector sensitive in the infrared (IR). This method is often used to minimize system sensitivity to lighting	OE	
IR Camera	Pose	Similar to optical camera-based pose, but with a detector sensitive in the IR. This method is often used to minimize system sensitivity to lighting	OE	
		Laser-Based Systems		
Laser Range Finder	Range	Time of flight measurement using a single laser beam	OE, Shuttle	
Laser Range Finder	Bearing	Combines known orientation of LRF in chaser vehicle body frame with chaser vehicle inertial attitude to determine bearing to the target vehicle	OE, Shuttle	

Table 19web-1. Typical Onboard Relative Navigation Sensors. (Continued)

Sensor	Measurement Type	Description	Mission Heritage	Applicable Range of Op
AVGS	Bearing	Bearing measurements computed by centroid processing of an optical (2D) image of a retroreflector on the target illuminated by a laser in the sensor. System uses multiple laser frequencies and optical filters in target retro-reflectors to ensure lighting insensitivity.	DART, OE	
AVGS	Pose to cooperative target	Pose of target is determined by inverse prospective algorithm processing of multiple (>3) centroid measurements of reflectors on target	OE	
Flash Lidar	Range	Range measurement computed by centroid processing of point cloud data gathered by an array of time of flight detectors		10s of km to 2m
Flash Lidar	Bearing	Bearing measurement computed by centroid processing of point cloud data gathered by an array of time of flight detectors		10s of km to 2m
Flash Lidar	Pose to cooperative target		STORRM	
Flash Lidar	Pose to non-cooperative target			
Scanning Lidar	Range		Shuttle, XSS-11, ATV, HTV	
Scanning Lidar	Bearing		Shuttle, XSS-11, ATV, HTV	
Scanning Lidar	Cooperative Pose			
Scanning Lidar	Noncooperative pose		TriDAR DTOs	
RF-Based Systems				
RF Radar	Range to passive target	Direct range to target by time of flight measurement of transmitted signal bounced off target, Shuttle uses its gimballed Ka-band high gain antenna	Shuttle	100s of km to 100s of m
RF Radar	Range rate to passive target	Direct range rate to target by Doppler shift of transmitted signal bounced off target, Shuttle uses its gimballed Ka-band high gain antenna	Shuttle	
RF Radar	Bearing to passive target	On shuttle, bearing is computed from known position of the high gain antenna	Shuttle	
RF Crosslink	Range to active target	Direct range to target by time of flight measurement of 2-way signal (requires radio on both chaser and target vehicle), Shuttle uses its gimballed Ka-band high gain antenna	Shuttle	100s of km to ~1km
RF Crosslink	Range rate to active target	Direct range rate to target by Doppler shift measurement of 2-way signal (requires radio on both chaser and target vehicle), Shuttle uses its gimballed Ka-band high gain antenna	Shuttle	
RF Crosslink	Bearing to active target	On shuttle, bearing is computed from known position of the high gain antenna	Shuttle	
Phased Array Radar				

* Value may very greatly as a function of camera optics and chase vehicle attitude determination system
** Value may very greatly as a function of optics and camera baseline
*** Mass and power required for additional computing resources not included

Acronyms:
ATV: Automated Transfer Vehicle
HST: Hubble Space Telescope
HTV: H2 Transfer Vehicle
OE: Orbital Express
RF: Radio Frequency
RNS: Relative Navigation System - flight demo on HST Servicing Mission 4
STORRM: VNS test flight on STS-124
TriDAR: Neptec Triangulation and Time of Flight LiDAR
XSS-11: