The Sensors for Autonomous Systems topic is defined to include sensors, sensor components or sensor systems that provide relative information between a spacecraft and another body, independent of Earth-based assets or personnel. The scope of this topic encompasses relative navigation for rendezvous, proximity operations and docking (RPOD) between a spacecraft and a target vehicle, such as the International Space Station or lunar module, and also precision landing and hazard detection for landing on a lunar or planetary surface. Technology development is needed to create robust sensor capabilities that work within the required environments and meet functional and performance requirements to accomplish the defined missions.

**Subtopics**

**X2.01 Autonomous Rendezvous and Docking Sensors**

**Lead Center:** JSC  
**Participating Center(s):** ARC, GSFC, JPL, MSFC

The Exploration Systems Architecture defines missions that require rendezvous, proximity operations, and docking (RPOD) of two spacecraft both in Low Earth Orbit (LEO) and in Low Lunar Orbit (LLO). Uncrewed spacecraft must perform automated and/or autonomous rendezvous, proximity operations and docking operations (commonly known as Automated Rendezvous and Docking, AR&D). The crewed versions may also perform AR&D, possibly with a different level of automation and/or autonomy, and must also provide the crew with reliable, fault tolerant relative navigation information for manual piloting. The capabilities of the RPOD sensors are critical to the success of the Exploration Program. The relatively low technology readiness of existing relative navigation sensors for AR&D has been carried as one of the Crew Exploration Vehicle (CEV) Project's top risks.

This subtopic seeks innovative technologies that can provide relative navigation capabilities for rendezvous, proximity operations and docking of two spacecraft. Long-range rendezvous sensors should provide bearing from beyond 200 km to 5 km distance between spacecraft, but range and range-rate are also desirable. Proximity operations sensors should provide range, range-rate, and bearing from approximately 5 km to 100 m. Docking sensors should provide relative position and relative attitude from approximately 100 m to docking; relative attitude may only be needed from 30 m in to docking but longer ranges are desirable. Ideal solutions would combine multiple relative navigation sensing capabilities into a single system in order to reduce mass, volume, and power. Solutions should be designed to operate in Low Earth Orbit, Low Lunar Orbit, or both. Solutions can include a relative navigation sensor "suite" that consists of multiple sensor types but covers the full range; the sensor suite...
should allow RPOD under any lighting conditions. Solutions should also include a robust and fault tolerant capability that is suitable for a human-rated space vehicle. In addition, the relative navigation technologies should be designed so that existing infrastructure on the International Space Station (reflectors, communications systems, etc.) does not interfere with the relative navigation capability of the maneuvering vehicle.

Some specific technology focus areas of interest include: (1) use of relative navigation sensors that do not require special retro-reflectors or targets on the target spacecraft but can make use of natural features or existing infrastructure; this focus area may make use of Light-Imaging Detection and Ranging (LIDAR) components in order to get range and range-rate to the objects in the field of view, or may use video-based technology; (2) fault tolerant sensor systems; and (3) other technology areas for long-range rendezvous sensors that may include star trackers, infrared sensors, and radio frequency-based sensors; these types of sensors may have an extended range well beyond 200 km.

**X2.02 Autonomous Precision Landing and Hazard Detection and Avoidance**

*Lead Center: JSC*

*Participating Center(s): JPL, LaRC*

NASA seeks innovative sensor system technologies to support autonomous precision landing with hazard detection and avoidance for landing spacecraft on the lunar surface with extensibility to Mars. Sensor systems that can characterize and identify spacecraft landing surface hazards for purposes of avoidance and surface relative navigation with high precision and accuracy are of interest. The emphasis of this solicitation is for sensor systems or sensor components that can be utilized in current sensor systems to go beyond current technology capability. These systems or components must be compatible with the environmental conditions of spaceflight and the rigors of landing on the planetary surface. Proposals for development of certain aspects of these technology systems including sensor components that include partnering with other vendors developing this kind of technology are encouraged.

Candidate items include but are not limited to the following:

- Innovative lidar sensor systems and component technologies that directly address autonomous precision landing and hazard avoidance needs
  - 3D imaging lidar systems capable of generating elevation maps covering terrain areas 10k to 100k square meters from 1-2 km altitude with a resolution of the order of 20 cm
  - High efficiency focal plane arrays with over 16k pixels capable of detecting laser pulses shorter than a few nanoseconds (wavelengths of interest are 1 to 1.5 microns)
  - Reliable Readout Integrated Circuit (ROIC) with high frame rate capability greater than 20 hertz and capable of resolving target depth to a few centimeters
Novel real-time lidar image reconstruction and processing technologies;

- Passive or active detector systems which operate in certain ranges between 100 km to 2 km for utilization in terrain relative navigation systems;
- Sensor systems which provide very high accuracy and precision for determining velocities and altitudes relative to the surface with 0.1% accuracy;
- Robust and reliable sensor system or sensor system components which significantly reduce the impact of incorporating such sensors or components on the spacecraft in terms of volume, mass, power, thermal dissipation, placement or cost;
- Semiconductor or solid-state-controlled mirror systems capable of rapidly moving a lidar FOV over a defined areas;
- Innovative systems that significantly improve current precision landing and hazard detection capability for lunar descent and landing.

Proposals should describe the expected improvements and advantages of proposed deliverables over existing technologies and should estimate the effects of these improvements on the state-of-the-art navigation and hazard detection capabilities. Attributes of interest include reliability, precision, lighting requirements, accuracy, thermal sensitivity, heat dissipation capability and performance degradation due to rocket plumes and lunar dust.