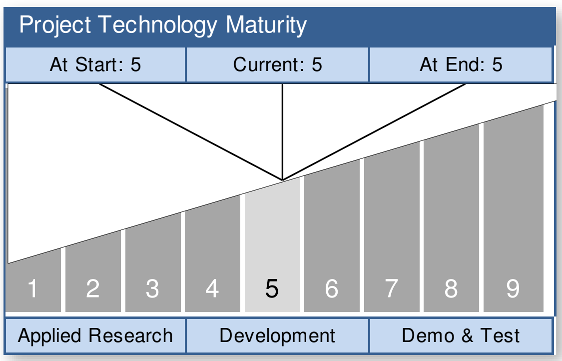
Autonomous Deep-Space Optical Navigation Project

Center Innovation Fund: JSC CIF (Also Includes JSC IRAD) Program

Space Technology Mission Directorate (STMD)

National Aeronautics and Space Administration

Autonomous Rendezvous Navigation Aid For Visual Odometry



ABSTRACT

This project will advance the Autonomous Deep-space navigation capability applied to Autonomous Rendezvous and Docking (AR&D) Guidance, Navigation and Control (GNC) system by testing it on hardware, particularly in a flight processor, with a goal of limited testing in the Integrated Power, Avionics and Software (IPAS) with the ARCM (Asteroid Retrieval Crewed Mission) DRO (Distant Retrograde Orbit) Autonomous Rendezvous and Docking (AR&D) scenario.

The technology, which will be harnessed, is called 'optical flow', also ...***Read more on the last page.***

Technology Area: Robotics, Tele-Robotics & Autonomous Systems TA04 (Primary)
Human Exploration Destination Systems TA07 (Secondary)

ANTICIPATED BENEFITS

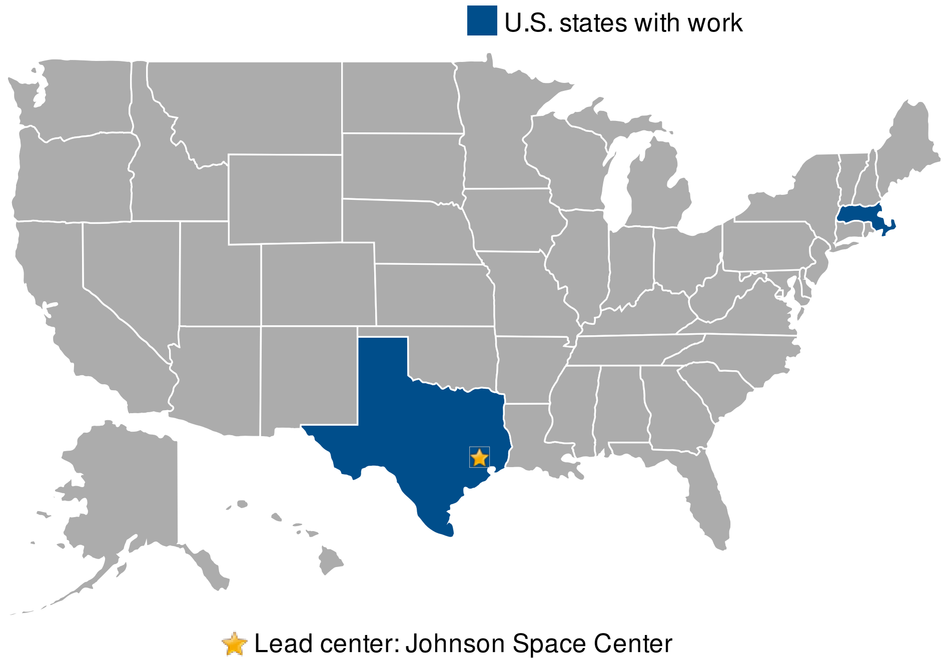
To NASA funded missions:

This Autonomous Rendezvous and Docking technology is planned to be integrated onto the Orion spacecraft for the future Asteroid Retrieval Mission (ARM) planned by NASA.

To NASA unfunded & planned missions:

This project aligns well with the human spaceflight needs of NASA. In particular it aligns with Autonomous Vehicle Systems Management, and especially ...

Read more on the last page.



DETAILED DESCRIPTION

Every one of the future exploration architectures being considered by NASA have, at their core, the need to rendezvous and dock with other vehicles or bodies. Future manned vehicles need to be able to do so with both cooperative and uncooperative vehicles or objects. To this end, the sensors being considered are all optical-based. In fact, passive sensors, such as IR cameras and visual cameras, are at the heart of any exploration architecture. There is a need for the onboard systems to be able to use the images provided by these sensors to rendezvous and dock/capture these objects. Therefore, this project will develop this capability to operate around a variety of objects, without a priori knowledge of their geometry. In particular, a technology called 'optical flow', also known as 'visual odometry' (VO), will be harnessed to develop a robust on-board capability using passive sensors; of course, if active sensors are available, they will be used as well. In fact, we will also apply this technique to navigating ...

MANAGEMENT

Program Executive:
John Falker

Program Manager:
Ronald G Clayton

Project Manager:
Chris D'souza

DETAILED DESCRIPTION (CONT'D)

around a cratered object (such as an asteroid). This project will enhance the Agency's ability to operate at distant locations, without the need for ground intervention.

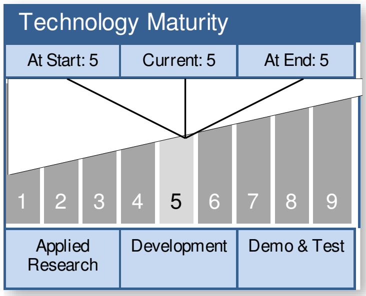
To date, all of the on-board navigation development performed has focused on either Low Earth Orbit (LEO) or Low Lunar Orbit (LLO). We seek to advance deep-space navigation technology by focusing this IRaD on rendezvous and navigation in a weak gravity environment –either at L2 or around an asteroid. Of course, this will apply to any destinations that have a strong gravity field as well. As well, the technology developed in this IRaD will apply to rendezvousing with vehicles such as ISS. We choose to focus our IRaD effort on the navigation algorithms and software for the ARCM DRO Mission, thus broadening our scope, maintaining our cutting-edge capability, and advancing US manned space exploration. Our goal is to be flexible enough to meet the needs of the NASA vision as it applies to any destination the Agency chooses to embark upon.

ADDITIONAL AND DETAILED TECHNOLOGY AREAS

- TA11: Modeling, Simulation, Information Technology & Processing

TECHNOLOGY DETAILS

Autonomous Deep-Space Optical Navigation



TECHNOLOGY DESCRIPTION

The technology, which will be harnessed, is called "optical flow", also known as "visual odometry". It is being matured in the automotive and SLAM (Simultaneous Localization and Mapping) applications but has yet to be applied to spacecraft navigation. In light of the tremendous potential of this technique, we believe that NASA needs to design a optical navigation architecture that will use this technique. It is flexible enough to be applicable to navigating around planetary bodies, such as asteroids.

This technology is categorized as a software macro for manned spaceflight

- Technology Area
    - TA04 Robotics, Tele-Robotics & Autonomous Systems (Primary)
    - TA07 Human Exploration Destination Systems (Secondary)
    - TA11 Modeling, Simulation, Information Technology & Processing (Additional)

This project’s objective is to develop a set of on-board navigation algorithms which can be implemented on a target flight processor using optical based sensors to provide the (inertial) relative position of a crewed (with application to un-crewed) vehicle relative to a target object.

To date, all of the on-board navigation development performed has focused on either Low Earth Orbit (LEO) or Low Lunar Orbit (LLO). We seek to advance deep-space navigation technology by focusing this IRaD on rendezvous and navigation in a weak gravity environment –either at L2 or around an asteroid. Of course, this will apply to any destinations that have a strong gravity field as well. As well, the technology developed in this IRaD will apply to rendezvousing with vehicles such as the International Space Station (ISS). We choose to focus our IRaD effort on the navigation algorithms and software for the ARCM (Asteroid Retrieval Crewed Mission) DRO (Distant Retrograde Orbit) Autonomous Rendezvous and Docking (AR&D) scenario, thus broadening our scope, maintaining our cutting-edge capability, and advancing US manned space ...

Performance Metrics		
Metric	**Unit**	**Quantity**
Accuracy of Pose Estimate	1	deg

TECHNOLOGY DETAILS

CAPABILITIES PROVIDED (CONT'D)

exploration. Our goal is to be flexible enough to meet the needs of the NASA vision as it applies to any destination the Agency chooses to embark upon.

POTENTIAL APPLICATIONS

This proposal directly will feed into the architecture associated with the Asteroid Redirect Mission (ARM). The technology will allow vehicles to rendezvous and capture uncontrolled target objects, including asteroids and debris objects (including spent upper stages). In addition, this technology will allow manned vehicles, such as Orion, to rendezvous and dock/capture the unmanned vehicle attached to the asteroid in a Distant Retrograde Orbit (DRO). It fits in seamlessly with any mission contained in the exploration architecture that is being considered at JSC and within the Agency. This is particularly important at destinations with greater than 6 second one-way light-time delay, where there would be a significant impact to safety and performance if relying on the ground. This project would allow for mission critical functions (i.e. navigation) to continue autonomously. It would also significantly improve mission critical functionality at destinations which have a delay time on the order of 3 seconds.

IMAGE GALLERY

Autonomous Rendezvous Navigation Aid For Visual Odometry

ABSTRACT (CONTINUED FROM PAGE 1)

known as ‘visual odometry’. It is being matured in the automotive and SLAM (Simultaneous Localization and Mapping) applications but has yet to be applied to spacecraft navigation. In light of the tremendous potential of this technique, we believe that NASA needs to design a optical navigation architecture that will use this technique. It is flexible enough to be applicable to navigating around planetary bodies, such as asteroids.

ANTICIPATED BENEFITS

To NASA unfunded & planned missions: (CONT'D)

with Crew Autonomy beyond LEO. And, finally, it aligns loosely with Mission Control Automation beyond LEO. The need for autonomous vehicle operation and performance beyond LEO and in case of a loss-of-communications with Earth make the need for autonomous deep-space navigation imperative and central to the need to perform the mission and return the crew safely to Earth.

Every future Exploration Architecture being considered by NASA has, at its core, the need to rendezvous and dock with other vehicles or bodies. Future manned vehicles need to be able to do so with both cooperative and uncooperative vehicles or objects. To this end, the sensors being considered are all optical-based. In fact, passive sensors, such as Infrared (IR) cameras and visual cameras, are at the heart of any exploration architecture, not least because they are small and lightweight. IR and optical cameras, in particular, have the added advantage of allowing for situational awareness. There is a need, therefore, for on-board systems to be able to use the images provided by these sensors to rendezvous and dock/capture (with) these objects. This project will, therefore, advance the state-of-the-art of onboard image-based navigation algorithms applied to AR&D with the added benefit of being extensible to being able to navigating around cratered objects such as the asteroids and the Moon.

The technology, which will be harnessed, is called ‘optical flow’, also known as ‘visual odometry’. It is being matured in the automotive and SLAM (Simultaneous Localization and Mapping) applications but has yet to be applied to spacecraft navigation. In light of the tremendous potential of this technique, we believe that NASA needs to design a optical navigation architecture that will use this technique. It is flexible enough to be applicable to navigating around planetary bodies, such as asteroids.

To other government agencies:

We anticipate that the use of the techniques developed here for optical navigation, particularly visual odometry have great potential in other fields such as robotics. In addition, it has military applications for navigating in/around buildings when GPS is not available. In fact, we intend to discuss the results of this research with our counterparts at the Air Force Research Labs (AFRL). JSC has had preliminary discussions with the AFRL to discuss the potential of these techniques.

...

ANTICIPATED BENEFITS

To the commercial space industry: (CONT'D)

Every future Exploration Architecture being considered by NASA has, at its core, the need to autonomous, rendezvous and docking (AR&D) with other vehicles or bodies. Future commercial manned and unmanned vehicles need to be able to do AR&D with both cooperative and uncooperative vehicles or objects. To this end, the sensors being considered are all optical-based. The technology developed in this project will directly utilize the measurements derived from these sensors.

To the nation:

This project directly meets the national need for AR &D for both cooperative and uncooperative (i.e. tumbling), target vehicles or bodies.