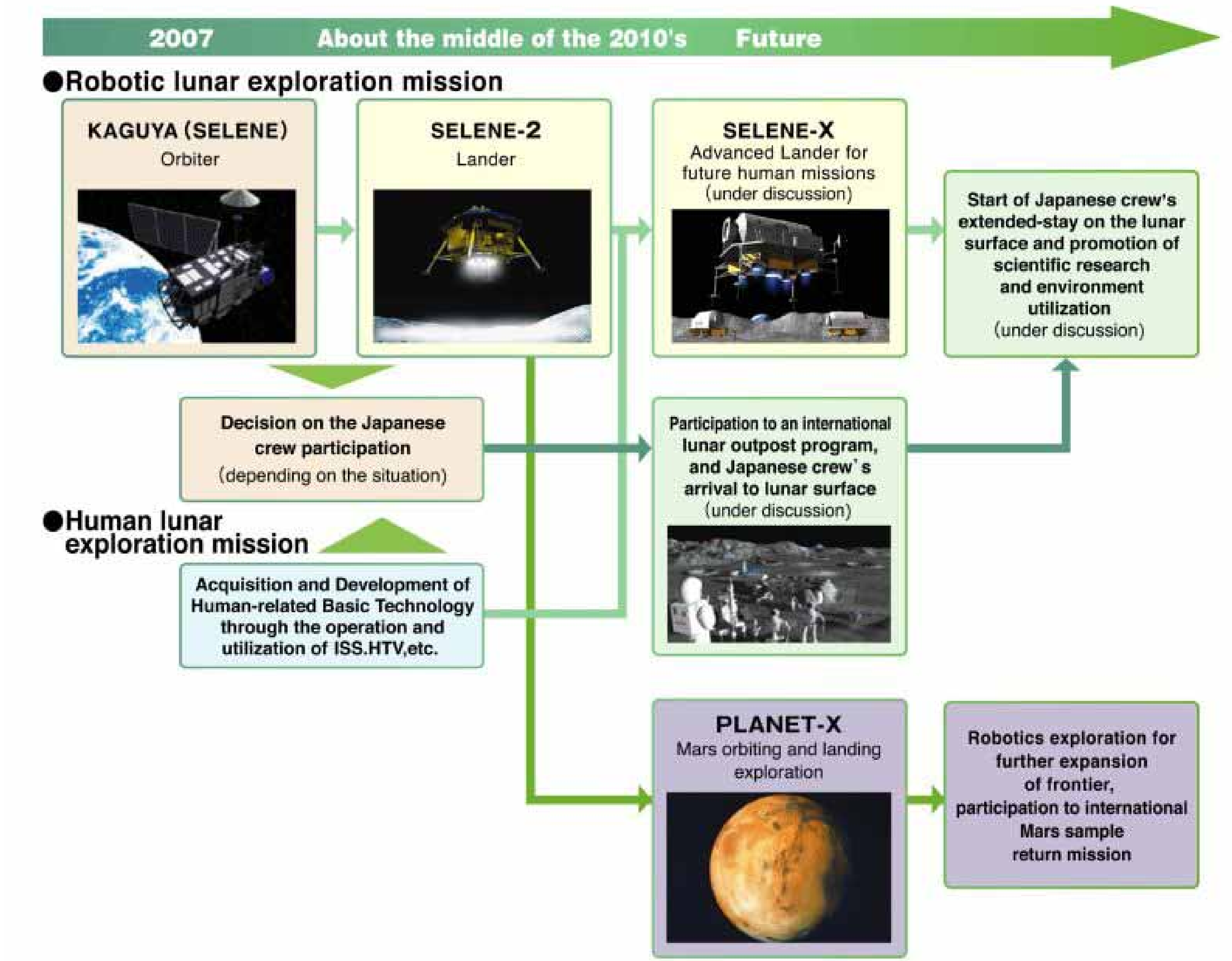
Robotics Technology for Planetary Surface Exploration

Takashi Kubota (JAXA/ISAS/JSPEC)
Kenji Nagaoka (*Graduate* Univ. for Advanced Studies)
Edmond So (*Graduate* Univ. for Advanced Studies)

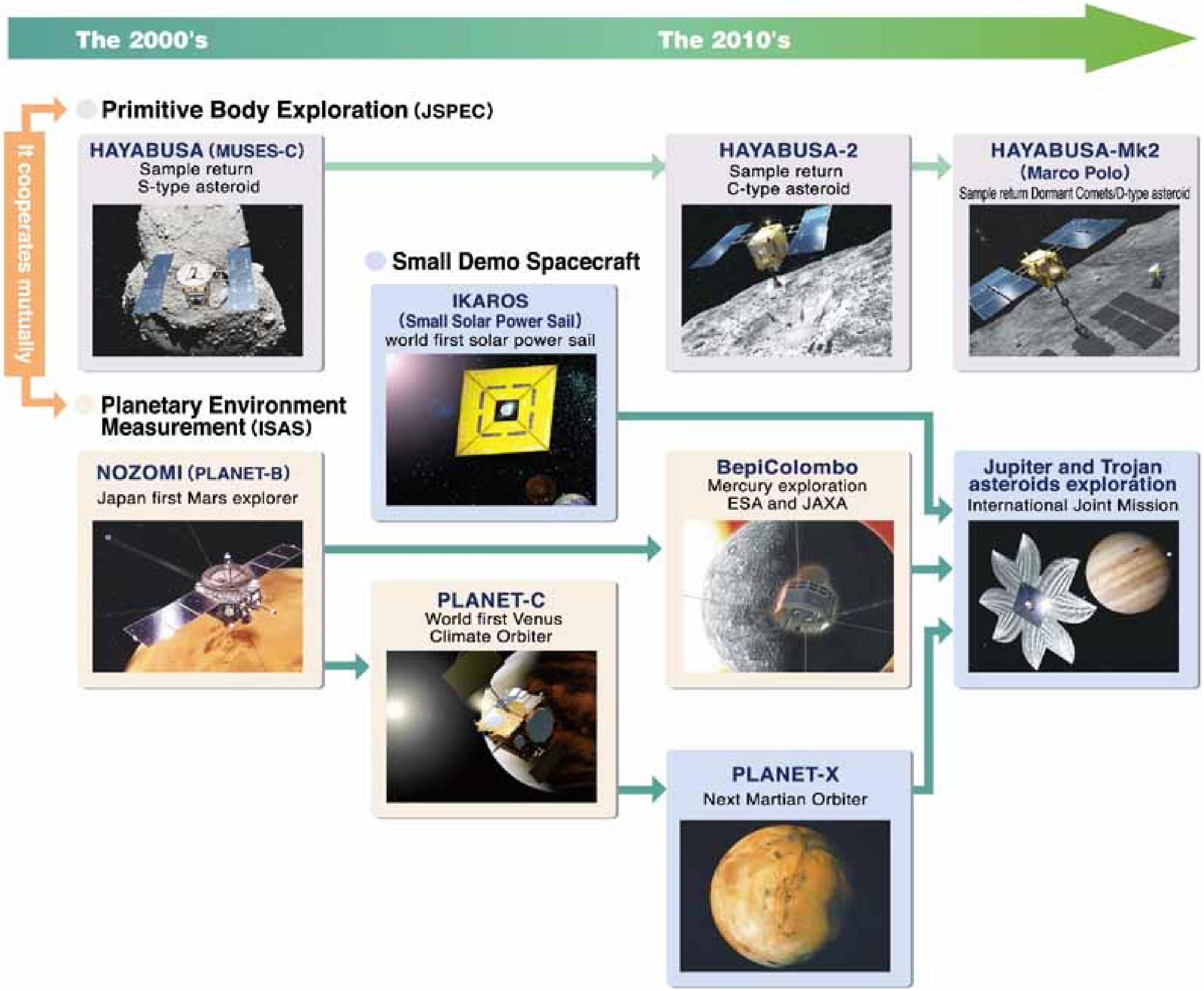
Lunar Exploration Road Map



Missions of SELENE-2

1. Development and demonstration of key technologies for future exploration,
   - Safe and accurate landing technologies
   - Surface mobility by rover
   - Night survival technologies
2. In-situ observation and investigation for science and future lunar utilization,
   - Detailed and sub-surface geological observation
   - Geophysics to know interior structure
   - Measure dust, radiation, soil environment
3. Contribution to international lunar activity and public interest.

Solar System Exploration Road Map



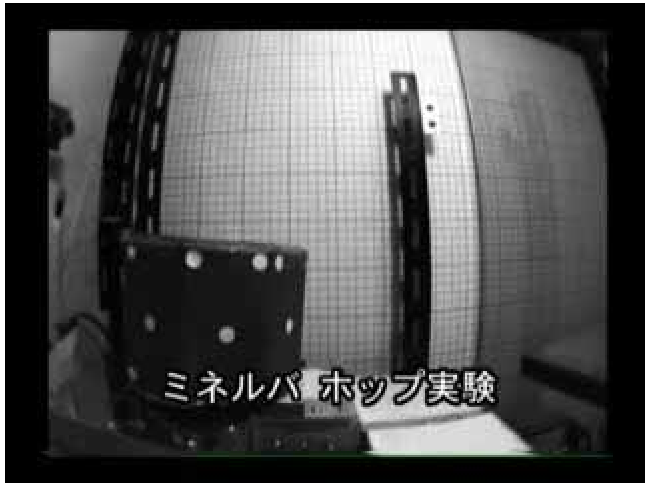
Hayabusa-2 Mission

Hayabusa-2 :

- Asteroid Sample Return Mission
- Target Asteroid : C-type, rocky
- Rocks contain more organic matters
- Challenge very interesting objectives
  > what are original organic matters existed in the solar system ?
  > how they are related to life ?

- Primitive body exploration
  - Programmatic follow-on of Hayabusa
- Sample return
  - from C-type asteroid 1999 JU3
- Window
  - 2011-2014
- Current Status
  - Phase-A

Hayabusa-2 Mission



MINERVA-II :

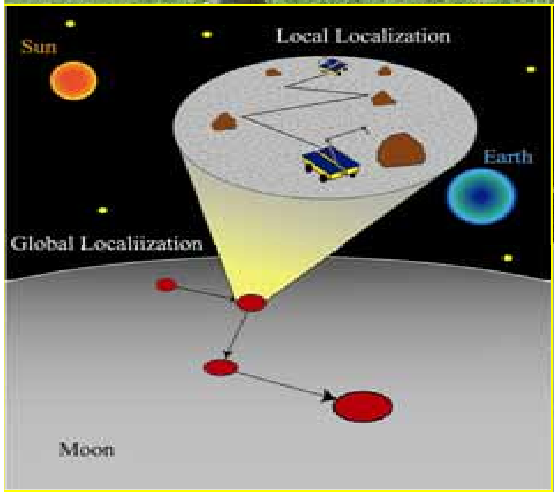
- Asteroid Surface Explorer
- Revenge of MINERVA
- Same Functions
  - Hopping Mobility
  - Small, Light, Low Power Consumption
  - Autonomous Behavior
  - Wide Area Exploration
- Sampling Site Exploration
  - Position Estimation
  - Navigation and Guidance

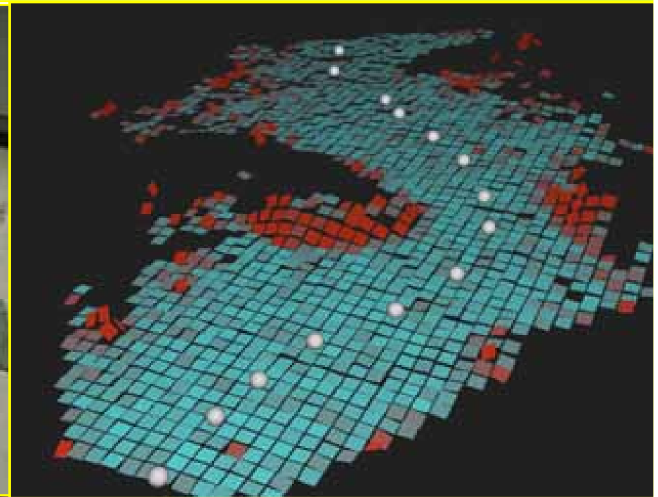
Rover Technology

Research & Development

- Mobility system
- Guidance & Navigation & Path Planning
- Tele-Driving system
- Tele-science by manipulator
- Digging Robot
- Hopping Robot
- Autonomy
- SLAM


MUSES-C
MINERVA


Sun
Local Localization
Earth
Global Localiization
Moon



Rover Technology

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Excavation

- Missions for lunar exploration by lander and rover in JAPAN
- Requirement by scientists is to excavate in depth of several meters to analyze geological samples or to deploy devices
- Drilling exploration on the moon in the past
  - Manned : 3[m] (Apollo missions)
  - Unmanned : 1.6[m] (Luna24)

↓

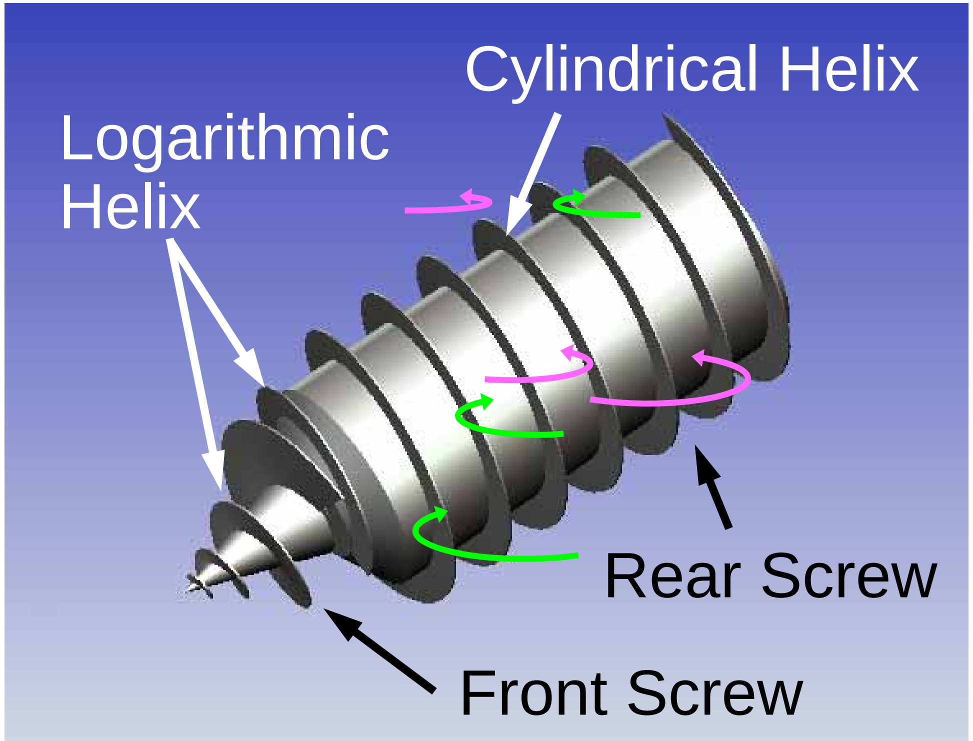
Novel drilling technology by small, light-weight robot is required for lunar or planetary exploration

(JAXA)

Core sampling in Apollo15

(NASA)

Proposal of Robotic Subsurface Explorer Using Screw Mechanism

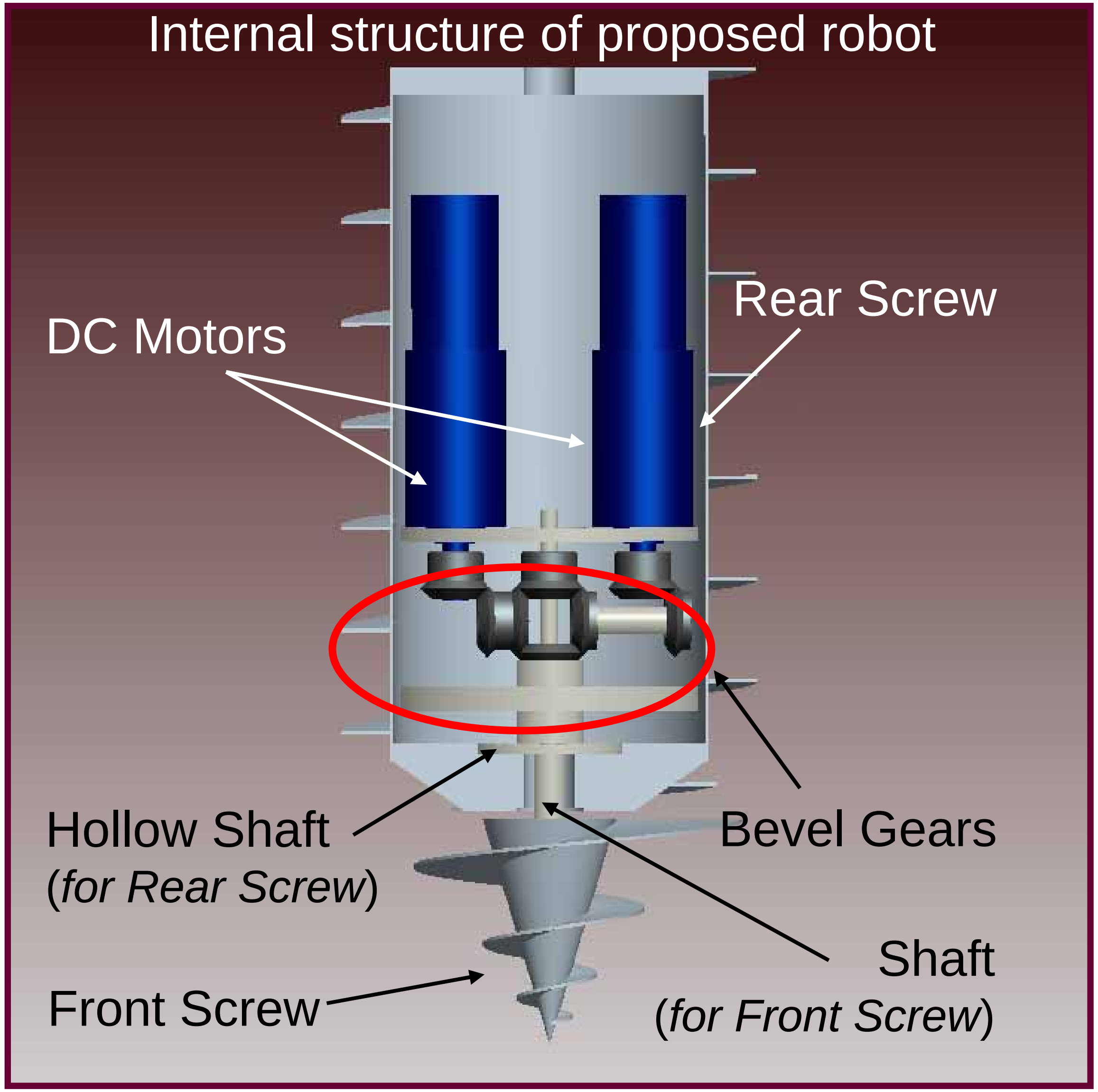


Conceptual model of burrowing screw explorer

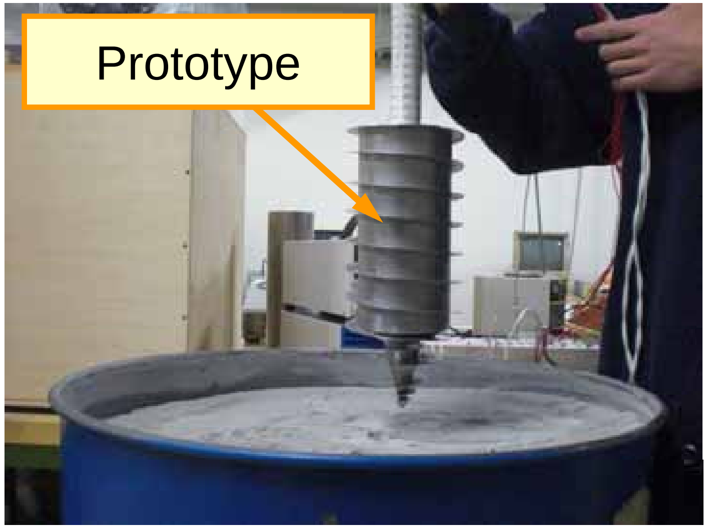
Concepts of Proposed Robot

- **Compact-sized Drilling Robot**
  - Diameter: 10cm
  - Length: 30～50cm
- **Burrowing into Lunar Soil**
  - Fine particles
  - High friction and cohesion
- **Drilling by Screw**
  - Reliable mechanism:
    <- remove and discharge fore-soils
  - Simple structure
  - Dust prevention
  - Cancel reaction torques by 2 motors
  - Agitating compacted soil layer by contra-rotor screws

Proposal of Robotic Subsurface Explorer Using Screw Mechanism



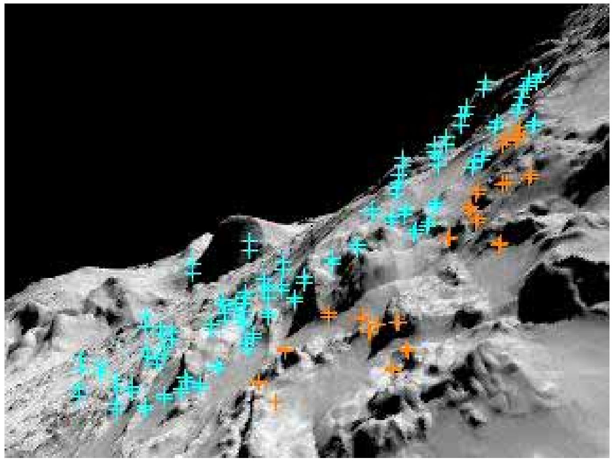
Experimental Results

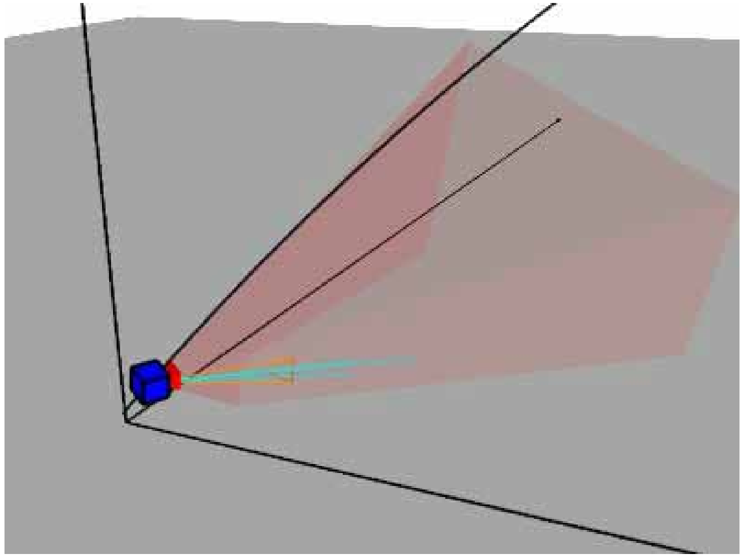


Visual Odometry for Hopping Rover

Motion Estimation on a Hopping Rover

- odometry allows rover to navigate to target destination accurately
- motion estimation of hopping rover using camera images
- visual odometry based on tracking features on ground terrain





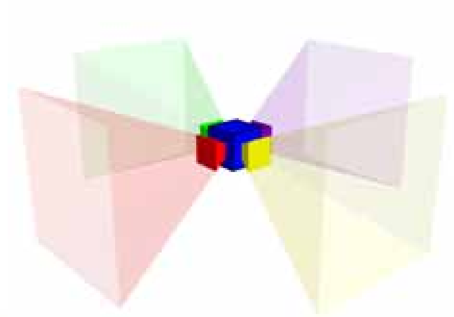
Hopping Odometry – Problem

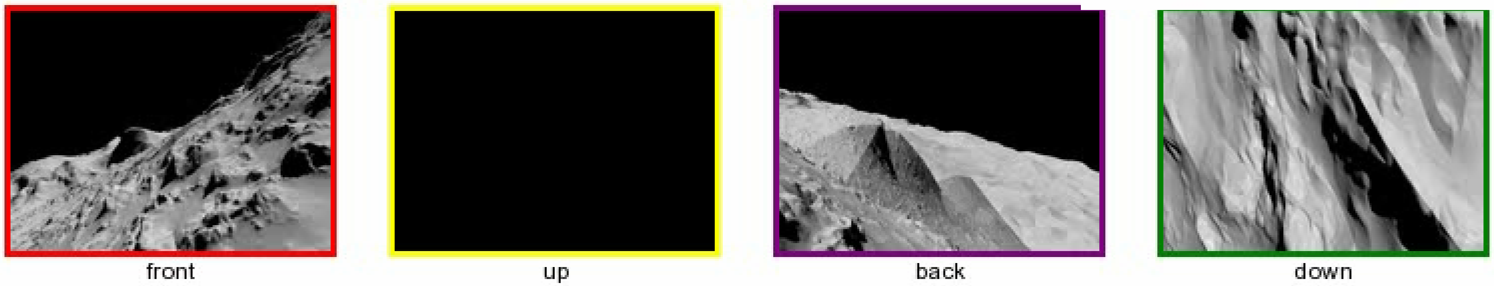
- hopping rover undergoes continuous rotational motion
- ground terrain cannot be continuously tracked by single camera

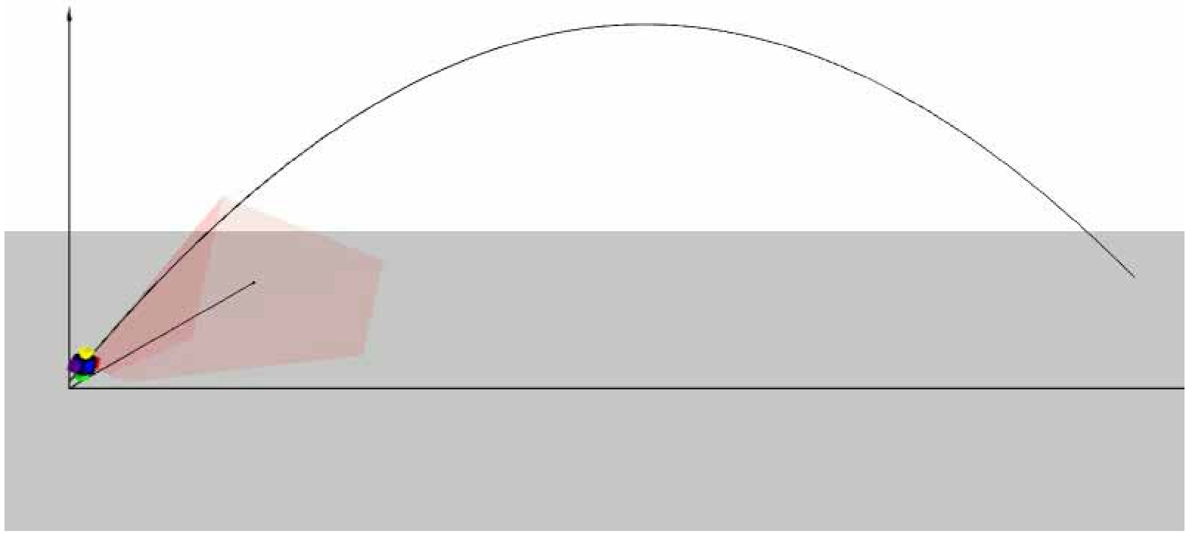
One of Solutions

One of Solutions:

Hopping Odometry using Multiple Cameras







Hopping Visual Odometry Algorithm

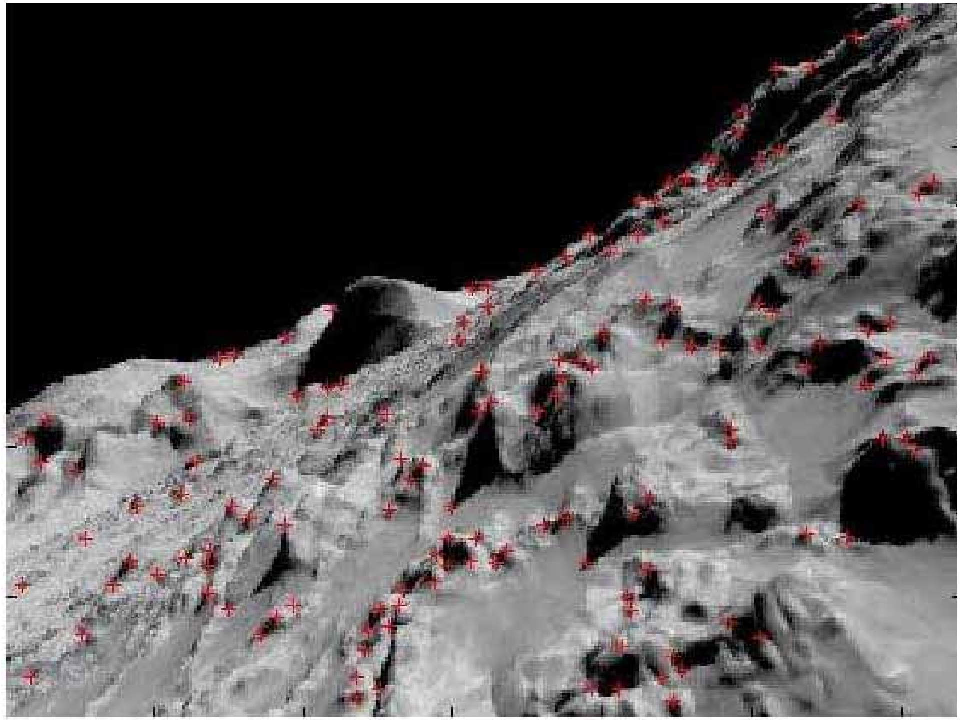
Hopping Visual Odometry Algorithm

- Initialization
  - Feature Correspondences and Triangulation using Small-Baseline Stereo at Beginning of a Hop
- Monocular Visual Odometry using One Camera
  1. Feature Tracking from $\mathcal{F}_i$ and $\mathcal{F}_{i+1}$
     - Tracking of Triangulated Features $\boldsymbol{x}_j$
     - Tracking of New Features $\boldsymbol{y}_j$
  2. Camera Pose Estimation of $\mathcal{F}_{i+1}$ with respect to $\mathcal{F}_i$ using Triangulated Features $\boldsymbol{x}_j$
  3. Triangulation of New Features $\boldsymbol{y}_j$ using estimated Motion $\{\vec{t}, R\}$
- Scale Propagation to Next Camera
  - Propagate Scale across Two Cameras using Two Pair of Synchronized Images

Feature Detection

Feature detected using Harris Cones

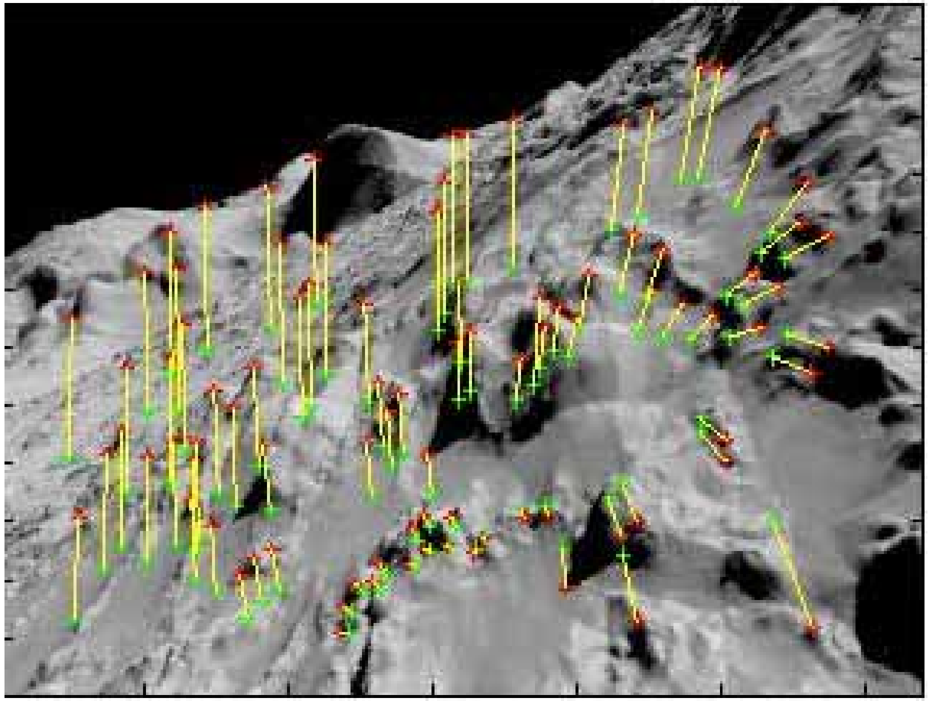
- based on intensity gradients
- 200 features / image



Feature Tracking

Feature tracked
using Lucas-Kanade Tracker

- based on linear image transformation model
- features tracked across every 10 frames



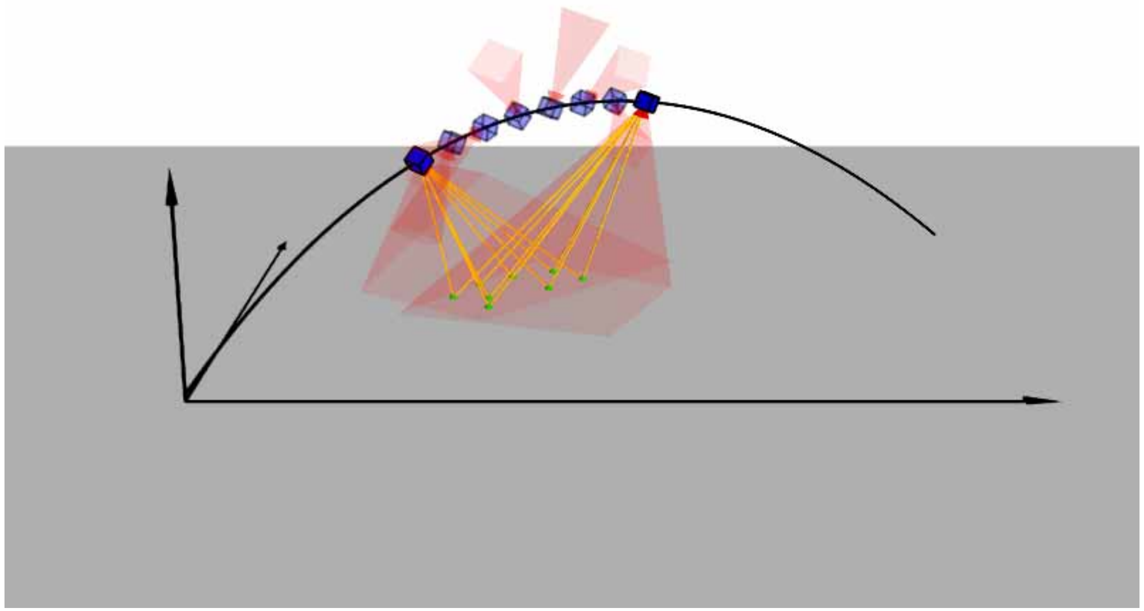
Selective Vision

Hopping Odometry using Landmark Registration

- improve estimation accuracy by reducing accumulation error
- eliminates need for multiple cameras

Proposal: Selective Vision

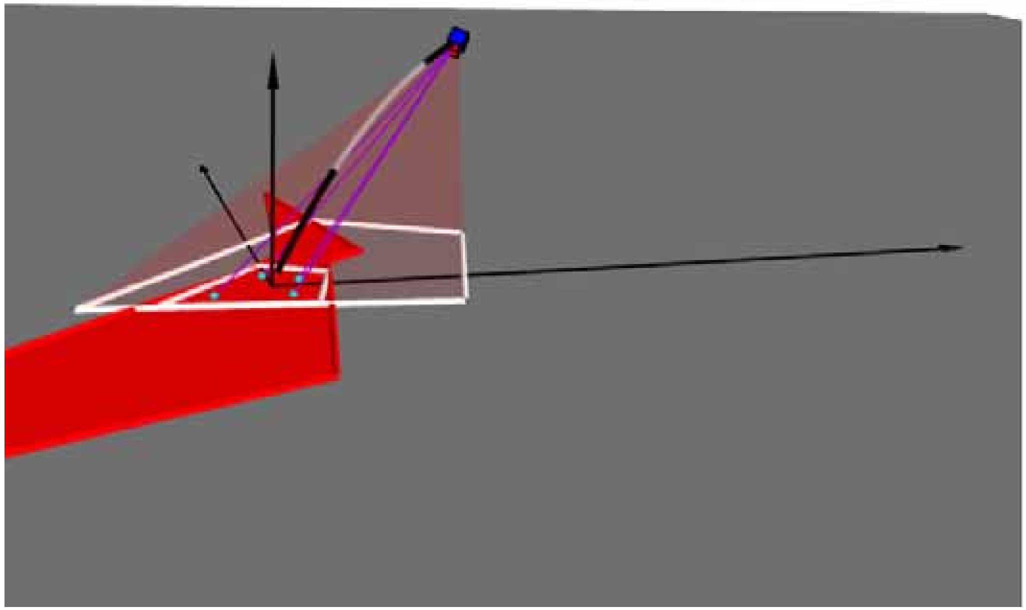
- feature matching only between images with same viewing angle

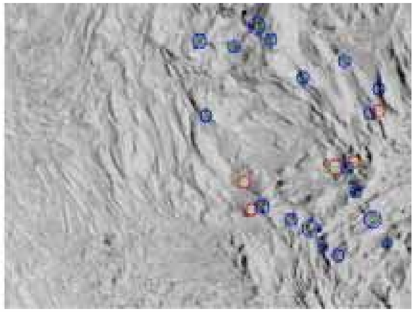


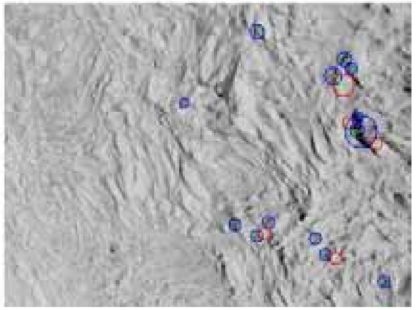
Selective Vision

Scale Recovery through Pose Estimation

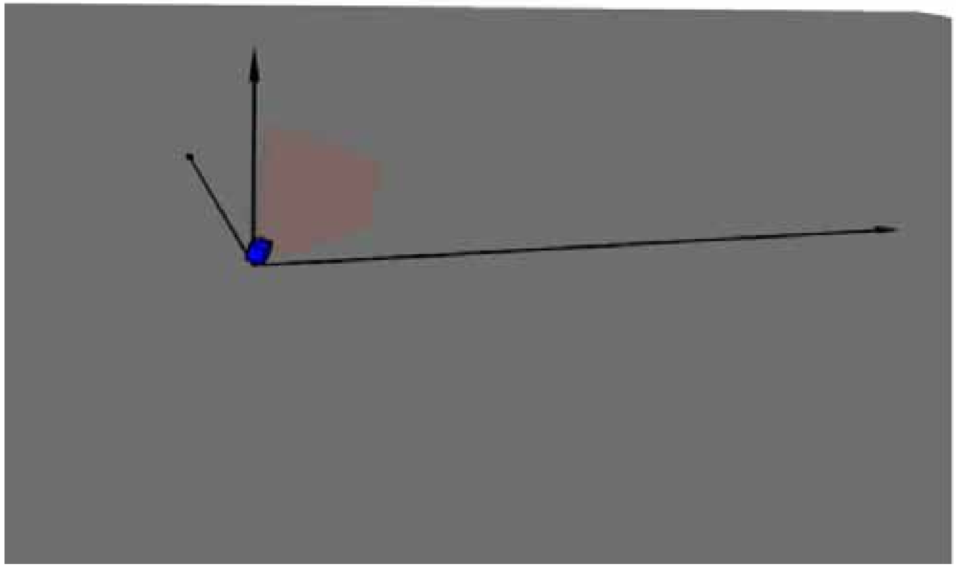
- identify landmarks using SURF features
- orientation of features can be used as additional constraint to reject false positives
- estimate absolute position of rover using 3-point pose estimation
- recover absolute position of observed landmarks

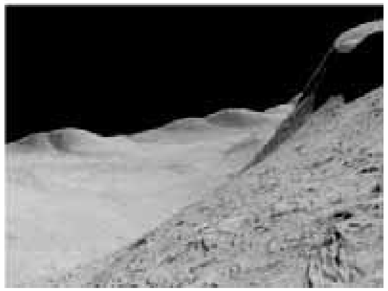


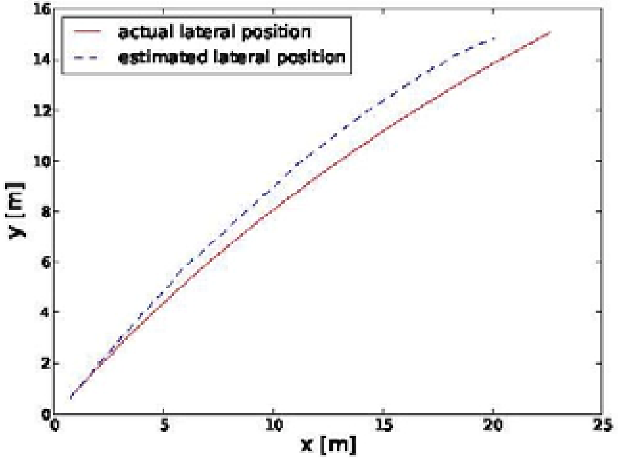


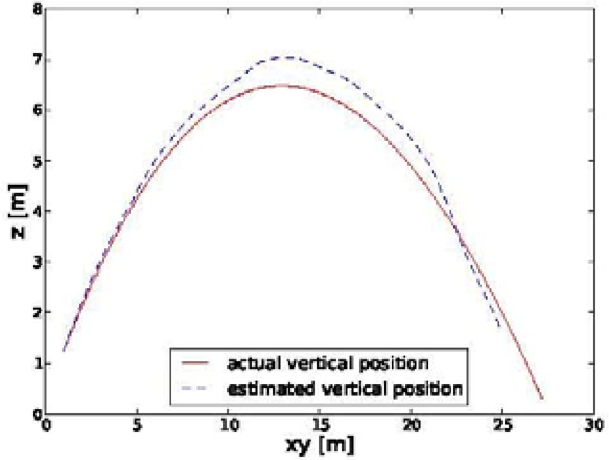


Selective Vision









Summary

- JAXA Roadmap of lunar or planetary exploration
- Robotics technology for planetary surface exploration
- Topics
    - Drilling robot for subsurface exploration
    - Visual odometry for hopping rover