3D vision studies for ESA EuroMoonMars 2018 campaign

Mr. Sandro Papais\textsuperscript{1}, Dr. Bernard Foing\textsuperscript{2}

\textsuperscript{1}McGill University, Montreal, Quebec, Canada
\textsuperscript{2}European Space Agency, ESTEC, Netherlands

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Agenda

1. Introduction
2. Relevant ESA Studies
3. Computer Vision Overview
4. Monocular Vision Studies
5. Stereo Vision Studies
6. Conclusion
1. Introduction
Introduction

ESA facts and figures
• 22 member states, over 50 years of experience.
• 8 sites/facilities in Europe, about 2200 staff.
• 80+ satellites designed, tested and operated.
• Involved in nearly every aspect of space activity.

European Space Research and Technology Centre (ESTEC)
• ESA’s technical heart located in Noordwijk, Netherlands.
• Where most ESA projects are born and developed.
Introduction

International Lunar Exploration Working Group (ILEWG)

- **Public forum** to support international cooperation towards **exploration and utilization of the Moon**.
- Since 2008 developing the EuroMoonMars research program for field work and training.

**EuroMoonMars**

- **ExoGeoLab** - robotic lander test bench.
- **ExoHab** - mobile laboratory habitat.
2. Programs at ESA Related to EuroMoonMars Vision Systems Studies
Programs at ESA Related to EuroMoonMars

Multisensory Real-time Space Telerobotics (MRST) Study

- **Operating a rover** and performing tasks with time-delay and haptic feedback.
- **Evaluated cognitive and physical responses** through data recording.
  - **Neurophysiological**: electroencephalographic (EEG) brain activity.
  - **Physiological**: metabolic response via physical activity monitor.
  - **Performance data**: efficacy, efficiency and safety factors via video.
Programs at ESA Related to EuroMoonMars

Lunar Exploration Activities and Remote Navigation (LEARN)

- **Lunar simulation mission** at LUNARES, Poland
- **Mission support** through monitoring vision algorithms
ExoMars 2020 Rover PanCam

- **Two Wide Angle Cameras** (WACs), panoramic imaging with 12-position filter wheels covering different wavelengths, enabling multispectral observations.
- **One High Resolution Camera** (HRC), for narrow high-resolution imaging.
- **One PanCam Interface Unit** (PIU), the "brain" of the instrument.
3. Computer Vision Overview
What is computer vision?

- Bridging the gap between pixels and “meaning”

Applications:
- 3D reconstruction
- Panoramic mosaics
- Recognition
- Special effects
- Medical imaging
- Autonomous cars
- Surveillance
- AR/VR
- Robotics

Processes:
- Image Formation
- Image Processing
- Features
- Segmentation
- Structure from Motion
- Motion
- Stitching
- Computational Photography
- Stereo
- 3D Shape
- Image-based Rendering
- Recognition
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4. Features
5. Segmentation
6. Stereo
7. 3D Shape
8. Image-based Rendering
9. Stitching
Vision System Basics

3D Reconstruction Methodologies Used:

1. Monocular vision
   - Structure from motion (SfM)

2. Stereo vision
   - Stereo matching/correspondence
4. Monocular Vision Studies
Monocular Vision System Study

HI SEAS, Mauna Loa, Hawaii

- June 2018 campaign terrain reconstructions
Monocular Vision System

Step 1: Calibration

- Estimate camera intrinsics, extrinsics, and lens distortion parameters.
- 42 images, mean reproduction error 0.10 pix.

![Diagram](image_url)
Monocular Vision System

Step 2: Solve structure from motion (SfM) problem

1. **Remove image distortion** based on camera parameters.
2. **Detect points** using corners detector via minimum eigenvalue algorithm.
4. **Estimate the transformation matrix** between two images.
5. **Remove outliers** and repeat for improved accuracy.
Monocular Vision System

Step 3: 3D reconstruction from SfM solution

1. **Compute 3D points by triangulation** of SfM matched points and camera pose.
2. **Get colour values** of each point detected from original images.
3. **Create point cloud** using 3D points and assigned colours.

Up to scale reconstruction of the scene:
Monocular Vision System

Results

- HI-SEAS crew on Mauna Loa
Monocular Vision System

Results

- Mauna Loa lava tubes
4. Stereo Vision Studies
Studies at ESA Related to EuroMoonMars Program

Mars Yard Analogue Terrain, Automation & Robotics Lab, ESTEC, ESA
- August 2018 digital elevation map (DEM) campaign
Stereo Vision System

Calibration

• 20 image pairs, mean error of 0.14 pix.
Stereo Vision System

Stereo reconstruction

1. **Remove image distortion** based on camera intrinsic parameters.
2. **Calculate disparity map** for two images.

3D anaglyph image

.disparity heat map
Stereo Vision System

Stereo reconstruction

3. **Create 3D pt. cloud** from disparity map, stereo parameters, and pixel colours.

4. **Repeat and combine** other stereo pairs for multi view stereo reconstruction.
   a. Down sample point clouds.
   b. Calculate point cloud transform using iterative closest point (ICP) algorithm.
   c. Align (register) point clouds by applying transform matrix.
   d. Merge (stitch) point clouds.
3D Point Cloud to Digital Elevation Map (DEM)

1. **Detect plane(s)** and extract with random sample consensus (RANSAC) algorithm.
2. **Find equation of plane** via least squares.
3. **Rotate plane** (axis-angle) to fixed frame.
3D Point Cloud to Digital Elevation Map (DEM)

4. Smooth point cloud via delaunay triangulation and scattered interpolation.

5. Plot height contours at intervals.
Additional Combined Vision Study

DECOS Mars/Moon Yard Analogue, Netherlands
- Combined vision systems fusion studies with stereo camera and drone.
- Aerial and ground-based imaging for localization and mapping.
6. Conclusion
Summary

- Successfully supported several campaigns by developing computer vision algorithms

- Independent studies completed
  - Built stereo camera prototype for developing and testing algorithms
  - Structure from motion algorithms
  - Digital elevation map algorithms
  - Developed stereo vision algorithms
Future Work

• Recover absolute scale of 3D monocular reconstruction.
  • Sensor fusion (GPS, IMU, etc.) for baseline of camera motion.

• Detect points of interest using deep learning to categorize 3D map sections and objects.
  • Fine-tune a pre-trained model (transfer learning) to detect landar, drone, and points of interest.

• Refine multiple view algorithms for better quality reconstruction.

• Path planning, simultaneous localization, and mapping (SLAM) for navigation.
Thank you for your attention and attending.

Questions?

sandro.papais@mail.mcgill.ca