DEM generation and rover landing at the south pole of the Moon and Mars. Lang. Feng[1] and Chao Deng[2], [1]Mullard Space Science Laboratory (MSSL), Department of Space & Climate Physics, University College London, Holmbury St Mary, Surrey, RH5 6NT, United Kingdom (lang.feng.14@ucl.ac.uk) , [2]Information Engineering University, Zhengzhou 450001, China.

Introduction: Radar (radio detection and ranging) is currently one of the important research areas for Earth and moon observation and for helping human being explore and detect the organics and life in planets and their ICE moons, many radar satellites have been or are about to be launched, such as Magellan (1994) radar for Venus ,Cassini (1997) RADAR instrument for Saturn and its moons, Mars Reconnaissance Or-biter (2005) Shallow Radar (SHARAD) sounder and Mars Express (2005) Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) for Mars, Lunar Reconnaissance Orbiter (LRO 2009) Miniature Radio Frequency (Mini-RF) for Earth's moon and in the near future JUICE mission [1] (RIME - Radar for Icy Moons Exploration, SWI - Submillimeter Wave Instrument, RPWI - Radio & Plasma Wave Investigation, 3GM radio science package - Gravity & Geophysics of Jupiter and Galilean Moons) for Jupiter and its moons. The Magellan multimode S band radar has three modes: SAR, altimetry, and passive radiometry to map almost all of the Venusian surface, while the Cassini RADAR instrument transmits and receives Ku-band micro-wave radiation, which operates in both passive (radiometer) and active (altimeter, SAR imaging, scatterometer) modes. Nowadays, Venera 15 and 16 radio occultation experiment data at Venus, Magellan stereo SAR data and Cassini RADAR data and Radio and Plasma Wave Science(RPWS) data are opened to public at PDS. Moreover, Lunar Reconnaissance Orbiter (LRO) Mini-RF data (S band and X band Raw data, Bistatic Radar data, Level 1 SAR, Level 1 interferometry, Level 2 SAR, Level 3 SAR mosaics, and Level 3 Sandia SAR Stereo data [2]) are available at PDS too, which will greatly advance our understanding of our moon, giving us the first look inside the Moon's coldest, permanently shadowed darkest polar craters with water ice. Our work in this study is primarily concerned with generation and fusion digital topographic models (DTMs) by LRO LROC NAC image via photogrammetry and LRO Mini-RF images (Stereo) via radargrammetry. Moreover, fast and automatic DTM co-registration with DTM will be studied for finding the correct and precise planned location for safe planetary rover landing at the south pole of the Moon and Mars.

DTMs generation using photogrammetry & radargrammetry: For the permanently shadowed darkest area of the south pole of the Moon, stereo radar images and metadata are first prepared in ISIS. Then a rigorous sensor model (RD model) is developed. After co-registering the radar images as closely as possible to one another to form a stereo radar pair, bundle adjustment and dense matching is employed for DTM production. For the Lunar Reconnaissance Orbiter (LRO) LROC Narrow Angle Cameras (NAC) data stacks, data is pre-processed in ISIS, to form the relative orientation, and absolute orientation with LOLA ranging data, employing an idealized camera, with subsequent jitter correction, image mosaic processing and stereo dense matching is developed with the help of the open source of the NASA Ames Stereo Pipeline (ASP) [3]. Meanwhile, for the NAC DTM, conventional dense matching, using stereo methods with map projected data and SGM methods are studied. It is shown that SGM has less holes, but the accuracy is not good enough, especially in rough areas. The stereo methods with map projected data have a higher accuracy and less holes than the conventional stereo method, as it can find more matches. Thus, a better DTM can be obtained by fusing stereo methods with map projected data and SGM methods. Finally, the two DTMs (optical and radar) are fused to generate the final DTM over the lunar south pole.
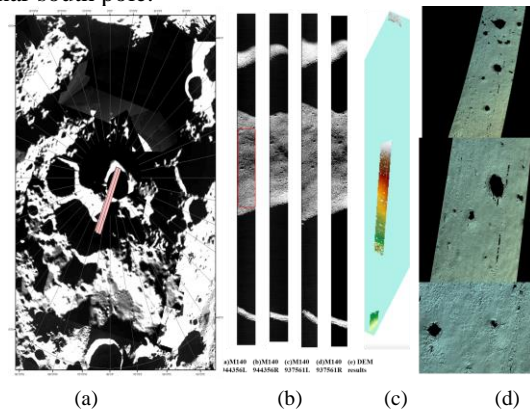

Figure 1: DEM generation (a) LRO LROC NAC image location, (b) LRO LROC NAC image data, (c) LRO LROC NAC image DEM result (holes via conventional stereo dense matching), (d) Zoom in of DEM hillshading map.
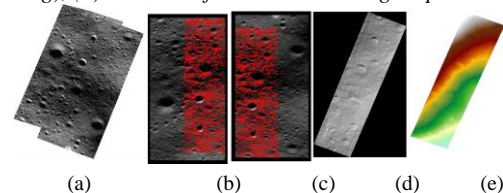
Figure 2: *DEM Processing and results (a) The stereo pair in the red rectangle area shown in Figure 1 (a), (b) SIFT matching points in the red rectangle area shown in Figure 1 (a), (c) LROC NAC image DEM hill shading result via SGM matching (less gaps), (d) 3D display of LRO LROC NAC image fusion DEM results via map-projected image and SGM matching.*

A fast and automatic DTM co-registration (TRN) algorithm helps to improve precise and safe rover landing on the south pole of the Moon and Mars: The TRN algorithm (DTM co-registration) is studied, whether the DTM is generated by imaging, lidar or radar techniques within the landing equipment, for finding the correct and precise planned landing location for safe planetary rover landing.
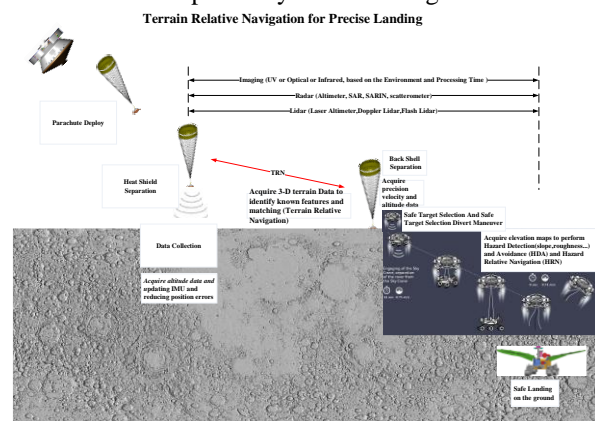

Figure 3: *The timeline for a Terrain Relative Navigation for Precise Landing in the atmospheric environment of a celestial body (the red line) (DTM can be made by lidar, radar altimeter, stereo imaging and so on), note: When the landing environment has an atmosphere, like on Mars, a parachute can be used, if landing area has no atmosphere, like the Moon, thrusters are used instead of parachutes and no heat-shield separation. (Background map is from USGS, the landing equipment picture materials is from NASA)*
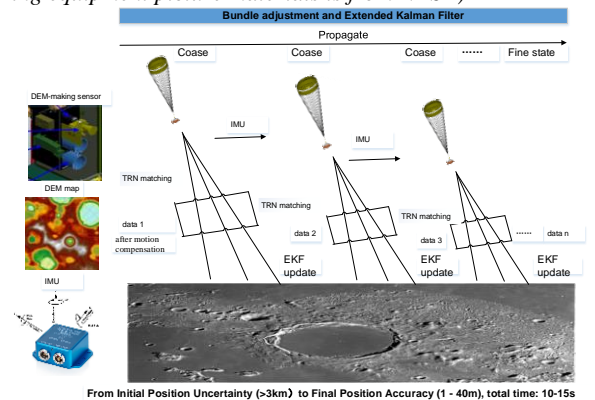

Figure 4: *The Terrain Relative Navigation for Precise Landing (the landing equipment picture materials is from NASA IMU picture is from RACELOGIC)*

Firstly, the coarse horizontal shift and vertical shift estimation are achieved using cross-correlation by cross-correlating the edge images of the two DTMs and cross-correlating the height histogram of the two DTM heights. Then, sparse initial registration via a pyramidal method is introduced to obtain an initial coarse matching matrix. Lastly, refined co-registration using Iterative Closest Point (ICP) is utilized to get high accuracy matching matrices with global optimization of each tile by using Gaussian weights to obtain the final co-registration results to solve the positioning error for landing.

In rover landing TRN step, after continuously DEM matching, the sensor position (based on photogrammetry space resection or other sensor model methods using DEM matching results) and the transformation matrix of this DEM matching algorithm will continuously be input (give feedback) into the Guidance, Navigation and Control system (especially with IMU and Kalman filter method) to calculate and refine the current attitude, current angular velocity, the current speed, the current acceleration and position for precise and safe rover landing. This is similar to simultaneous localization and mapping (SLAM) for navigation, the difference is rover landing is very fast, so the velocity-acceleration-distance and time model, EKF and bundle adjustment should be used in calculation, shown in Figure 4.

Discussion and Conclusions: In this study, DTM generation and fusion using photogrammetry and radargrammetry are studied and a fast and automatic DTM co-registration algorithm (TRN) is presented, and tested for finding the best landing site and a precise and safe rover landing at the south pole of the Moon and Mars. The lunar and Mars experiments demonstrate that the algorithm works well, but the speed of the algorithm still needs to be improved. The DTM generation method, DTM co-registration algorithm will be tested and improved for further future Entry Descent and Landing mission's scenarios of other planets, some moons of the planets, some comets, some asteroids and some habitable exo-planets in the future.

Previous and latest research results will be shown.

References: [1] Grasset O. et al. (2013) Planetary and Space Science, 78, 1–21. [2] Raney R. K. et al. (2011) Proceedings of the IEEE, 99(5) , 808–823. [3] Moratto, Z. M., et al. (2010). Ames Stereo Pipeline, LPSC XLI, Abstract #2364.