Comparison of SLAM algorithms on Unity-ROS(Robot Operating System) Simulator for Space Applications(URSSA)

Midhun S. Menon[1] and Michael E. Walker[2] and Daniel Koris[2] and Daniel Szafir[2,3] and Jack Burns[1]

Abstract— **Robots are critical enablers for space exploration as they help offset safety risks associated with a human astronaut, aid in precursor missions prior to manned missions, provide critical on-mission and post-hoc support. However, designing robotic systems to navigate, map and localize itself in hostile and unknown extraterrestrial worlds remains open challenge. The prime reason for this being the testing the semi-autonomous agents for robust performance in such environments. In this paper, we address this issue by using Unity-ROS(Robot Operating System) Simulator for Space Applications(URSSA) for compare performance of three popular Visual Intertial Odometry (VIO) Simultaneous Localization And Mapping (SLAM) algorithms on lunar surface. The test architecture, agent modelling, rationale for test cases and generation of ground truth data is discussed. Paper concludes with results from simulations comparing the algorithms and discusses on failure reasons and potential directions for improving algorithms for better applicability such environments. We believe such a comparative study can give vital pointers for future research directions and help accelerate development of specific algorithms for SLAM in extra terrestrial environments.**

I. INTRODUCTION

The last decade has seen major space faring nations chart out focussed plans for deep space exploration starting with the moon. The Artemis I**(Ref.)**, Chang'e-4 mission**(Ref.)** and Chandrayaan-2**(Ref.)** are some of the ongoing and completed precursor missions to put human explorers on lunar surface. These missions have robotic systems onboard to do remote investigation,survey and data collection of the lunar surface. The follow-up missions to all of these missions have a increasing component of robotic systems of which ground based mobility systems are central. Wheeled rovers are the most commonly used platform for planetary surface mobility. To date, they have been used for surface exploration, mapping and scientific investigation. However, future missions call for advanced mission operations including periodic monitoring of geo-spatially distributed scientific assets, remote assembly and In-Situ Resource Utilization(ISRU)**(Ref.)** tasks. The first of these call for navigation, mapping and localization capabilities over large ranges and the ISRU tasks require advanced manipulation and dexterity capabilities. More importantly, these algorithms need to be tested under a rich and varying environment to make sure they perform reliably. In this paper, the focus is on the testing of algorithms for navigation, mapping and localization. Currently, space robotics community relies on mission analogs for evaluation and testing of such on-board algorithms. These are operations carried out on Earth in a mock-up of the true mission environment. However, mission analogs are incapable of simulating certain critical, unique and finer aspects of the extraplanetary environment (e.g., gravity, photometric anomalies etc.) which impacts testing aefficacy. As an example, visual artefacts present in target environment but not simulated in a mission analog may artificially inflate expectations and over-estimate algorithm performance during testing. On similar lines, locating a matching topography for a mission analog on earth can also prove increasingly challenging as the geological processes governing surface formation and evolution will differ entirely in most cases.

In this research, we wish to address the problem of designing a virtual analogs for extra-terrestrial environments within a multiphysics framework for advancing research in algorithms that govern low-level autonomy and support interactive trade-offs between various levels of supervisory control. Furthermore, such virtual environments may enable future explorations into the design of new interfaces that support ground control and/or astronaut operation of surface robots from orbital stations to significantly improve critical space exploration missions.

Some of the existing frameworks for simulating the Moon have been used by NASA[1]. However, they have not been designed for evaluating robotic vision-based navigation algorithms and are limited in scalability and their ability to provide perceptually real-time simulation. In addition, other frameworks are mostly based on classic simulation environments such as Gazebo[2], which are not necessarily as efficient, realistic, or scalable as modern engines such as Unity ([3], [4]).

This is the reason for simulators becoming increasingly based on frameworks like ROS[5] and Unity([6], [7]). Hence, in this paper, in-house developed simulation framework Unity-ROS Simulator for Space Applications(URSSA)**(Ref.)** is used, that leverages the Unity game engine as a virtual environment simulator to take advantage of its advanced rendering pipeline, support for reliable physics engines and scalable memory management capabilities. ROS is used as the framework to model the autonomous/semi-autonomous robotic systems interacting with the virtual world in Unity. We demonstrate the comparative testing of three popular Visual and/or Intertial Odometry (VIO)**(Ref.)** Simultaneous Localization And Mapping (SLAM) algorithms for surface exploration of moon. Only visual and inertial sensing modal-

[1]Center for Astrophysics and Space Astronomy, University of Colorado Boulder

[2]Department of Computer Science, University of Colorado, Boulder

[3]ATLAS Institute, University of Colorado, Boulder

ities have been considered here as these are the ubiquitous sensors reliably flight tested and proven with minimal mass penalties on multiple missions to date by space agencies across the world. However, it may be noted that URSSA has no such restrictions.

II. SIMULATOR MODEL

The simulator architecture is shown in Figure **(Add architecture Figure)** and consists of three main components. Unity is used for simulating the environment, topography, photometry, rover dynamics and terrain interaction. The second main component is ROS and it is used to simulate the agent behaviour, which essentially takes in the cognitive information of the environment through the simulated sensors, and generates appropriate inferences(SLAM) and actions on how to interact with the environment(path planning). These two independent components are coupled through a communication framework called ROS#([7]), which also takes care of time synchronization and guarantees across the components. The details of the modelling are in **(Ref.)**. The following sections give a brief overview each of these components.

A. Environment model(Unity)

The virtual environment is modeled as multiple interacting sub-systems inside Unity environment.

1) Topographic Model: The lunar topography is simulated using high-resolution synthetic terrain modeled on actual lunar surface data from Lunar Reconnaissance Orbiter(LRO)-Narrow Angle Camera(NAC) Digital Terrain Models(DTM) which are available to a resolution of 0.5m(at best). Sub-millimeter super-resolved terrain is generated from these DTMs using observed lunar surface roughness parameters([8], [9]), crater distributions([10], [11]) and boulder distributions [12] from the Apollo missions to generate physically realistic terrain by fractal expansion algorithms. Rocks of envelope diameters in range of 0.5m–2.0m have also been procedurally generated and uniformly distributed on the terrain as these are not captured by LRO-NAC DTM in its resolution limits.**(Add teaser figure of terrain)**

2) Photometric Model: Custom shaders are developed based on Hapke photometric model[13] to simulate the photometric response of moon called Opposition Surge(OS)[14]**(add figure of OS)**, a specific behaviour exhibited by moon at low phase angles which induces visual artefacts like glare, lens flares and sensor saturation in optical imaging systems. Such artefacts can drastically affect mapping algorithms and perception-aided planners [15]. The Hapke Bidirectional Reflectance Distribution Function(BRDF) is implemented in the Unity Physically Based Rendering(PBR) pipeline[16] and the parameters for the same are derived from lunar parameter maps[17]. The variables in the BRDF are the incident angle θ_i, the reflected angle θ_r and the phase angle ϕ. The plot of the Hapke BRDF is shown in Figure **(Add BRDF plot)**, which shows the OS when the phase angle approaches zero.

3) Rover Model: The rover is modeled as a multi-body system based off the design of Mars Exploration Rover[18]

4) Terrain Interaction Model:

B. Agent Model(ROS)

In ROS.

C. Communication Framework(ROS#)

1) Time Synchronization:

2) Real Time compliance:

3) Fixed Update:

III. TEST SYSTEM MODEL

A. Test-Case generation

IV. SIMULATION

V. RESULTS AND DISCUSSION

VI. CONCLUSION

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TABLE I

AN EXAMPLE OF A TABLE

One	Two
Three	Four

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Fig. 1. Inductance of oscillation winding on amorphous magnetic core versus DC bias magnetic field

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APPENDIX

Appendixes should appear before the acknowledgment.

ACKNOWLEDGMENT

References are important to the reader; therefore, each citation must be complete and correct. If at all possible, references should be commonly available publications.

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