

Comparison of SLAM algorithms on virtual test bed URSSA for space applications

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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 Simulator for Space Applications(URSSA) for compare performance of three popular Visual Inertial 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 advanced navigation, mapping and localization capabilities and the ISRU tasks require advanced manipulation and dexterity capabilities.

Through this paper, we aim to address the problem of designing robust test beds to robustly test and design Visual Inertial Odometry (VIO) (Ref.) Simultaneous Localization And Mapping (SLAM) algorithms specific to extra-terrestrial

environment. This paper specifically discusses a case-study of using in-house developed Unity-ROS Simulator for Space Applications(URSSA) to test and compare performance of these algorithms in a virtual lunar environment. Some simulators exist in literature, but have their fair share of shortcomings.

II. SIMULATOR MODEL

The simulation environment uses Unity for simulating the environment, topography, photometry, rover dynamics and terrain interaction. The details of the modelling are in [].

A. Environment model

- 1) *Topographic Model:*
- 2) *Photometric Model:* Include Skymap
- 3) *Rover Model:*
- 4) *Terrain Interaction Model:*

B. Agent Model

In ROS.

C. Timer Model

- 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

We suggest that you use a text box to insert a graphic (which is ideally a 300 dpi TIFF or EPS file, with all fonts embedded) because, in an document, this method is somewhat more stable than directly inserting a picture.

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

The preferred spelling of the word acknowledgment in America is without an e after the g. Avoid the stilted expression, One of us (R. B. G.) thanks . . . Instead, try R. B. G. thanks. Put sponsor acknowledgments in the unnumbered footnote on the first page.

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

REFERENCES

- [1] G. O. Young, Synthetic structure of industrial plastics (Book style with paper title and editor), in *Plastics*, 2nd ed. vol. 3, J. Peters, Ed. New York: McGraw-Hill, 1964, pp. 1564.
- [2] W.-K. Chen, *Linear Networks and Systems* (Book style). Belmont, CA: Wadsworth, 1993, pp. 123135.
- [3] H. Poor, *An Introduction to Signal Detection and Estimation*. New York: Springer-Verlag, 1985, ch. 4.
- [4] B. Smith, An approach to graphs of linear forms (Unpublished work style), unpublished.
- [5] E. H. Miller, A note on reflector arrays (Periodical styleAccepted for publication), *IEEE Trans. Antennas Propagat.*, to be publised.
- [6] J. Wang, Fundamentals of erbium-doped fiber amplifiers arrays (Periodical styleSubmitted for publication), *IEEE J. Quantum Electron.*, submitted for publication.

- [7] C. J. Kaufman, Rocky Mountain Research Lab., Boulder, CO, private communication, May 1995.
- [8] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, Electron spectroscopy studies on magneto-optical media and plastic substrate interfaces(Translation Journals style), *IEEE Transl. J. Magn.Jpn.*, vol. 2, Aug. 1987, pp. 740741 [Dig. 9th Annu. Conf. Magnetism Japan, 1982, p. 301].
- [9] M. Young, *The Techincal Writers Handbook*. Mill Valley, CA: University Science, 1989.
- [10] J. U. Duncombe, Infrared navigationPart I: An assessment of feasibility (Periodical style), *IEEE Trans. Electron Devices*, vol. ED-11, pp. 3439, Jan. 1959.
- [11] S. Chen, B. Mulgrew, and P. M. Grant, A clustering technique for digital communications channel equalization using radial basis function networks, *IEEE Trans. Neural Networks*, vol. 4, pp. 570578, July 1993.
- [12] R. W. Lucky, Automatic equalization for digital communication, *Bell Syst. Tech. J.*, vol. 44, no. 4, pp. 547588, Apr. 1965.
- [13] S. P. Bingulac, On the compatibility of adaptive controllers (Published Conference Proceedings style), in *Proc. 4th Annu. Allerton Conf. Circuits and Systems Theory*, New York, 1994, pp. 816.
- [14] G. R. Faulhaber, Design of service systems with priority reservation, in *Conf. Rec. 1995 IEEE Int. Conf. Communications*, pp. 38.
- [15] W. D. Doyle, Magnetization reversal in films with biaxial anisotropy, in *1987 Proc. INTERMAG Conf.*, pp. 2.2-12.2-6.
- [16] G. W. Juette and L. E. Zeffanella, Radio noise currents n short sections on bundle conductors (Presented Conference Paper style), presented at the IEEE Summer power Meeting, Dallas, TX, June 2227, 1990, Paper 90 SM 690-0 PWRS.
- [17] J. G. Kreifeldt, An analysis of surface-detected EMG as an amplitude-modulated noise, presented at the 1989 Int. Conf. Medicine and Biological Engineering, Chicago, IL.
- [18] J. Williams, Narrow-band analyzer (Thesis or Dissertation style), Ph.D. dissertation, Dept. Elect. Eng., Harvard Univ., Cambridge, MA, 1993.
- [19] N. Kawasaki, Parametric study of thermal and chemical nonequilibrium nozzle flow, M.S. thesis, Dept. Electron. Eng., Osaka Univ., Osaka, Japan, 1993.
- [20] J. P. Wilkinson, Nonlinear resonant circuit devices (Patent style), U.S. Patent 3 624 12, July 16, 1990.