

L.U.N.A. - A Laser-Mapping Unidirectional Navigation Actuator

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Abstract The abstract goes here. README: Feel free to change and cut content as you see fit! I've written down everything that came to my mind fairly independent of its quality. - A.

1 Introduction

In today's world, autonomous robots have found their way into everyday life in a variety of ways. This includes, but isn't limited to, the vacuum cleaner that independently navigates one's living-room or mobile robots employed for exploration of areas that are too dangerous for humans. To foster new advances in the latter, specifically for underground environments, the Defense Advanced Research Projects Agency (DARPA) of the US Defense Department established the yearly "SubT" Challenge in 2017. In this challenge, teams are tasked to "Drive novel approaches and technologies to allow warfighters and first-responders to rapidly map, navigate, and search dynamic underground environments." [2] proving the demand for further research in this domain. One difficulty of this challenge is building an accurate 3D model of the environment, i.e. mapping the surroundings. The teams that participate in the DARPA challenge take advantage of high-quality hardware, such as state-of-the-art 3D laser-scanners and cameras, thus making their solutions rather expensive. However, the demand for mapping-solutions in the low-cost sector is non-negligible. For example a set of disposable mapping devices could be used to create a 3D model of an area from different initial locations.

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One such approach using a 2D laser scanner to scan 3D indoor environments has been proposed in [9]. The authors mounted a 2D laser scanner on a cylindrical structure. An operator then initiated a rolling movement by manually pushing the contraption. This enabled the scanner to sense the 3D environment with great results. However, manually pushing the scanner is not practical, especially for long scans.

Previous work was also done at the Julius-Maximilians University Würzburg [5]. The RADLER (RADial LasER scanning device) consists of a 2D laser scanner attached to the axle of a unicycle. An operator then pushes the unicycle along a requested path. The inherent rotation of the wheel then creates a radial 3D laser-scanning pattern. However, this approach still requires an operator, therefore does not fulfill the autonomy requirements.

A more autonomous approach was taken in [7]. The authors mounted a rotating 2D laser-scanner on top of a *turtle-bot* thus removing the need of an operator. In contrast to the RADLER however, the *turtle-bot* does not provide an inherent rotation. Therefore an extra actuator is required to create the radial 3D scanning-pattern.

This paper builds upon the results of the RADLER and has a specific application of mapping lunar craters autonomously in mind. We propose a novel approach to low-cost 3D laser-scanning using a 2D laser-scanner inside a spherical robot based on conservation of angular momentum (COAM): the L.U.N.A. - sphere (Laser-mapping Unidirectional Navigation Actuator). The 2D laser-scanner is fixed to the spherical structure, hence a similar situation as with the RADLER is given: the inherent rotation of the sphere creates a radial 3D scanning pattern. Using the format of a spherical robot permits the system to be designed more compact. Furthermore, an operator is no longer required given the drive implemented in the robot.

2 State of the Art

As evolution of RADLER as hand-driven radial scanner device, a self-driving spherical approach was chosen to ensure robustness and autonomy. There have been several works in literature regarding approaches for spherical robots as well as 3D scanning mechanisms.

2.1 Spherical Robots

An early idea of an self-driving sphere has been introduced by J.L. Tate in 1893 who claimed the patent 508 and 558 in the U.S. for a sphere, driven by an inner moving counterweight, which got its torque from an spring. This idea of an actuator attached to an counterweight pointing to the bottom and therefore the torque being transferred to the sphere and moving it, is still a wide spread approach for spherical robots.

In [6] a basic motion control system for the BYQ-III is introduced. The BYQ-III has a mass of 25kg and a diameter of 600mm and its diving mechanism has been proposed in [1] by S.Hanxu, X.Aiping, J.Qingxuan and W.Liangqing. It contains a counterweight pendulum, four gyros providing movement for two axes and one IMU mounted on the gyro case. There is no extra payload or sensor, nor would there be space for a centered measurement unit due to the centered counterweight. Therefore the counterweight leads to a steady movement not relying on acceleration but on velocity of the actuators and therefore providing continuous speed.

A second spherical robot with its driving mechanism relying on inner counterweight is presented in [11]. This was designed for movement on water-surface and therefore having orthogonal to the movement mounted fins on the shell. Two actuators attached to the shell and the inner counterweight provide movement around one axis. In contrast to the BYQ-III a middle-centered sensor would be possible, but this would have no movement relative to the surface, as it would be part of the relatively non-moving inner counterweight. It also has steady, well-controllable movement. The sphere presented in [10] [4] provides a solution for a driving system which does not rely on a moving inner counterweight but uses internal reaction wheels to provide torque. This leads to theoretically having middle-centered space which is rolling and not steady relative to the environment. But the prototype provided by Vijay Muralidharan shows less controllability than counterweight-driven spheres. Also now it is driven by acceleration and not velocity which leads to limited movement.

A third approach for spherical robots relies on an internal unit which drives the sphere. A design and control approach is provided in [3] where a four-wheeled vehicle moves in the sphere to force it rolling by moving the center of mass in the desired direction. This technical solution is capable of a nearly maximum size of possible payload in relation to the overall-size, but also does not provide without further mechanics a rotation of the sensor which would be needed for 3-dimensional laser scanning. Also this provides just like the counterweight-driven approach a good controllability, it is obviously not as stable regarding external perturbations or forces, due to the missing fixed connection to the shell. This would make it not suitable for missions with extreme forces and unknown starting conditions like missions involving a rocket launch or a drop to the starting point, which would lead to harsh movements of the sphere in the worst case a start with the unit being rotated 180 degrees and therefore not being able to bring torque to the sphere. This would also happen if the sphere was stuck to the environment and therefore the inner unit trying to perform a whole revolution of the sphere, which leads to a supine position.

Overcoming this shortage of the inner unit just relying on gravity to apply its force to the shell, [8] introduced the approach of a rod, expanded by a spring to the maximum possible size and having a wheel on one side. The wheel generates the movement by again moving the center of weight. But now the non-reversible supine position does not exist anymore, because even with the wheel being at the top, it is still pressed to the shell by the spring and therefore being able to maintain its movement. Again this approach does not provide space for a centered placed sensor without further contraptions.

2.2 3D Laser Scanning

Talk about 3D laser scanning. Specifically on mobile robots

3 Technical Approach

Small intro to technical approach

3.1 Hardware Setup

Talk about hardware setup

3.2 Sensor Integration

Talk about sensor integration

4 Experimental Results

4.1 3D Laser Scanning

4.2 COAM Drive

5 Conclusions

Add conclusion

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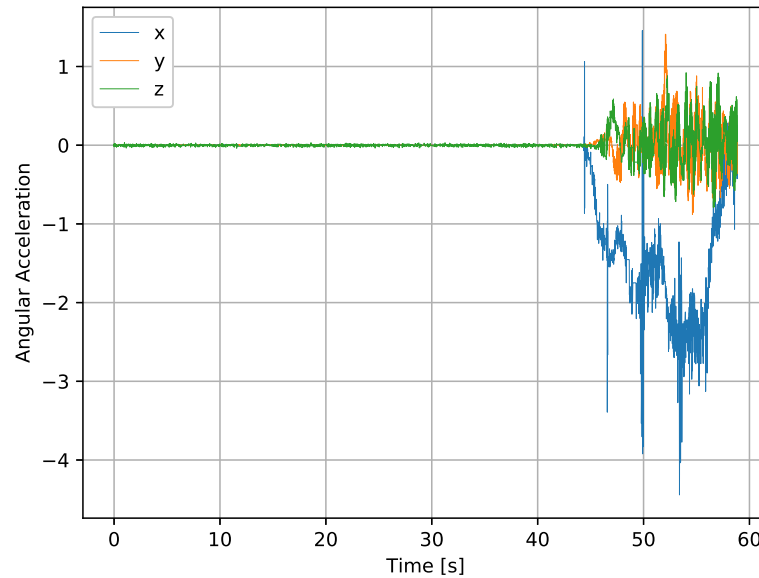


Fig. 1 Angular velocities of the L.U.N.A. - sphere during a test run. The flywheels rotate around the x-axis in positive direction. Velocities in the other direction can mostly be contributed to vibrations and tilt of the robot.

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