laser ranging, mapping, and imaging systems for exploration robots

Alex Styler <styler@cmu.edu>

Echo ranging technology

- The high-level abstraction for laser echo range finding uses a mode-locked laser, a sensor (photon counter), and a very accurate clock (on the order of pico-seconds)
- Laser pulses are emitted in the desired direction at a specific frequency and the round trip time is calculated when the sensor detects the laser pulses.
- Distance is then calculated from the one-way trip time and speed of light in expected medium.

Laser ranging technology

- Trip times are so short that actual methods involve amplitude modulated frequencies (continuous waves instead of pulses) to receive more data than just the single phase shift
- Another earlier method involves emitting laser pulses at multiple frequencies, determining the phase shifts in the return signals, and solving the resulting system of equations to determine distance
- Manufacturers are constantly researching ways of improving this low-level sensing in their LiDARs in order to improve accuracy

LiDARs (Laser Rangefinders)

- While a single laser range measurement is useful, modern LiDARs actively sweep the laser beams horizontally and/or vertically so robots can map out or image a large area
- Some robots mount horizontally scanning LiDARs on gimbals to sweep vertically in order to get an entire image
- For example some laser range finders have fixed lasers and actuate a mirror to sweep the beam as necessary
- With each range measurement, the sensor will report the angle of emission from the sensor, allowing the robot (with knowledge or where the sensor is) to convert measurements to its local coordinate frame

LiDARs vs. SONAR

LiDAR has many advantages over sonar:

- Narrow beam width, higher resolution
- Not affected by temperature or vacuum
- Greater accuracy and faster response

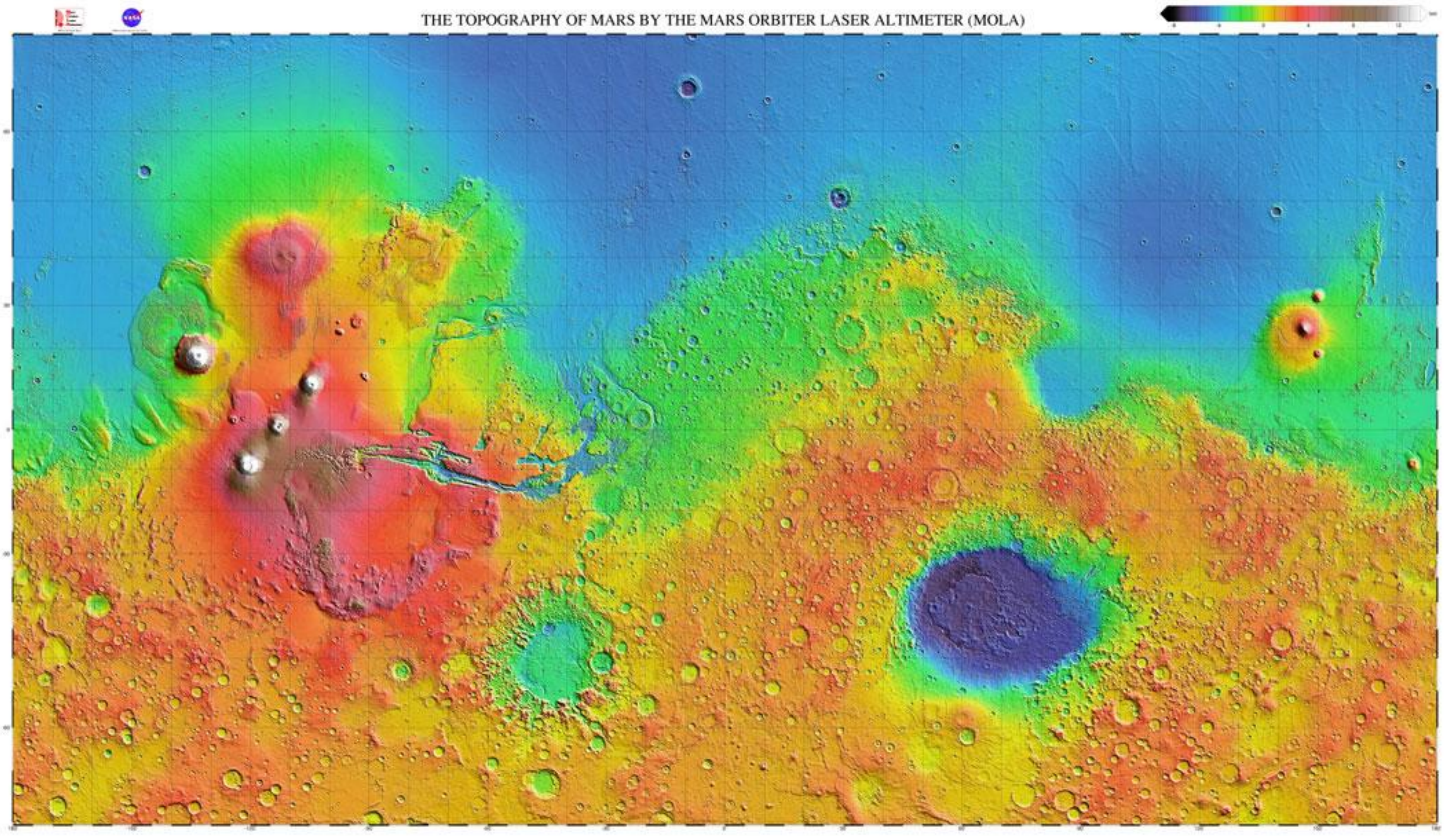
Sonar has some advantages as well:

- Cheaper due to simpler components
- Lighter (lightest LiDARs are around 1 Kg.)
- Works in poor visibility (dense refraction particles) and underwater

Future uses of laser ranging systems in planetary exploration

- Topography mapping from satellites such as the Mars Orbital Laser Altimeter (MOLA)
- Obstacle avoidance and navigation for surface rovers
- Terrain and cave mapping for future advanced rovers
- Detailed LZ mapping

MOLA Mars Topography Map



Localization and Mapping with LiDAR

- LiDAR accuracy allows rovers to accurately map and localize in foreign environments, enabling meaningful movement and exploration
- Most recent significant breakthrough was Montemerlo's FastSLAM. FastSLAM particles use EKFs to track map features. As particles are certain of their position, Rao-Blackwellization allows landmark positions to be independent measurements.

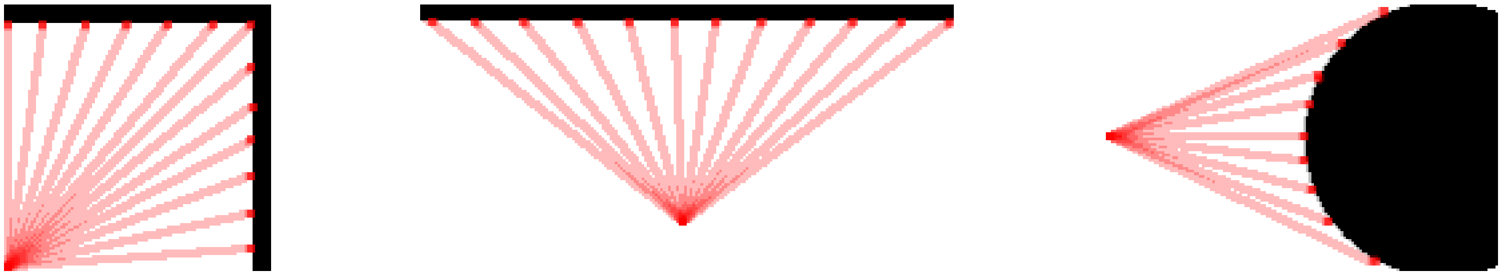
Particle Filter Localization with LiDAR

video

Assignment

- Assume you are given a set of 20 perfect planar LiDAR measurements of the form (r, θ), where r is the measured range and θ is the angle of the laser with respect to your robot's orientation (0 degrees is straight forwards).
- You can assume all 20 measurements were taken simultaneously so you don't have to worry about robot motion

1. Describe an algorithm in pseudo-code for detecting a corner given such a set of measurements (versus seeing walls or rounded objects).
2. How would your algorithm fare if the measurements were noisy? Why? How might you improve the algorithm?
3. How might you detect a circular object assuming you had no noise? Hand-waving is fine here, no pseudo-code necessary.



Improving LiDAR

Important LiDAR specifications:

- Field of view
- Scanning Range
- Resolution
- Statistical error
- Response time

Improving one spec for some given device requires sacrifices in other specs. (e.g. decrease field of view to improve response time)

SICK LMS200 Spec Sheet

Technical data

Field of view:	180 °
Angular resolution:	1 ... 0.25 °
Response time:	13 ... 53 ms
Resolution:	10 mm
Systematic error:	+/- 15 mm
Statistical error (1 sigma):	5 mm
Laser class:	1
Enclosure rating:	IP 65
Ambient operating temperature:	0 °C ... +50 °C
Scanning range:	80 m
Data interface:	RS-232, RS-422
Data transmission rate:	9,6 / 19,2 / 38,4 / 500 kBaud
Switching outputs:	3 x PNP
Supply voltage:	24 V DC +/- 15%
Power consumption:	20 W
Storage temperature:	-30 °C ... +70 °C
Weight:	4.5 kg
Dimensions (L x W x H):	156 x 155 x 210 mm

Improving LiDAR

- Research groups using LiDAR buy off the shelf units from commercial suppliers, as they don't have the resources to research improvements (similar to processors or hard drives)
- All research toward improving hardware seeks new techniques to allow improving some spec without sacrificing others
- Most research is proprietary due to the competitive industrial automation business

Commercial suppliers of LiDAR

- SICK AG – A large Germany-based company, provides LiDARs used by Stanley, Boss, and many industrial robots
- Velodyne – Boss' mid-range LiDAR supplier
- Continental – Boss' long-range LiDAR supplier

Top-of-the-line researchers, labs, and applications of LiDAR

- SLAM - basis for modern localization enabled by LiDAR system
- Fast-SLAM - De facto standard implementation for SLAM using a particle filter for Rao-Blackwellization
- Urmson, Kantor - Localization combining LiDAR and satellite imagery
- CMU Red Team – BOSS and autonomous driving using LiDAR for obstacle and vehicle detection

Successes and failures of laser ranging and mapping systems

- MOLA successfully generated useful topography maps of Mars
- Laser range finding for mapping and localization is widely successful, e.g. Stanley & Boss
- Groundhog 3D mine mapping

References

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