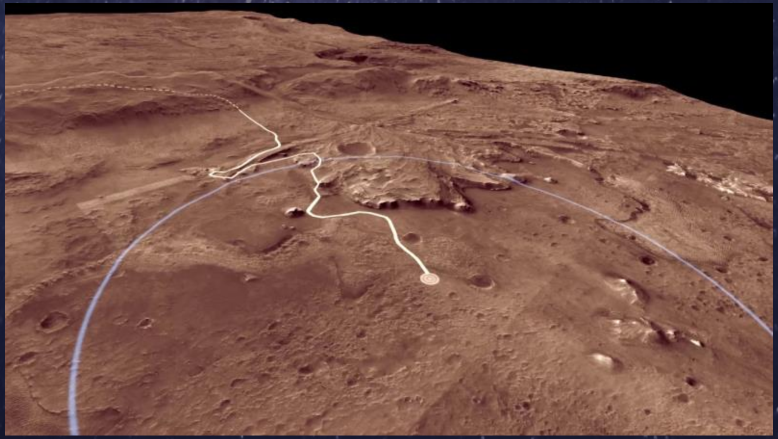
# TEAM BUMSIROVERS

(Anurag Mukherjee, Vamsi Grandhi)

# CHALLENGE STATEMENTS ADDRESSED

- Design a mobility suspension system for a Mars rover (1A)



- Design an autonomous navigation algorithm for a Mars rover (4D)

# ROVER MOBILITY SYSTEM

# MOBILITY SYSTEM OVERVIEW

- Mobility is an extremely crucial subsystem
- Autonomous planetary rovers require reliable and robust mobility systems.

## Basic requirements for rover mobility system:

- Simple mechanism with high reliability
- Lightweight
- High degree of mobility
- Low power consumption
- Small size

# COMPARISON OF DIFFERENT MOBILITY SYSTEMS

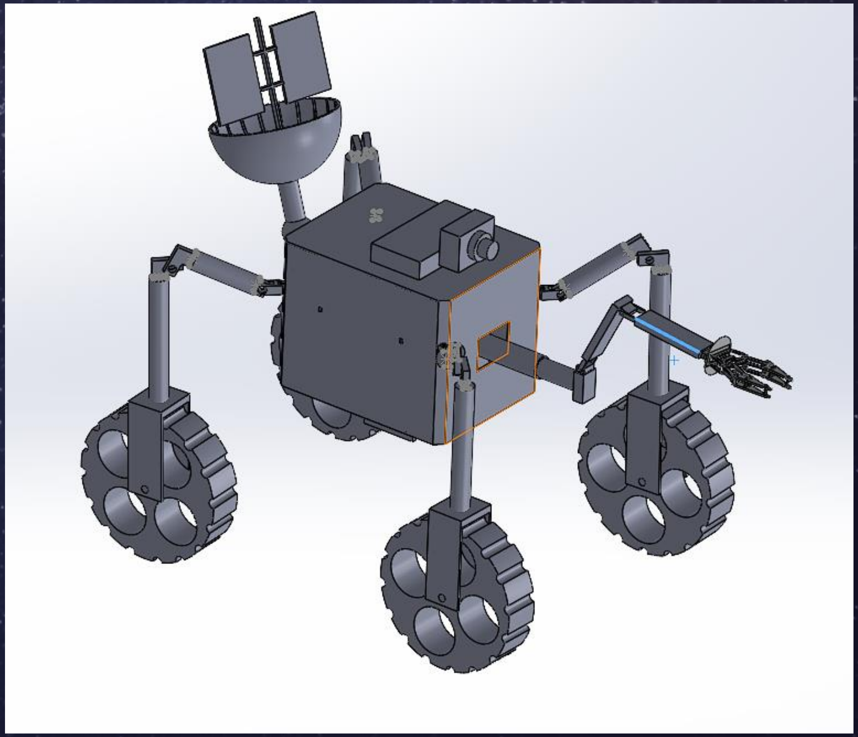
| System | Advantages | Disadvantages |
|---|---|---|
| Wheels | • High speed<br>• Simple and mature technology<br>• Adequate redundancy<br>• Energy efficient | • Low slope climb capacity<br>• Low obstacle traverse capacity |
| Tracks | • Matured technology for terrestrial applications<br>• Better traction on loose soil<br>• Handles hinders, ditches, holes better<br>• Good payload capacity | • Inefficient due to lot of friction<br>• Slow speed<br>• Low redundancy<br>• Prone to jamming of parts and failure |
| Legs | • Very good obstacle and slope traverse capability | • Mechanically complex<br>• Slow<br>• Poor payload to mechanism weight ratio |
| Hoppers | • Better obstacle traverse capability<br>• High speed | • High impact during hopping<br>• Very prone to failure |
| Hybrids | • Advantages of multiple systems combined | • Very complex<br>• Low technology maturity |

# SHORTCOMINGS OF ROCKER-BOGIE SYSTEM

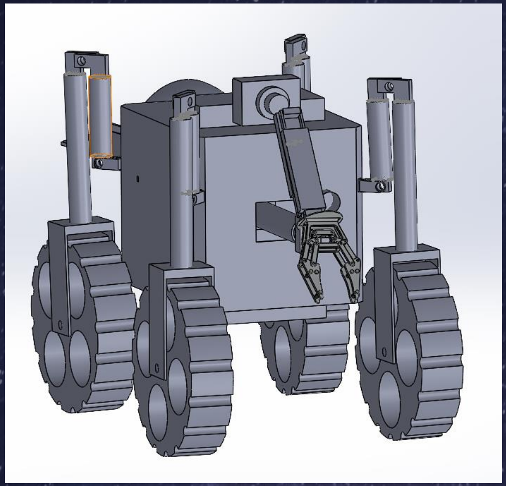
- Excessive wheel slippage which results in total rover immobility.
- Impossible to recover the rover if it is stuck in loose soil.
- Small force on the wheels cause strong stress on the links and the joints because of lever-like structure.
- Need strong structure for the links resulting in increased rover weight

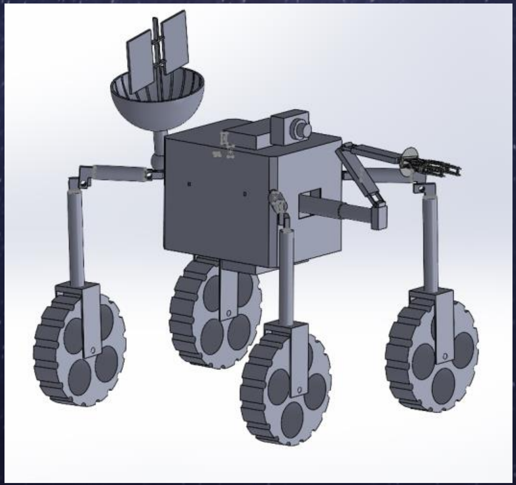
# PROPOSED SUSPENSION SYSTEM

- A hybrid legged and wheeled active suspension system.
- Consists of 4 legs with 1 drivable wheel at the end of each leg
- 5 degrees of freedom in each leg
- Drivetrain can produce a torque of 70Nm per wheel
- Maximum rover speed 700mm/s



# SALIENT FEATURES





- Fold up to reduce rover volume
- Independent actuation of each leg and wheel
- Omnidirectional motion control
- Variable ground clearance.
- Adjustable Centre of Mass height.
- Auto self level on slopes.

# ADVANTAGES OF ACTIVE SUSPENSION OVER PASSIVE SUSPENSION

- Higher manoeuvrability and more varied rover pose configurations
- Easier to recover the rover if stuck
- Suspension degrees of freedom can aid in other rover functions thus reducing engineering complexity.

# POSSIBLE CONCERNS WITH ACTIVE SUSPENSION

- Requires more energy to manipulate than passive suspension like rocker-bogie.
- Very complex control architecture.
- higher engineering complexity for the suspension system and chances of failure.

# ROVER WHEELS

## Some considerations while deciding wheel rigidity:

Flexible wheel on soft soil can achieve:

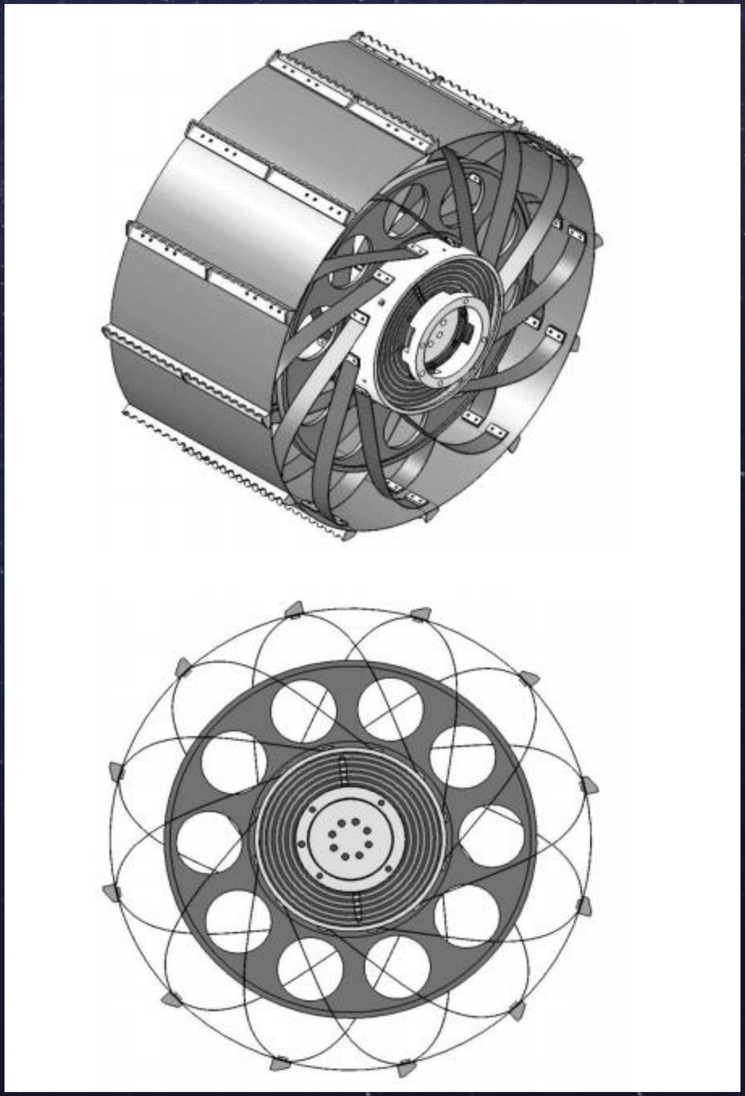
- An increase in transferable force between the wheel and the ground.
- A strong decrease of the bulldozing and compaction resistance.
- An increase in hysteresis resistance.

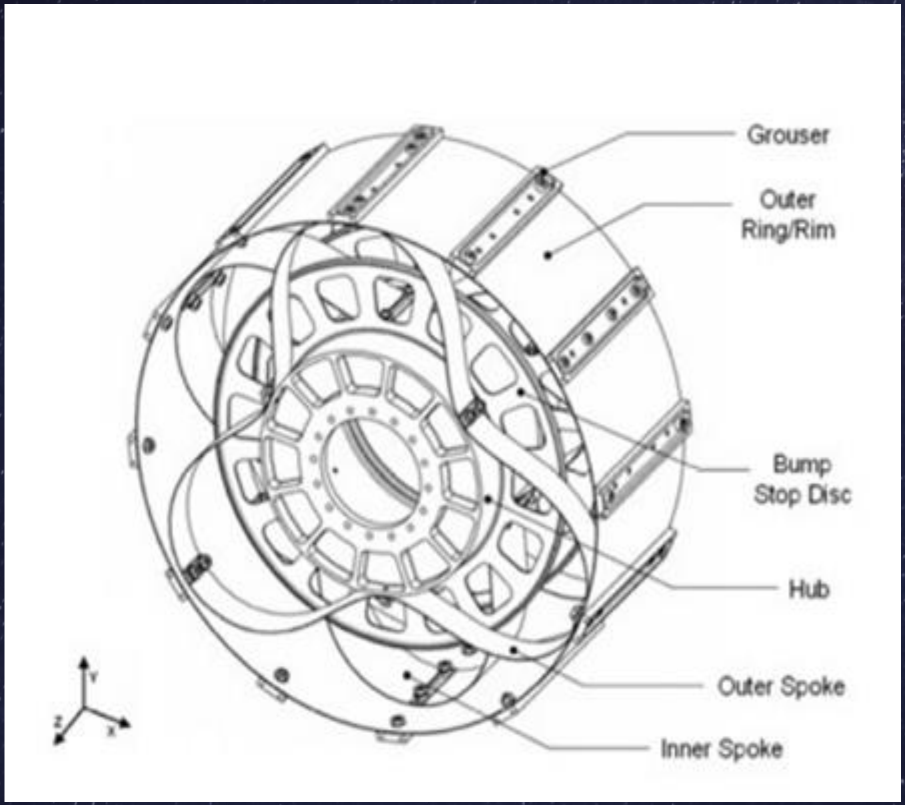
Flexible wheel on hard soils leads to:

- An increase in transferable force between wheel and ground.
- A relatively small decrease of the bulldozing and compaction resistance.
- A large increase in hysteresis resistance.

# PROPOSED WHEEL DESIGN

- Based on the tensioned spoke wheel (bicycle wheel).
- Diameter of 400 mm, a width of 200 mm
- Can withstand load of upto 600N, torque load of 127Nm and a skid force of 300N on a slope of 30 degrees.

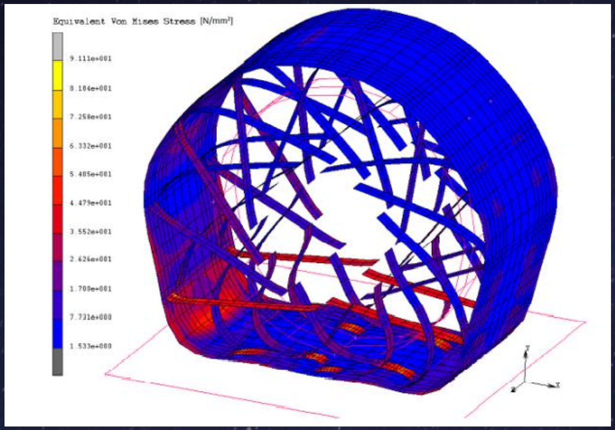




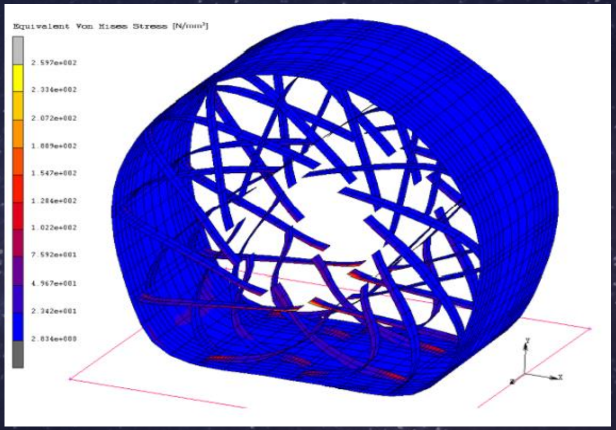

When loaded, the lower blades deform and flatten the tread of the wheel to the ground, while the upper blades stretch and carry the load like a bicycle wheel.

| Element | Material | Composition |
|---|---|---|
| Spokes/Bands | Spring stainless steel | X10CrNi18-8 |
| Outer ring | Spring stainless steel | X10CrNi18-8 |
| Hub | Aluminum | AlSi1MgMn. |
| BSD's | Aluminum | AlSi1MgMn. |
| Grouser | Aluminum | N/S |
| Other fixation elements | Aluminum | N/S |

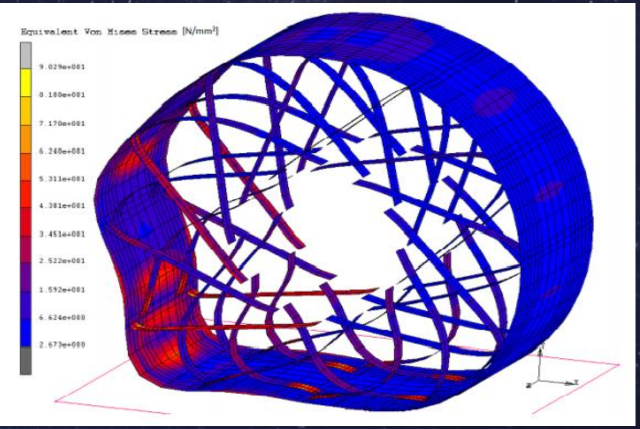
# SIMULATION RESULTS




(a)




(b)




(c)

Stress distribution on wheels when subjected to (a) Normal fore of 600N in negative Y direction, (b) Torque of 127Nm, (c) skid force of 300N in positive Z direction

# ADVANTAGES OF PROPOSED DESIGN

- Large deflections and contact surface areas
- High load carrying capability and no critical curvature radius when deformed
- Increased ability to take high torques due to distribution on all blades in tension
- All blades have the same form, easy to manufacture

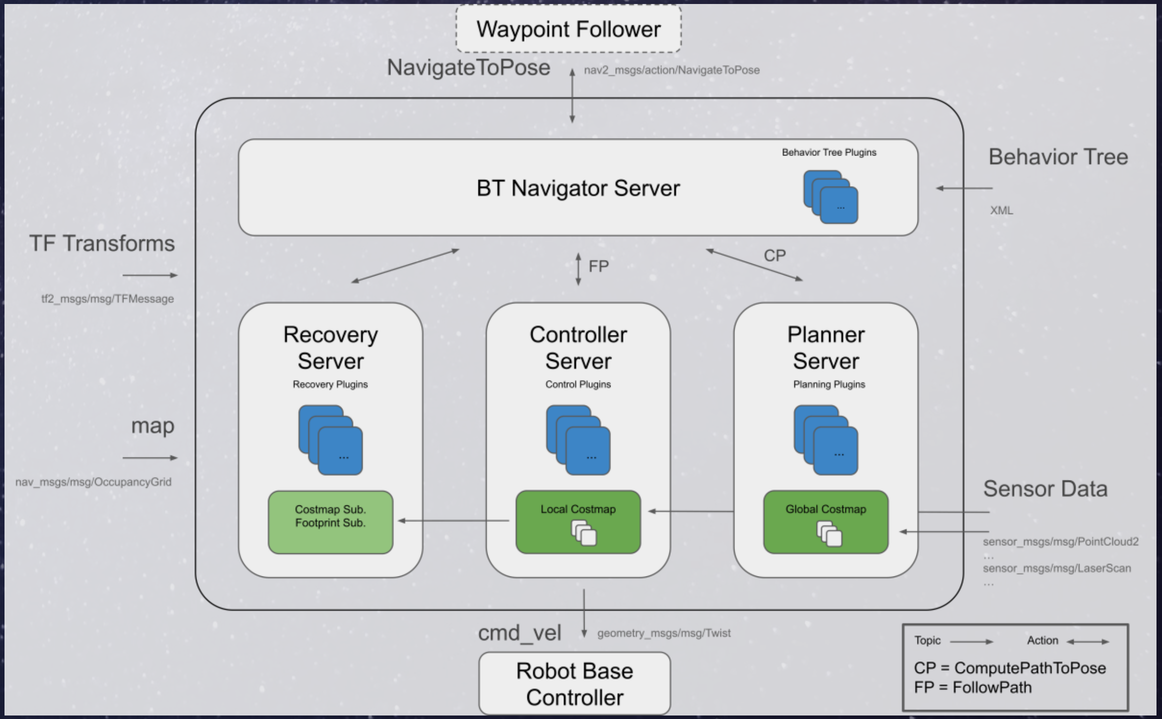
# AUTONOMOUS NAVIGATION

# INSPIRATION: NAV2 FROM ROS2

## Nav2 Architecture

Advantages

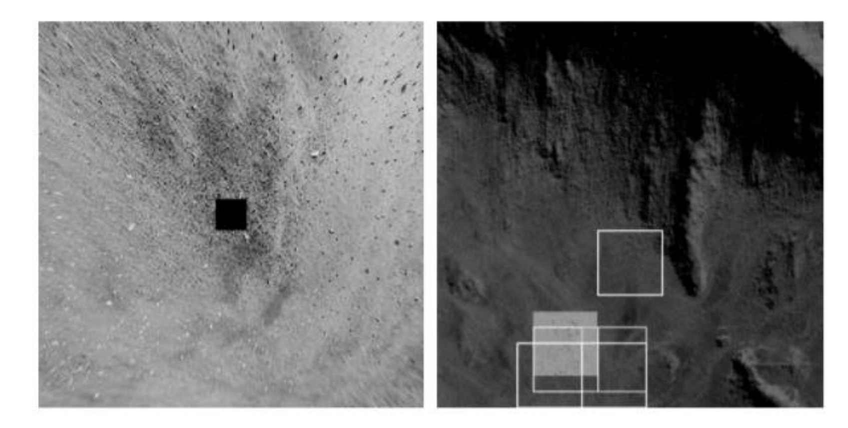
1) Reliable communication
2) Easily configurable behavior trees(XML) to create complex state machines
3) Multiple plugins of algorithms




[],[]

# LOCALIZATION

Surface perspective to-satellite image matching model, using machine learning by NASA Frontier Development Lab



| Type | Amount | Description |
| --- | --- | --- |
| Surface images | $2.42 \times 10^6$ | 1920 x 1080 pixels |
| Satellite images | $6.06 \times 10^5$ | 50 m x 50 m; 0.05 m/pixel |
| Reprojected images | $6.06 \times 10^5$ | 50 m x 50 m; 0.05 m/pixel |
| Point clouds | $1.00 \times 10^5$ | 360 degree point cloud |
| Environment size | 8 km x 8 km | 2 km x 2 km zone used for training;<br>1 km x 1 km zones for testing and validation |
| Data size | 10 TB | - |

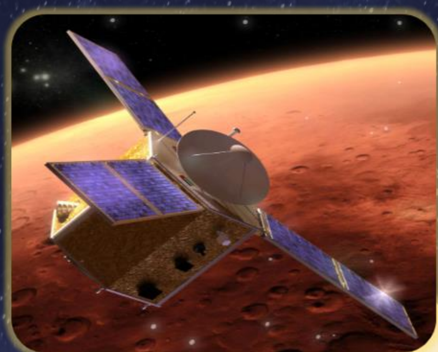
Table 1. Summary of total data generated.

*The ground truth location is shown as a solid gray square in the right panels, while hollow white squares show the neural network's top 5-10 matches to the reprojected image*

*Summary of the dataset used for training*

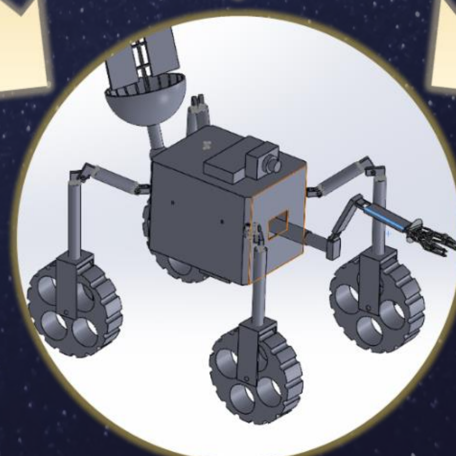
# PROPOSED LOCALIZATION

Increasing accuracy of the localization using the RGBD camera on the drone that produces a **global costmap**



Approximate Location using perspective  to-satellite image matching

Onboard lidars and RGBD cameras for creating **local costmap**

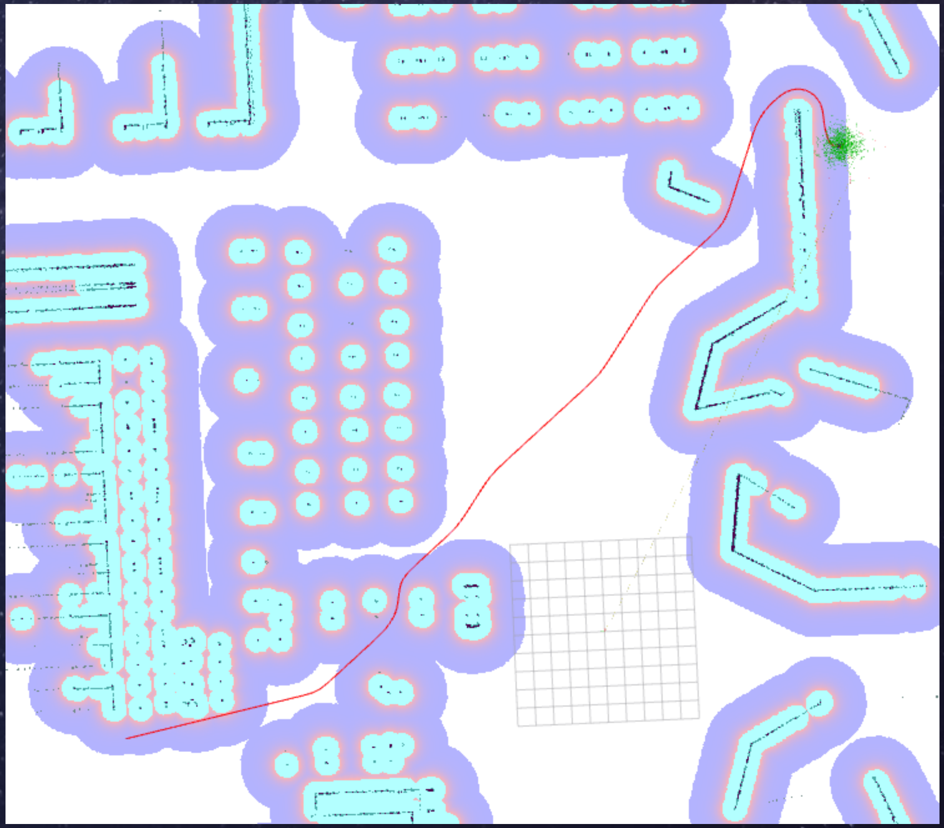


# GLOBAL PLANNER ALGORITHM

## Smac Planner

Advantages

1) Highly optimized
2) Fully reconfigurable grid-based A*implementation
3) Supports Ackermann, car, car-like robots, Circular, differential or omnidirectional robots
4) Testable independently of ROS or the planner

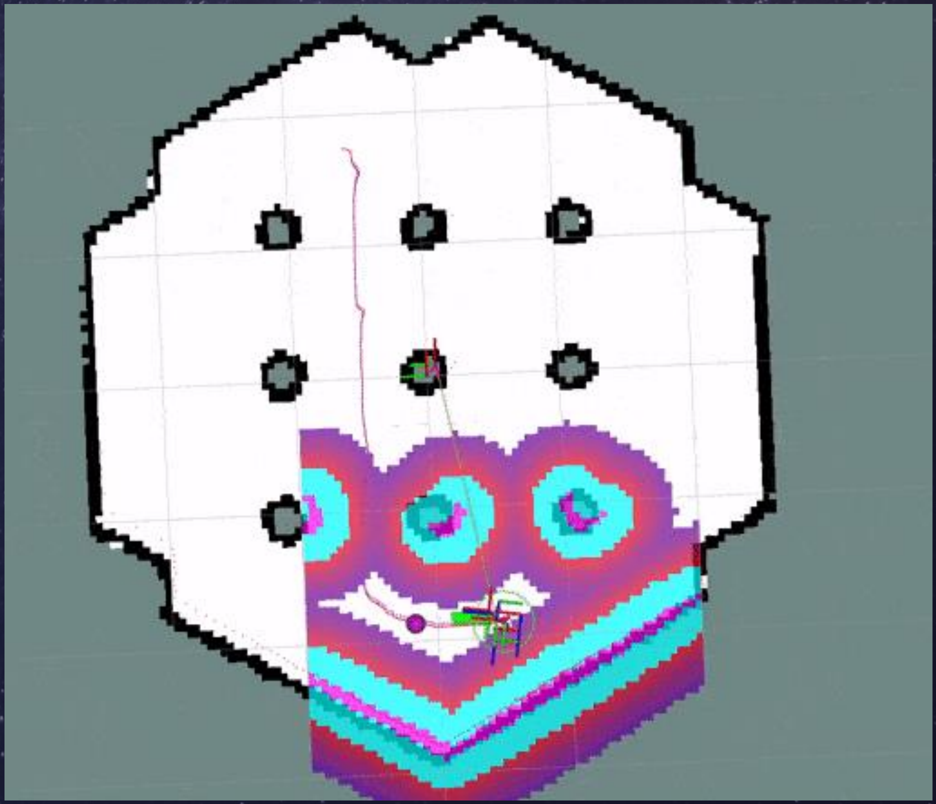


# LOCAL PLANNER ALGORITHM

## Regulated Pure Pursuit Controller

Advantages

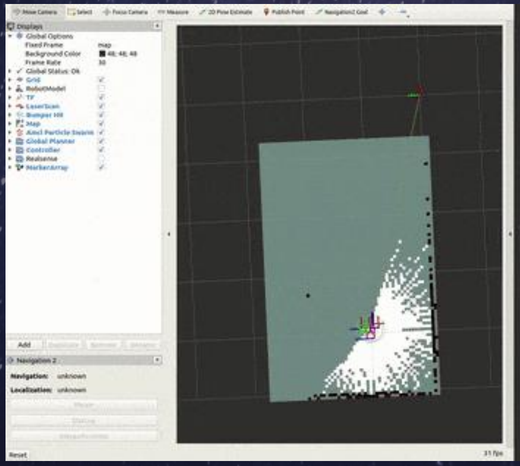
1) Regulates the linear velocities by curvature of the path and proximity to other obstacles
2) Time-scaled collision checker
3) Suitable for use on all types of robots

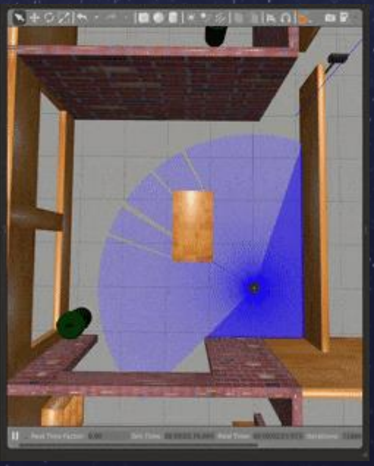


# 2D MAPPING

## Slam Toolbox

Checking Localization





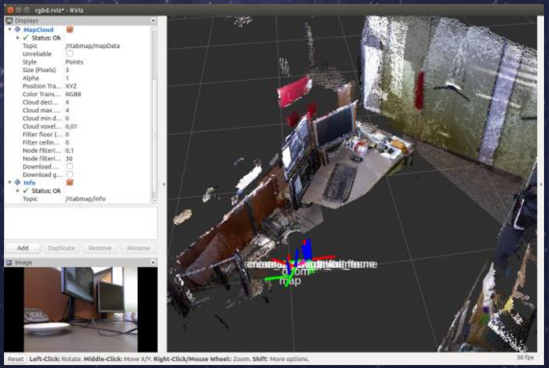
### Advantages

1) Can map large spaces ($24{,}000\ m^2$)
2) Kinematic map merging
3) Multi-session mapping
4) Reduced computation time

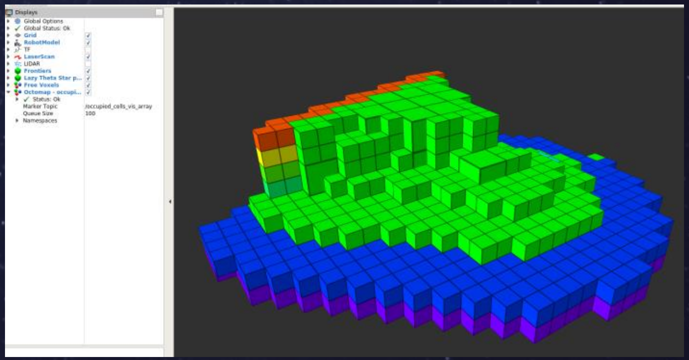
Click here to check out our current implementation

# POSSIBLE CONCERNS AND SOLUTIONS

Highly uneven terrain might lead to some difficulties in mapping



RTAB Map ROS



Octomap ROS

# REFERENCES

[1] R. Sonsalla et al. “Towards a Heterogeneous Modular Robotic Team in a Logistic Chain for Extraterrestrial Exploration”. In: Proceedings of the International Symposium on Artificial Intelligence, Robotics and Automation in Space (i-SAIRAS 2014); June 17-19, Montreal, Canada. o.A., June 2014.

[2] Lindemann, R.A. ; Voorhees, C.J.: Mars Exploration Rover mobility assembly design, test and performance. In: Systems, Man and Cybernetics, 2005 IEEE International Conference on Bd. 1, 2005, S. 450–455 Vol. 1.

[3] Mishkin, A.H. ; Morrison, J.C. ; Nguyen, T.T. ; Stone, H.W. ; Cooper, B.K. ; Wilcox, B.H.: Experiences with operations and autonomy of the Mars Pathfinder Microrover. In: Aerospace Conference, 1998 IEEE Bd. 2, 1998. – ISSN 1095–323X, S. 337– 351 vol.2.

[4] NASA JPL. Homepage of Curiosity Mission. Web. April 2014.

[5] A. Seeni, B. Schäfer, and G. Hirzinger, “Robot Mobility Systems for Planetary Surface Exploration - state-of-the-art and future outlook: A literature survey,” in Aerospace Technologies Advancements, p. 492, January 2010.

# REFERENCES

[6] J.Y. Wong, Theory of Ground Vehicles. John Wiley & Sons, Inc., 2nd ed., 1993.

[7] Lindemann R.A., Bickler D.B., Harrington B.D., Ortiz G.M., and Voorhees C.J., "Mars Exploration Rover Mobility Development: Mechanical Mobility Hardware Design, Development, and Testing", IEEE Robotics & Automation Magazine, June 19-26, 2006.

[8] Kuroda Y., Teshima T., and Sato Y., "Mobility Performance Evaluation of Planetary Rover with Similarity Model Experiment", IEEE International Conference on Robotics and Automation, ICRA2004, April 26 - May 01, 2004.

[9] Kubota T., Kunii Y., Kuroda Y., and Working Group, "Japanese lunar robotics exploration by co-operation with lander and rover", Journal of Earth System Science 114, No. 6, 777-785, December 2005.

[10] iSAIRAS (mit.edu)

[11] A Four-Wheel-Rhombus-Arranged Mobility System for a New Lunar Robotic Rover - Guilin Wen, Chuanshuai Ma, Dong Cheng, Qiutan Jin, Zhewu Chen, Xingfa Yang, Hanfeng Yin, Jingyu Zhou, 2013 (sagepub.com)

[12] IEEE Xplore Full-Text PDF: (ntu.edu.sg)

# REFERENCES


[13] https://navigation.ros.org/index.html

[14]https://static1.squarespace.com/static/5b3ca159710699a5690b4022/t/5bf572a940ec9a5b3f096b74/1542812335712/Space+Resource+2+Tech+Memo.pdf

[15] https://ai.stanford.edu/~ddolgov/papers/dolgov_gpp_stair08.pdf

[16] https://github.com/ros-planning/navigation2/tree/main/nav2_regulated_pure_pursuit_controller

[17] https://www.theoj.org/joss-papers/joss.02783/10.21105.joss.02783.pdf