ASTRA 2023 – SINAV

INNOVATIVE SOLUTIONS FOR FAST AUTONOMOUS NAVIGATION

Date: 17/10/2023
Ref: ASTRA2023SINAV
Template: 83230347-DOC-TAS-EN-010

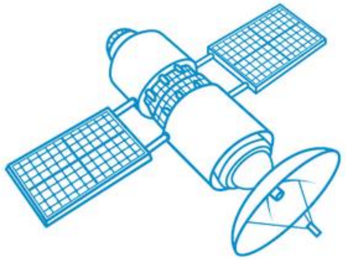
SINAV STUDY

SINAV explores the domain of co-operative agents for planetary exploration, enabling faster rover navigation with the help of new onboard technologies and data provided by drones & satellites.

/// Co-founded by Italian Space Agency

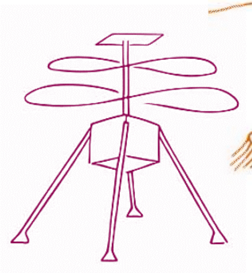
/// ALTEC as Prime Contractor

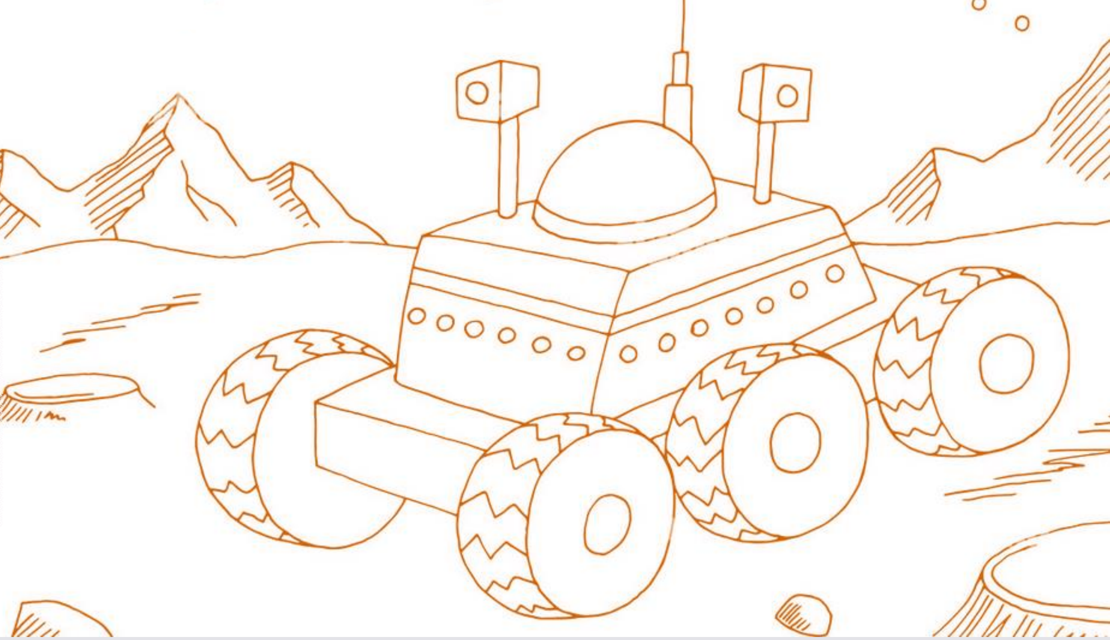
/// TAS-I responsible for Rover Testbed & Rover Autonomy



/// Autonomous Navigation SW goals:

- Average linear speed greater than 6 cm/s
- Navigation in dark & shadowed environments
  - Active sensors
- Continuous navigation
  - Replanning





HW PLATFORM - VEHICLE

/// SINAV Rover Testbed is a custom robotic platform, based on a COTS MobileRobots Seekur Jr.

/// Retrofitted with:

- Intel Mainboard + Nvidia Jetson Xavier
- High capacity LiFePo battery
- Direct control of factory actuators (via CANopen)
- Networking (internal GigE switch + AirMax PtP wireless link)

/// Skid-steered robot:

- Simple to control (SINAV is not a locomotion study!)
- Difficult to track (wheel odometry from slipping wheels…)

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HW PLATFORMS - SENSORS

/// Stereolabs ZED 2i Stereo Camera

- Passive sensor, used in daylight conditions
- SDK outputs:
  - 3D Point Clouds (PC) – also as 2D Depth Images
  - Visual Odometry (VO)

/// Lucid Vision Helios 2+ ToF (Time of Flight) Camera

- Active sensor(s), used in dark conditions
- Sensor outputs:
  - 3D Point Clouds (PC) – also as 2D Depth Images

/// Movella Xsens 620 VRU (Vertical Reference Unit)

- 3 DoF accelerometers
- 3 DoF gyroscopes
- NO magnetometer

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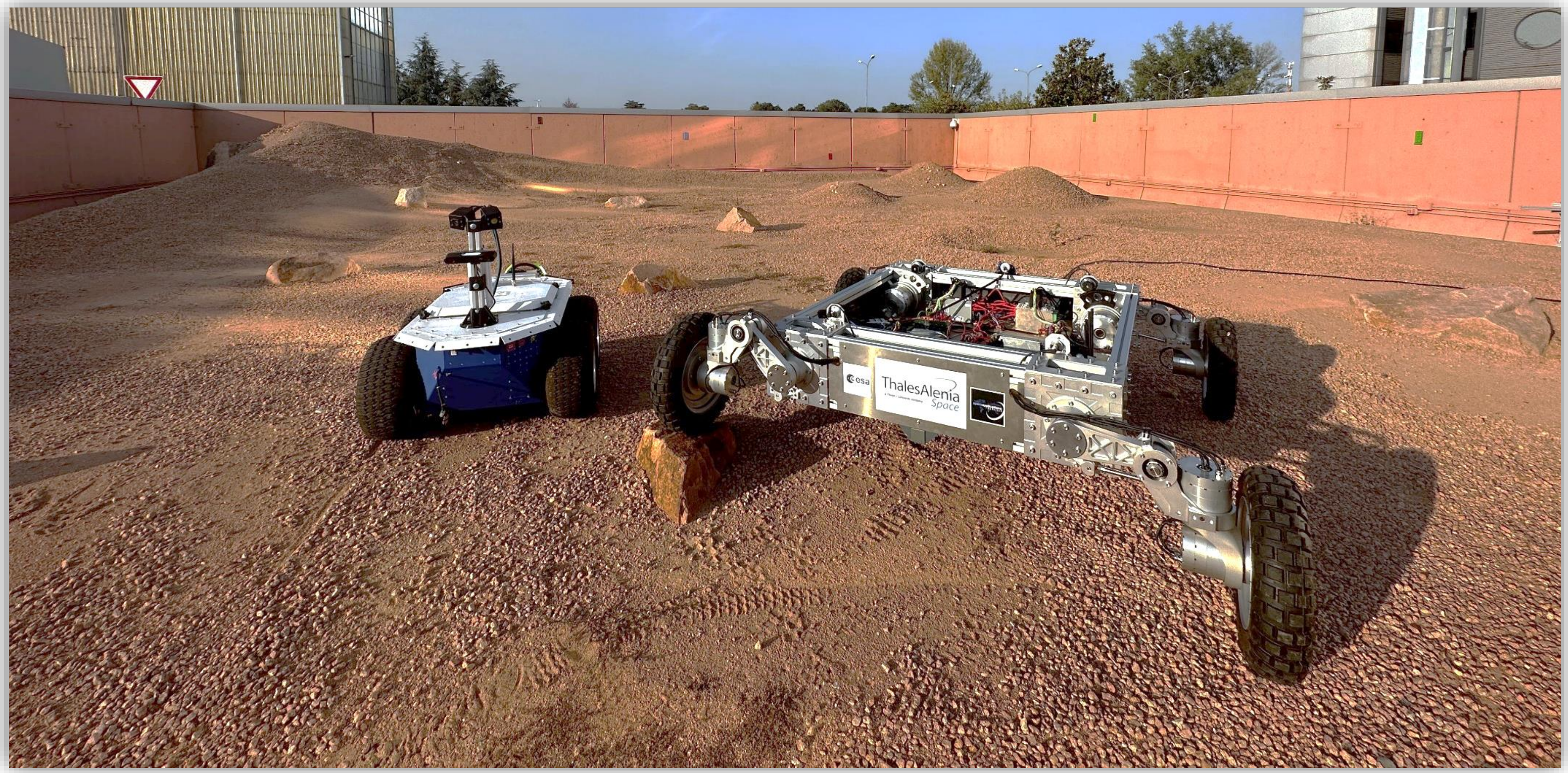
ROXY FACILITY



/// TAS-I Rover eXploration facilitY (RoXY) – 500m^2 outdoor area with rocks, small craters, slopes

/// Nearby offices / control center & support workshop with rapid prototyping capabilities.

AUTONAV DEVELOPMENT

SINAV AutoNav leverages open-source libraries and tools at its core.

/// TAS-I Robotic R&D Team uses **C++** ROS 2 Framework in every major TRL <= 5 activity

/// In particular:

- Motion control: **ros2-canopen**
- Locomotion: **ros2-controls**
- Path planning: **nav2**
- Path tracking: **nav2**
- Localization: **robot_localisation** / now upgrading to **fuse**

/// Certain subsystems are custom:

- Perception: custom HALs
- Mapping: **Traversability Toolkit**

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WHY ROS 2

ROS 2 is a framework abstracting common utilities useful when building complex robotic SW.

/// In particular, it was born to offer:

- Message sending via Publish/Subscribe
- Synchronous & Asynchronous RPCs via Services & Actions

…across a number of standalone processes even across different machines, via DDS protocol

/// Inter-Process Communication is typically slow → Granularity of efficient architectures is limited

/// But ROS 2 evolved to seamlessly support Intra-Process Communication:

- Nodes can be written as composable components and loaded in a single process
- Zero-copy message passing via the shared memory space
- Note: this is not applicable for communication across different machines

ADVANTAGES OF ROS 2

Runtime Composition and Intra-Process Communication support means that:

/// During development:

- Nodes can be build & tested as standalone units
- Debug is easier

/// During deploy:

- Nodes can be composed inside a single, multi-threaded process
- Efficiency increases

/// The developer can:

- write & build code **one** time
- instantiate different setups & architectures with different launch scripts
- rely on strong separation of concerns by design
- compose an highly concurrent architecture without explicitly using synchronization primitives

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TAS-I TRAVERSABILITY TOOLKIT

A library comprising a wide set of sources, sinks & operands implemented as ROS 2 components:

CloudAligner	*CloudToGrid*	*DepthCropper*	*NormalsViewer*
CloudCleaner	*CloudToImage*	*DepthLogger*	*SlopeBinary*
CloudCuller	*CloudToIntensity*	*DepthIntensityFilter*	*SlopeClipper*
CloudFusion	*CloudToLabelledMap*	*DepthToCloud*	*SlopeContours*
CloudIntensityFilter	*CloudToNormals*	*DepthToNormals*	*SlopeErodeDilate*
CloudLogger	*CloudToSlope*	*DepthViewer*	*SlopeLogger*
CloudMuxer	*CloudTransformer*	*GridToDem*	*SlopeServer*
CloudPlayer	*CloudVoxelizator*	*ImageCompressor*	*SlopeSmoother*
CloudStitcher	*DemLogger*	*ImageDecompressor*	*SlopeTransformer*
CloudTagger	*DemServer*	*ImageViewer*	*SlopeTrimmer*
CloudToDepth	*DemToGrid*	*NormalsRefiner*	*SlopeWalls*

/// It comprises utilities to work with (or convert between):

- Point Clouds (also with surface normals and intensity)
- Depth Maps
- Images
- Digital Elevation Maps
- Traversability maps (encoding slopes, obstacles…)

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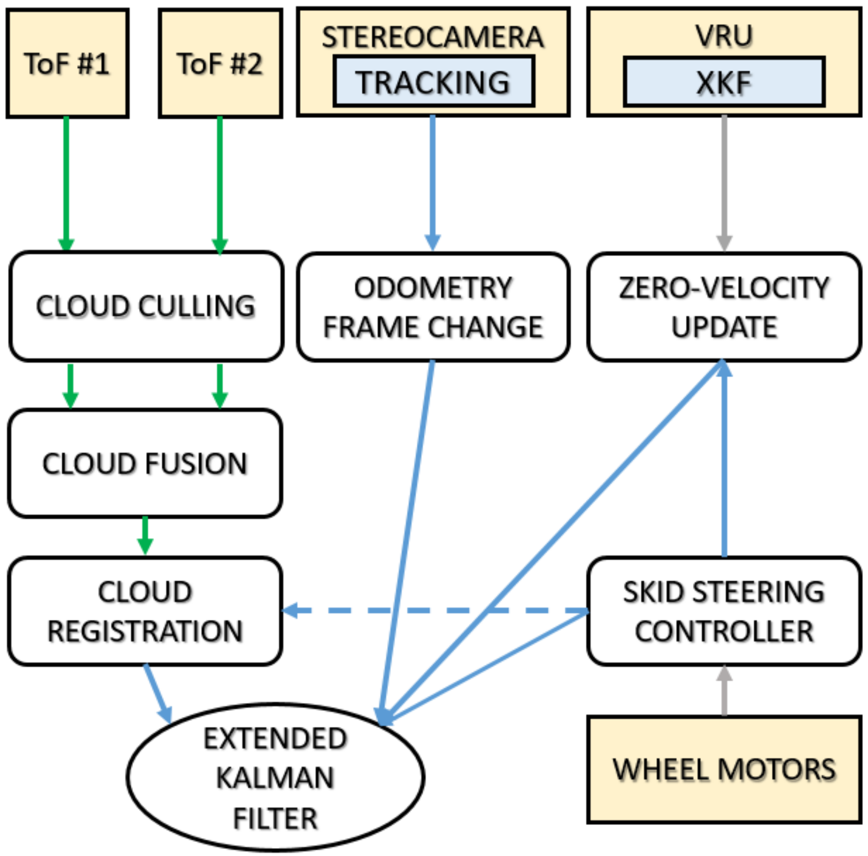
LOCALIZATION



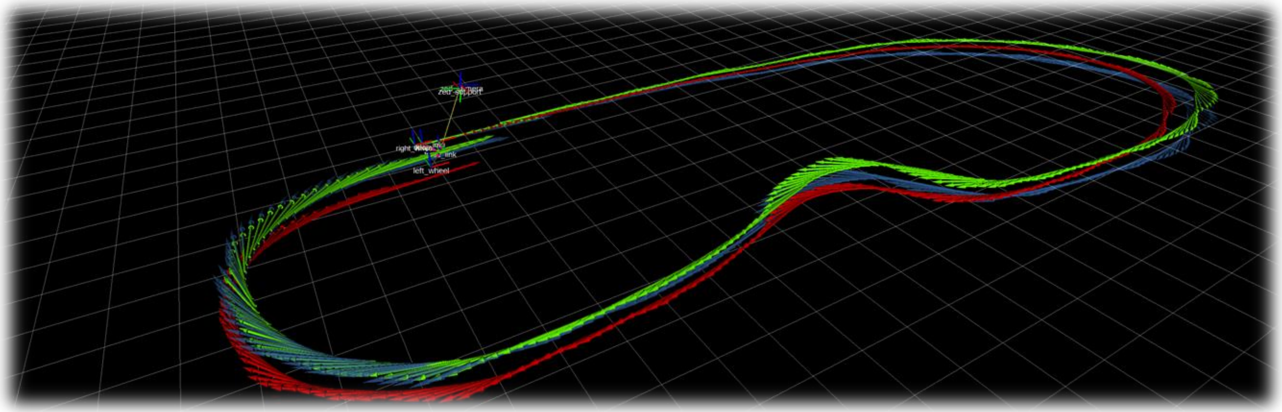
/// Relative localization only, without magnetometer & GNSS

/// An EKF fuses three sources:

- Visual Odometry
- Inertial measurements
- Mechanical Odometry

/// Zero Velocity Update is implemented on VRU:

- To suppress VRU drift due to absence of magnetometer
- When the rover is steady, lock the yaw angle by subtracting the drift



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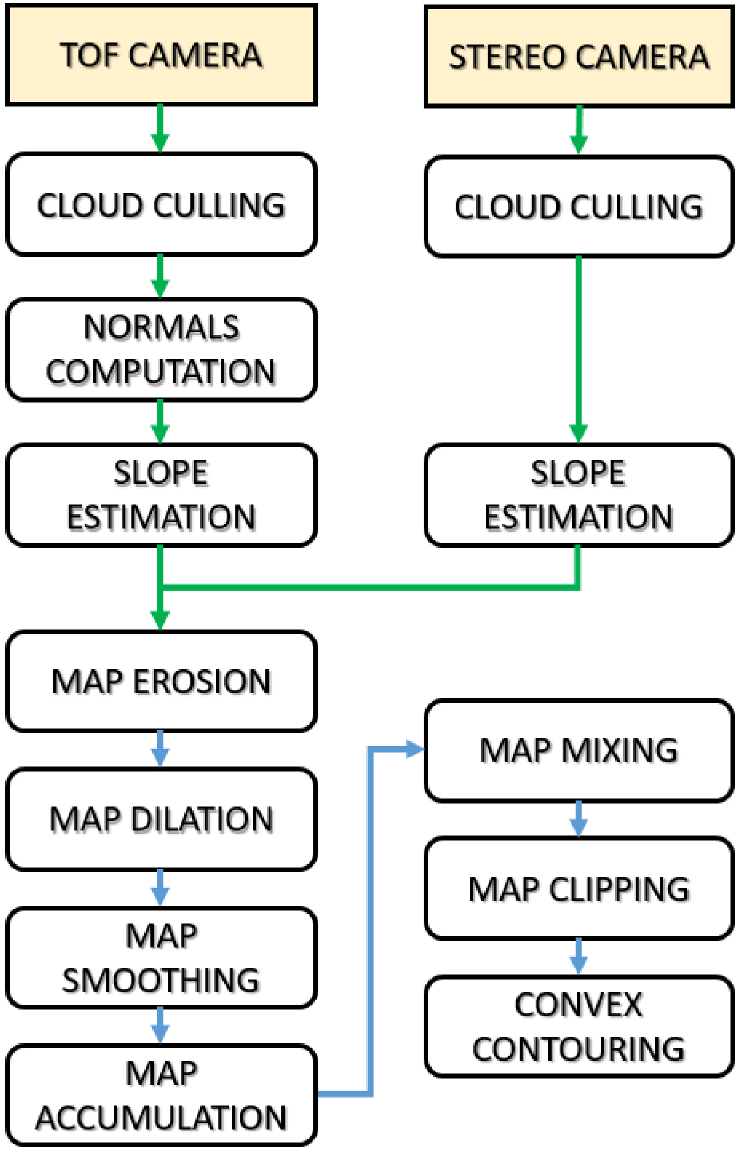
MAPPING: TRAVERSABILITY TOOLKIT SETUP

/// Pipelined execution of filtering and transformation stages:

- Input: *structured* Point Clouds
- Points belonging to the border of the sensor are discarded
  - "Frustum culling" discards points with potential distortion due to imprecise calibration
- Normals to each point are computed (if not provided by sensor SDK)
  - Algorithm complexity is reduced by spatial locality of nearby points in memory
- Points are binned on a 2D grid, average slope and height are computed
  - SINAV does not rely on DEMs but only Slopes Maps
- 2D slope info is scaled between absolute values (-1, 100)
  - This is a traversability map
- Map is filtered via erosion, dilation (salt & pepper noise removal) and smoothed
- Subsequent map updated are merged
- Different kind of semantic maps can be overlaid and mixed
- Value clipping is done to enhance "free" and "obstacle" levels
- Obstacles are contoured to discard cul-de-sac topologies



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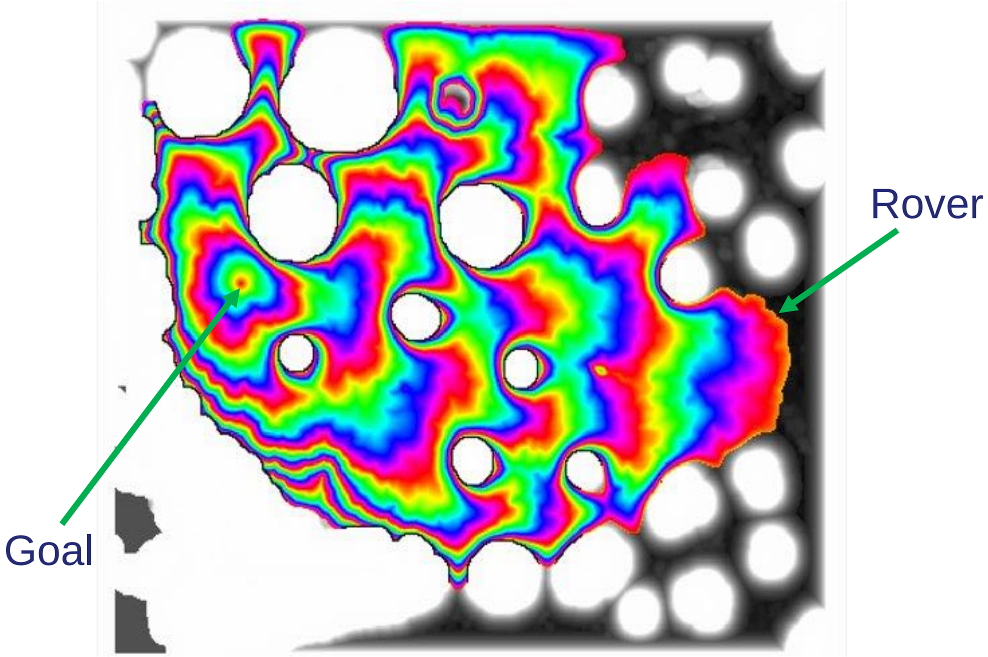
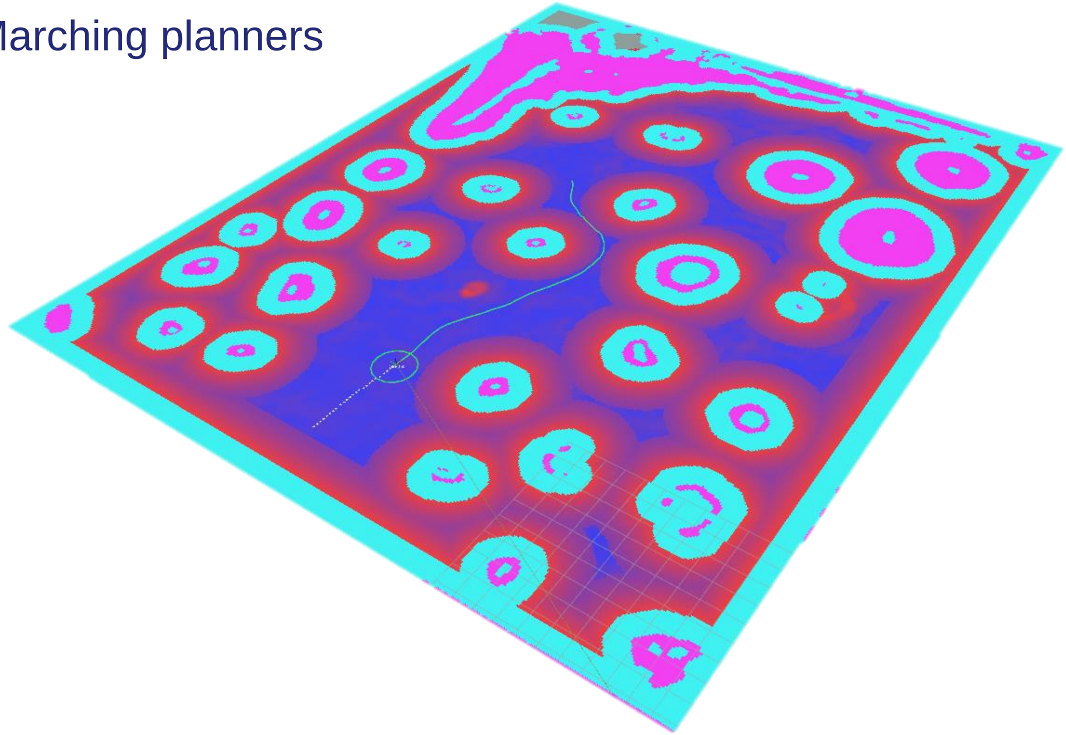
PLANNING: SHIFTED GRID FAST MARCHING

/// Simplification of Field D* (NASA replanner for MER rovers)

- Starting from the Goal Point, a frontier is propagated “like a wave”, and the speed of propagation is regulated by the traversability score of the map in each cell.
- The propagation stops whenever the rover position is met.
- The path with the lowest cost is then computed by gradient descent and sent to the controller.
- This FD* optimization come from the observed dualism with Fast Marching planners





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DISTRIBUTED ARCHITECTURE ISSUES

/// Intra-process communication not possible across multiple networked machines

/// The designer must partition tasks so that the deta exchange among the different machines is limited

- e.g. Better not to transfer Point Clouds, Depth Maps are better

/// DDS protocol instantiates N*N links between each resource (publisher, subscriber) on the network

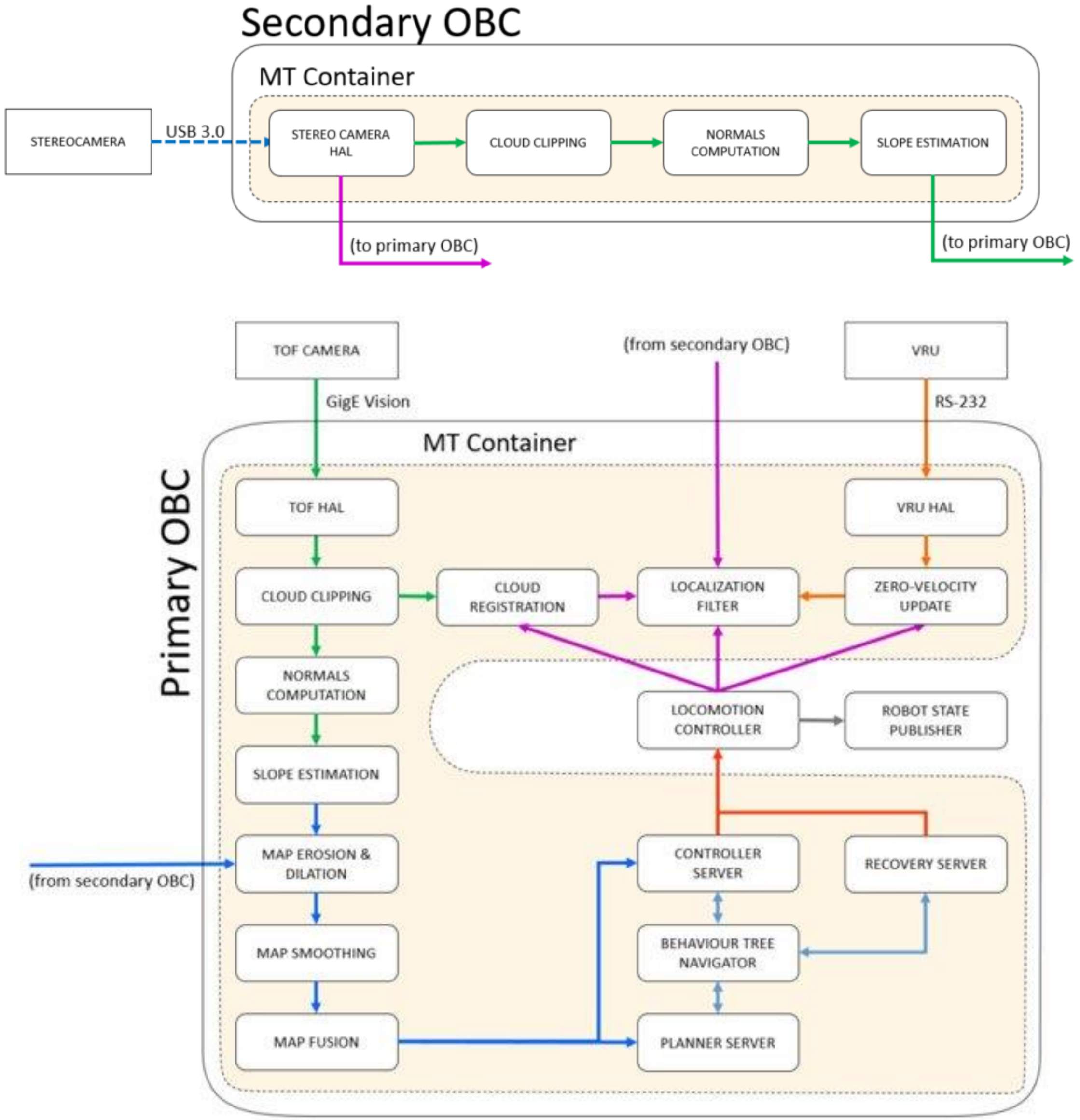
- By default, it also uses multicast

/// Zenoh bridges were deployed to use Zenoh among the different machines instead of DDS

- Reduced bandwidth, jitter & packet loss

/// Next ROS 2 release will include Zenoh as an official alternative to DDS

- Other RMW layers may be implemented to cope with existing (Space-graded) data transfer protocols/frameworks



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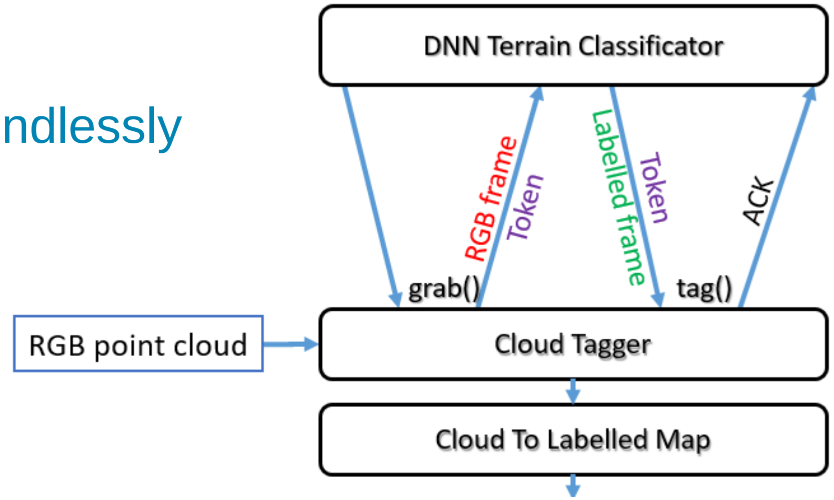
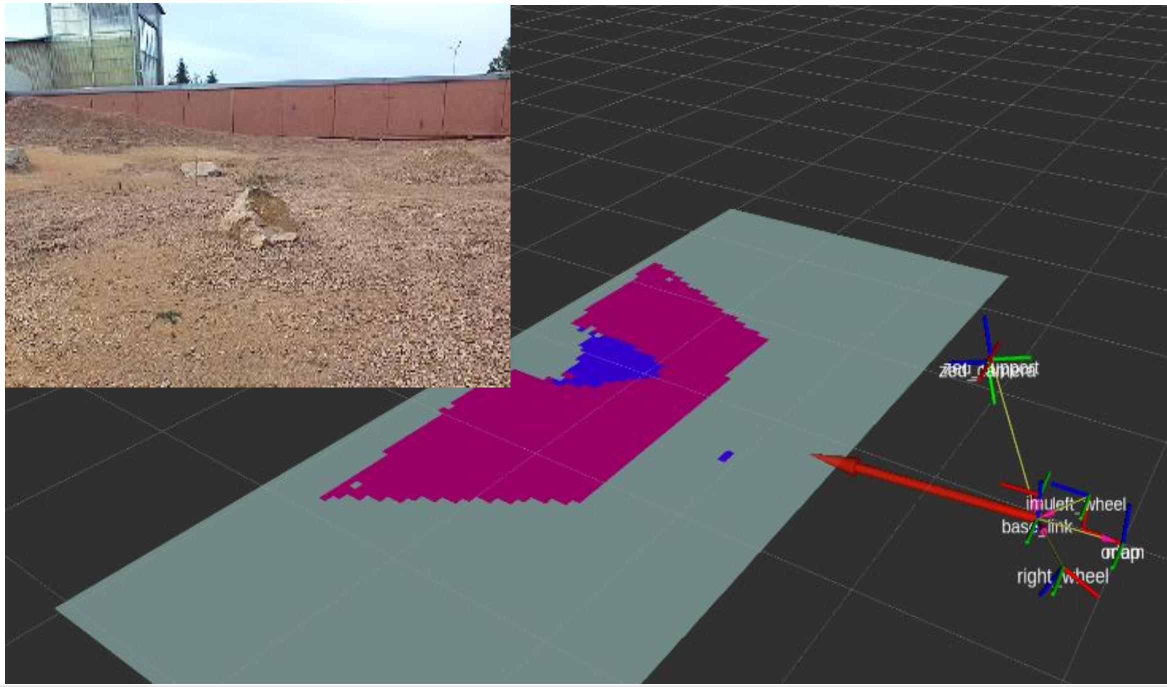
AI INTEGRATION

/// The flexibility of the ROS 2 – based framework allows to extend it endlessly

/// Example - to inject DL-based online terrain segmentation:

- A Tagger component is composed to the stack
- DL client request RGB frame from the Point Cloud
- The Tagger extracts the RGB frame and replies
- The Tagger stores the associated Point Cloud
- DL client sends back a level map with classified pixels
- The Tagger component adds this info to the Point Cloud
- The tagged Point Cloud is released downstream
- Another component applies grid binning to obtain the **semantic map**





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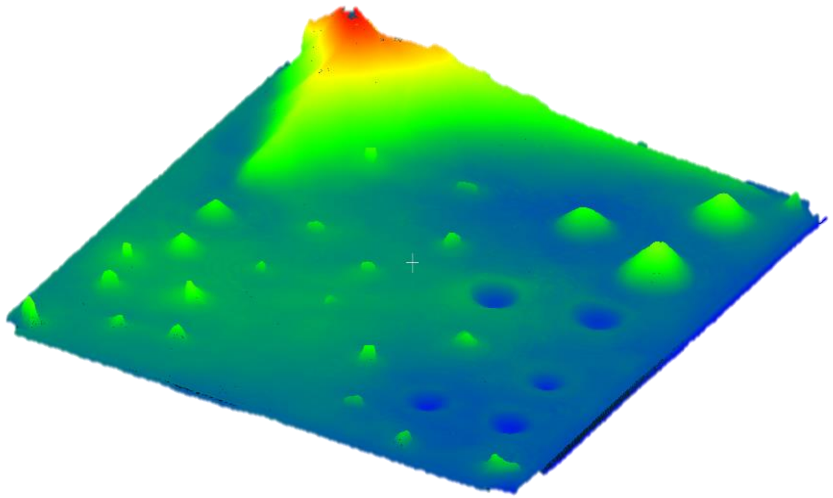
SIMULATION ASSETS

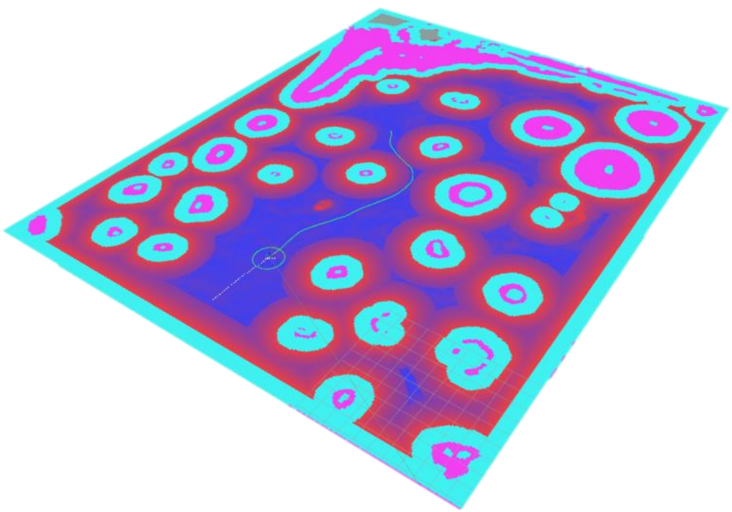
/// Closed-loop kinematic simulation:

- To validate mapping, planning, tracking
- Two variants: map known beforehand, map unknown beforehand

/// Closed loop dynamic simulation:

- To validate localization and end-to-end solution, simulating sensor behaviour





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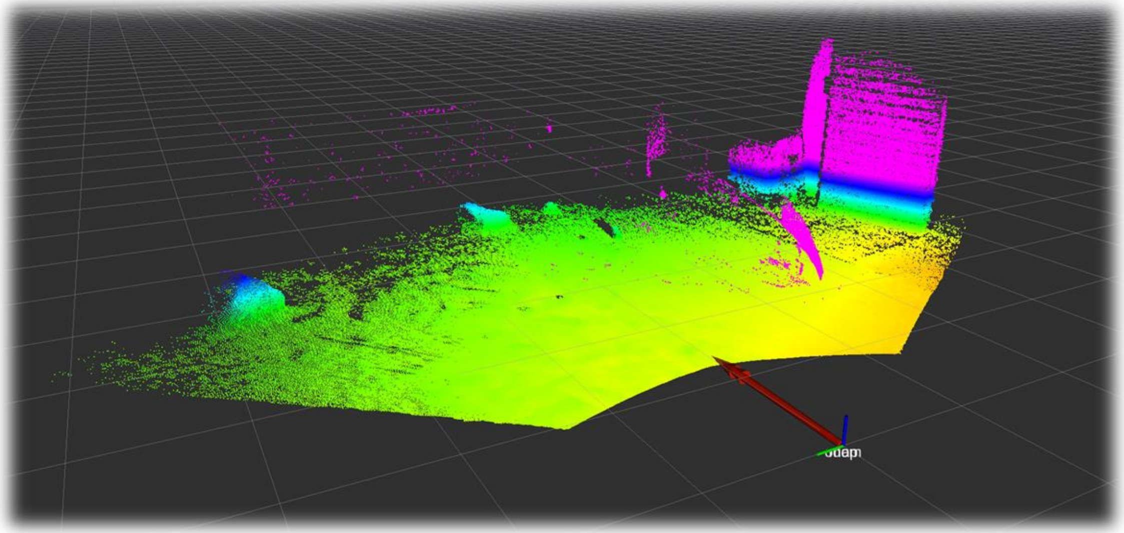
ACTIVE SENSOR MODE TEST

The integration of the active ToF sensors has been tested in the night case.



The 2 cameras can generate a very dense point cloud of the rovers' surroundings even in no-light condition.

However, visual odometry implemented without color-space descriptors is more prone to errors.

ACHIEVED PERFORMANCES

- AutoNav Configuration:
  - Map grid tiles: 5 cm^2
  - Stereo Camera resolution: 1280 x 720
  - ToF Camera resolution (x2): 640 x 480
  - Max slope: 15°
  - Smoothing kernel size: 7
  - Map level clipping: 40(free) – 85(obstacle)
- Navigation speed (day): 10 cm/s
- Odometry drift (day): 10 cm / 100 m
  - w/o loop closure
- Navigation speed (night): 10 cm/s
- Odometry drift (night): 25 cm / 100 m
  - w/o loop closure

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FUTURE WORK

/// TAS-I plans to evolve its AutoNav to allow deployment on more complex locomotion platforms:

- EMRS (and future iterations) offer multiple types of locomotion maneuvers
- EMRS (and future iterations) offer the ability to transit above obstacle of limited height

/// Profiling and optimization targeting space-graded avionics

/// Development of analogous space-graded sensors

/// Participation to Space ROS community:

- To align with its static analysis best practices, boost ROS 2 maturity and enable reuse in future projects

ROXY

ROVER EXPLORATION FACILITY

TAS-I ROBOTICS GROUP

THANKS FOR YOUR ATTENTION!