

Presentation 'Benchmarking Autonomous Robotics Controllers' by Pablo Muñoz (University of Alcalá)

Introduction by TO (M. van Winnendael, TEC-MMA)

Title of the contract: Cooperative Systems for Autonomous Exploration Missions

Budget + Program: 90 k€, NPI (Networking/Partnering Initiative)

Duration: 3 years

Contractor: University of Alcalá, UAH (Spain)

Subject of the activity: On-board autonomy of space robotics systems, in the first place planetary rovers

Main Objectives:

- Metrics for measuring planning and execution performance
- Path planning algorithms to define navigation routes
- Algorithms for controlling the reactive behavior of ESA's Goal-Oriented Autonomous Controller (GOAC) in uncertain situations

07/12/2016

Benchmarking Autonomous Robotics Controllers

Pablo Muñoz Martínez

TEC-ED & TEC-SW Final Presentation Days

ESA/ESTEC December 7, 2016



Universidad
de Alcalá



PhD funded by ESA NPI

Technical officer:

Mr. Michel van Winnendael



PhD program on space research

PhD advisor:

Dra. María Dolores Rodríguez Moreno



PhD co-advisor:

Dr. Amedeo Cesta

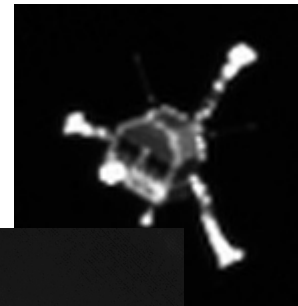
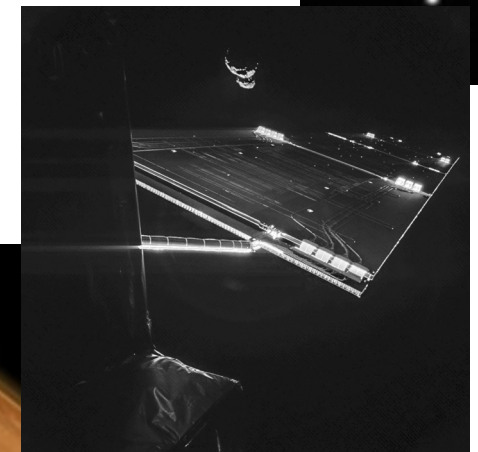
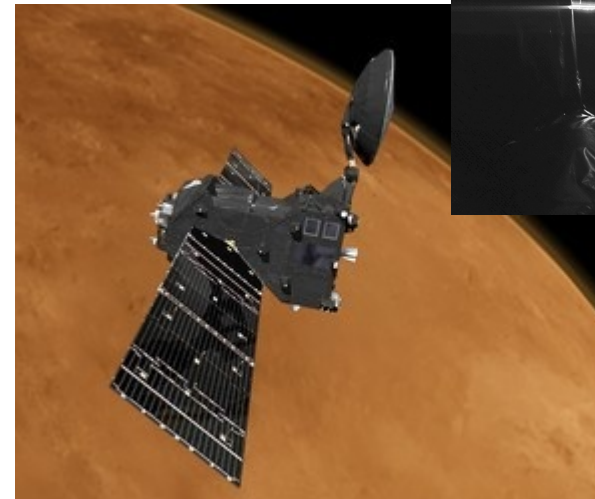
Dr. Andrea Orlandini

Contents

1. Introduction
2. Objectives
3. Planning for planetary rovers
4. Evaluating autonomous controllers
5. OGATE Demo

Motivation

- ▶ Space exploration is a challenge
- ▶ New missions carry more science instruments
- ▶ Go deeper into the space
- ▶ On-board autonomy can be helpful to
 - ▶ Maximize science return
 - ▶ Minimize risks
 - ▶ Reduce operators workload



Photos: ESA

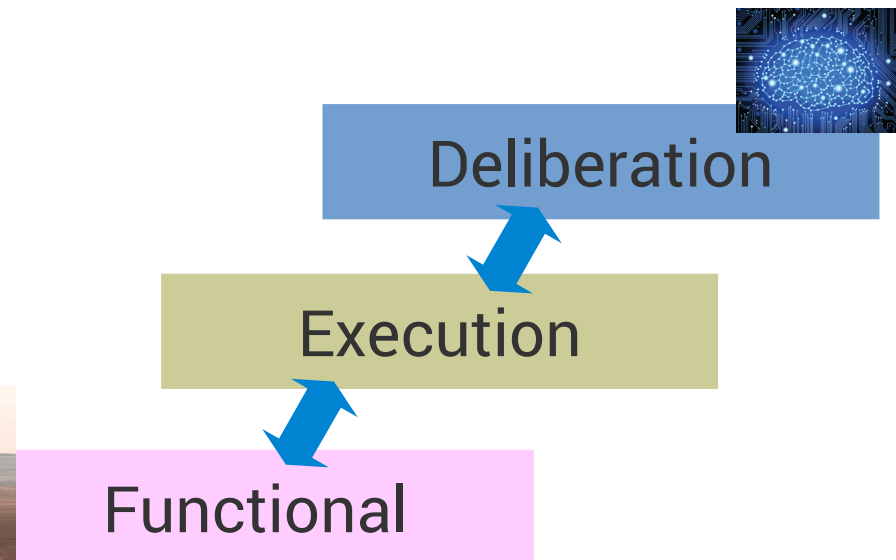
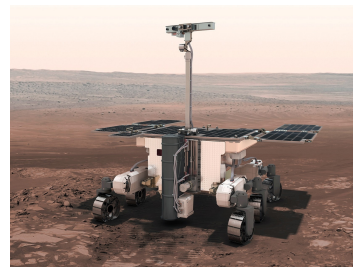
Autonomy levels

- Decision making capability (AI)
- According to ESA standards

| | |
|----|---|
| E1 | On-ground control (teleoperation) |
| E2 | On-board scheduler for on-ground commands |
| E3 | Event based autonomous operation |
| E4 | Goal oriented and mission replanning |

Autonomous controllers

- Integration of P&S (Planning & Scheduling) in robotics
- P&S is used for on-ground operations
- Most common schema: 3T (3-Tired)
- Wide research field
 - ESA: GOAC
 - NASA: IDEA, RA
 - UAH: MoBAr



Open issues

- No appropriate software to facilitate operation
- Lack of experimentation
- Hard to extract meaningful data
- Approaches are validated with few scenarios
- Difficult to generate reproducible experiments
 - Tests can be seen as *proof of concept*
 - Difficult to compare approaches
 - Hard to trust in autonomy

Contents

1. Introduction
2. Objectives
3. Planning for planetary rovers
4. Evaluating autonomous controllers
5. OGATE Demo


Objectives

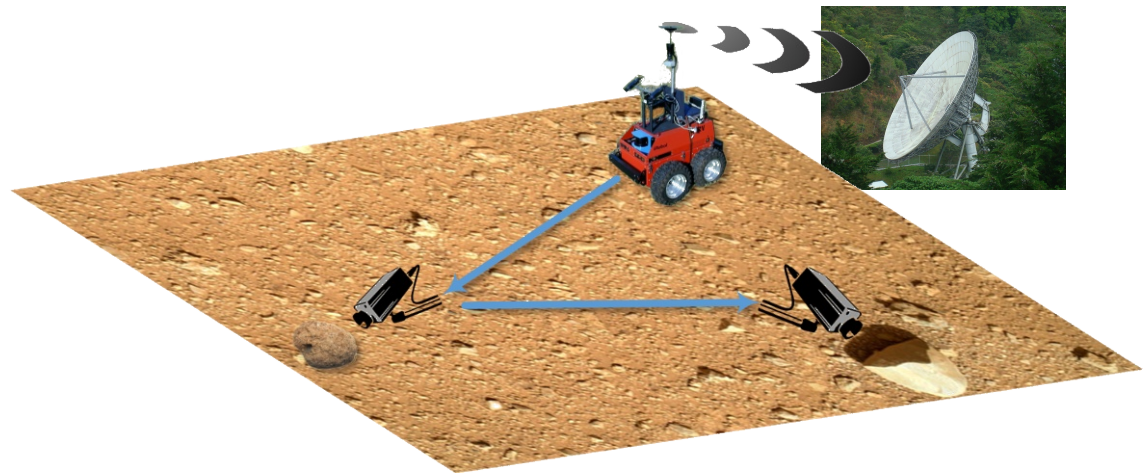
- ▶ Create a framework for autonomous controllers characterization and evaluation
 - ▶ Testbench methodology
 - ▶ Performance metrics
 - ▶ Compare at least two controllers
 - ▶ Ease deployment and operation
 - ▶ Improve trust in autonomy for robotics

Contents

1. Introduction
2. Objectives
3. Planning for planetary rovers
4. Evaluating autonomous controllers
5. OGATE Demo

Planetary exploration case study

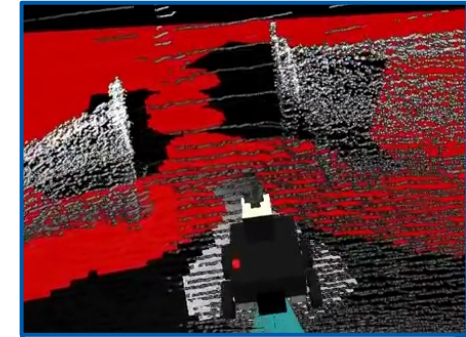
- ▶ Perform scientific tasks in different locations
 - ▶ Limited communication opportunities
 - ▶ E4 autonomy: user provides initial goals
 - ▶ Common scenario for autonomous controllers testing
 - ▶ Requires
 - ▶ Task planning
- 
- ▶ Path planning



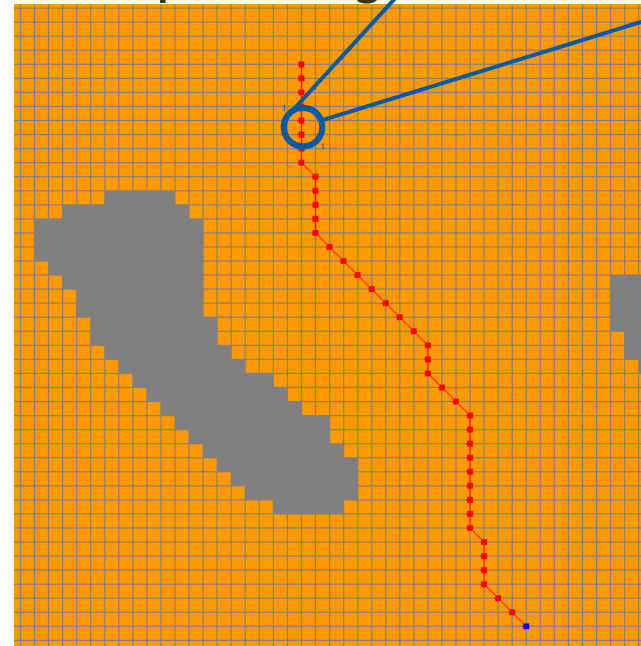
Path planning

- ▶ Obtain feasible and optimal paths
- ▶ 2D binary grid map
 - ▶ Used in real missions
 - ▶ Deterministic algorithms
 - ▶ A*
 - ▶ A*PS
 - ▶ Theta*

Navigation



Path planning

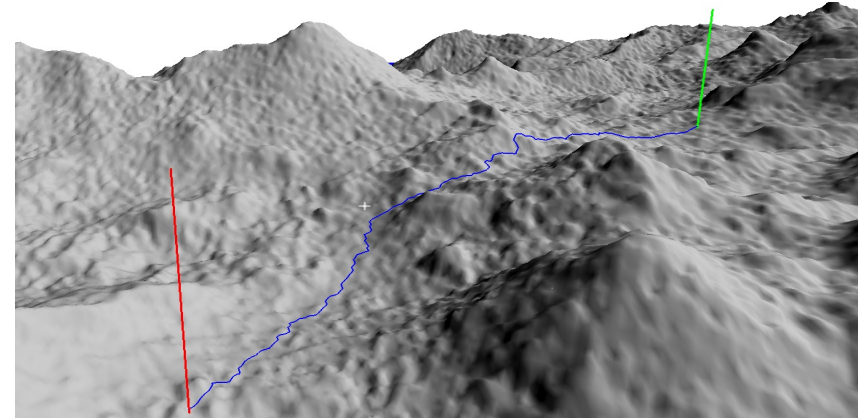
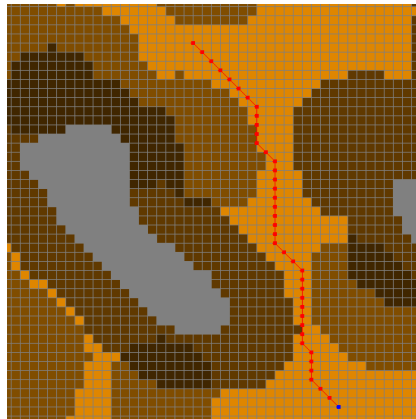


More about 2D path planning:

P. Muñoz and M.D. R-Moreno. On Heading Change Measurement: Improvements for Any Angle Path Planning. *Novel Applications of Intelligent Systems*, ch. 6 (2015)

Path planning

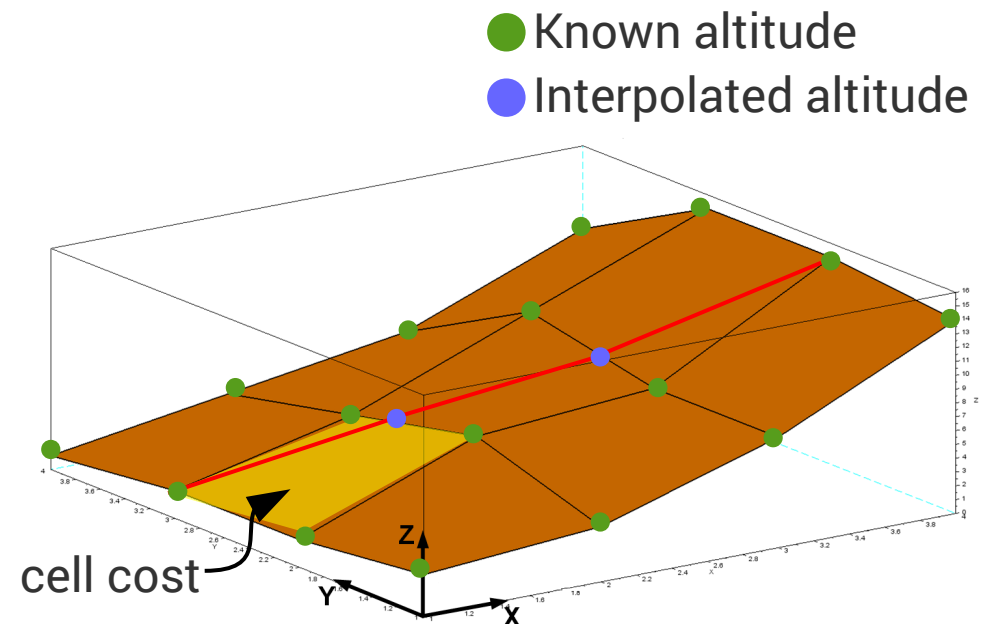
- ▶ Planetary robotics require more realistic terrains with
 - ▶ Terrain characteristics (cost maps)
 - ▶ Altitude (DTM)



- ▶ Field D* (MER/MSL operations) exploits cost maps
- ▶ Modified A* can use different DTM representations

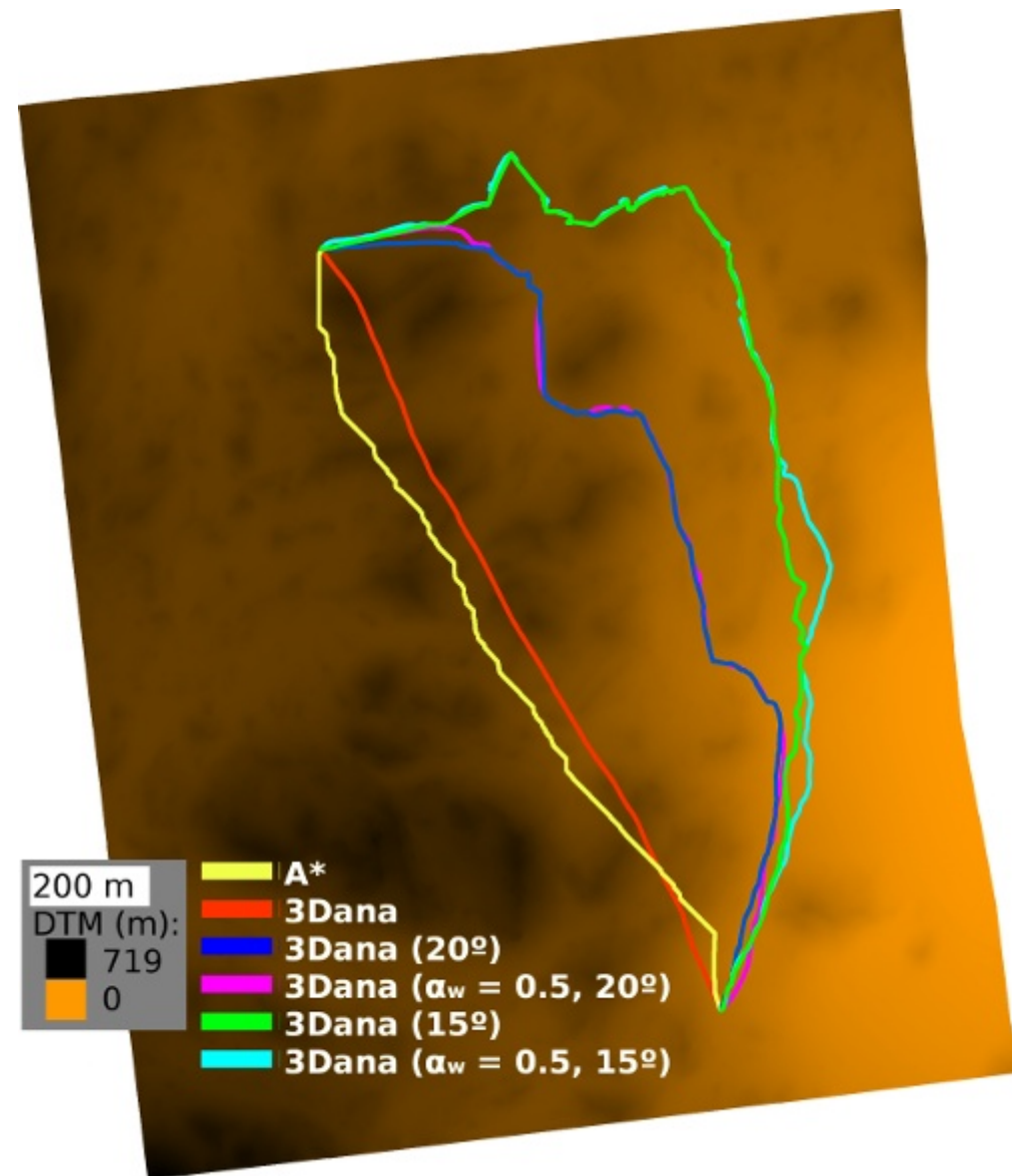
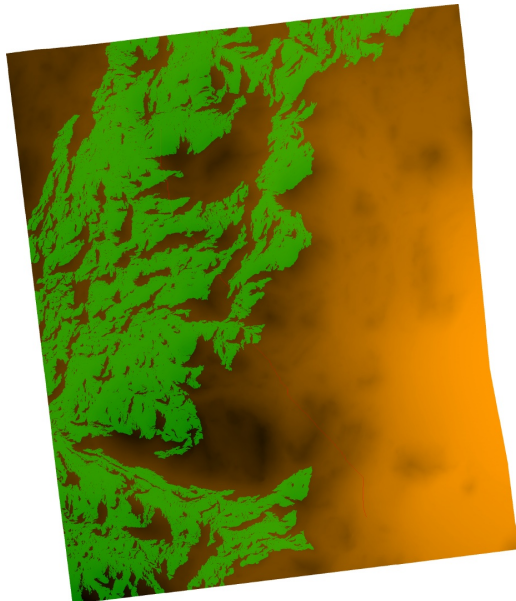
Path planning – 3Dana

- ▶ 3Dana: path planning on realistic surfaces
 - ▶ Accurate lineal interpolation
 - ▶ Allow DTM and/or cost map
 - ▶ Path cost = path length \times cell cost
 - ▶ Heading changes heuristic
 - ▶ Terrain slope



Path planning – 3Dana

- Evaluation on Mars DTM
 - 3Dana provides safer paths
 - Slope limitation
 - Reachability map



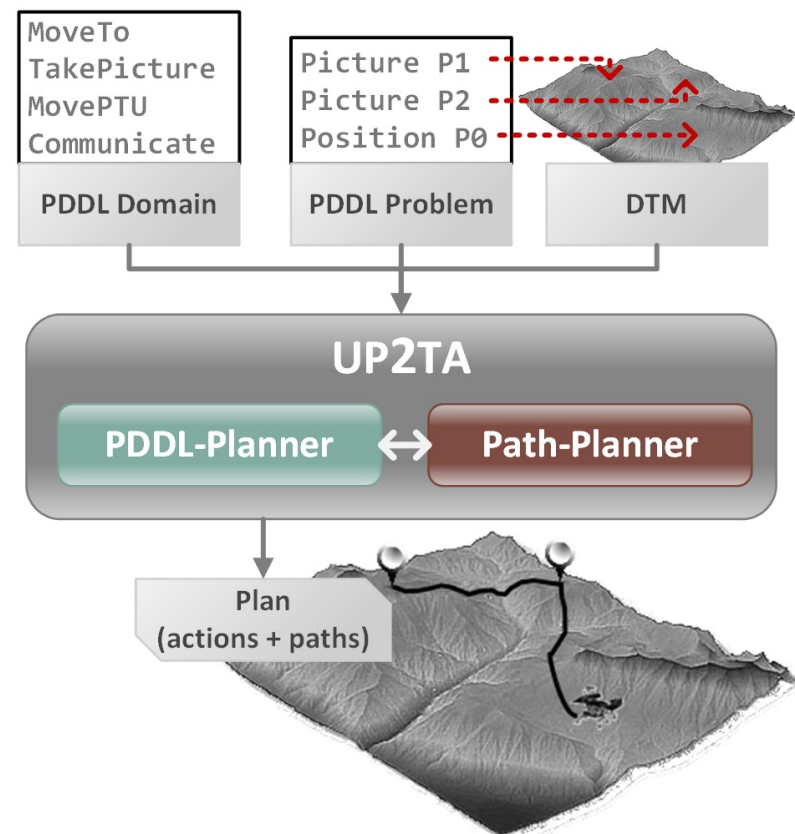
More results:

P. Muñoz, M.D. R-Moreno and Bonifacio Castaño. 3Dana: Path Planning on 3D Surfaces.

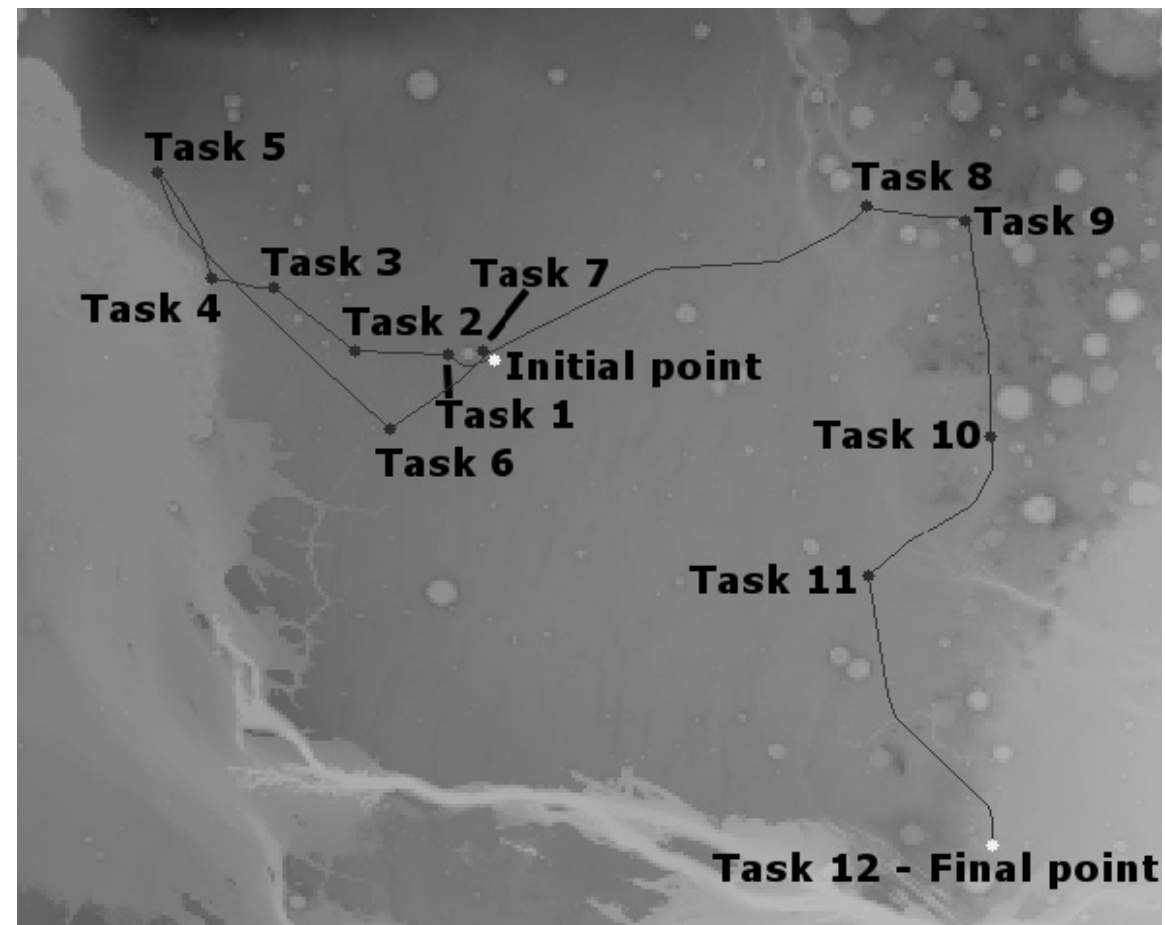
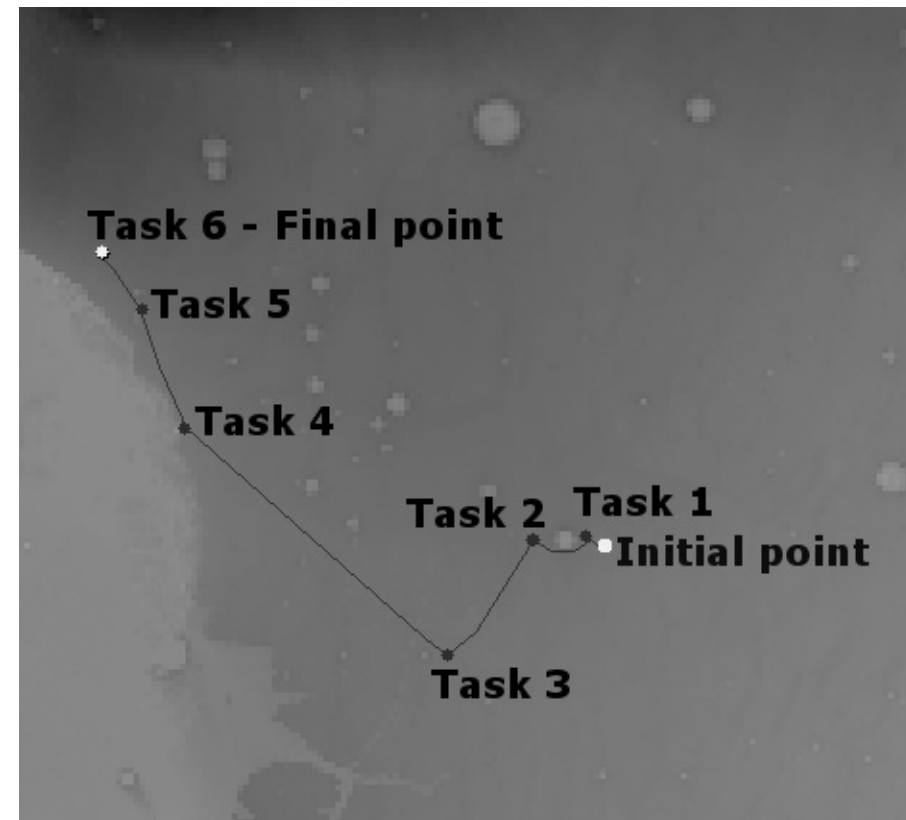
In procs. of the 36th SGA International Conference on Artificial Intelligence (2016)

Task planning – The UP2TA planner

- Exploration requires to achieve multiple goals
- UP2TA (Unified Path planning & Task planning Architecture)
 - PDDL planner: FF
 - Path planner: 3Dana
- Objective: optimize the plan
 - Minimize travelled distance
 - Best task ordering



Task planning – The UP2TA planner



More results:

P. Muñoz, M.D. R-Moreno and D. F. Barrero. Unified Framework for Path Planning and Task Planning for Autonomous Robots. *In Robotics and Autonomous Systems*, vol. 82, pp. 1–14 (2016)

Contents

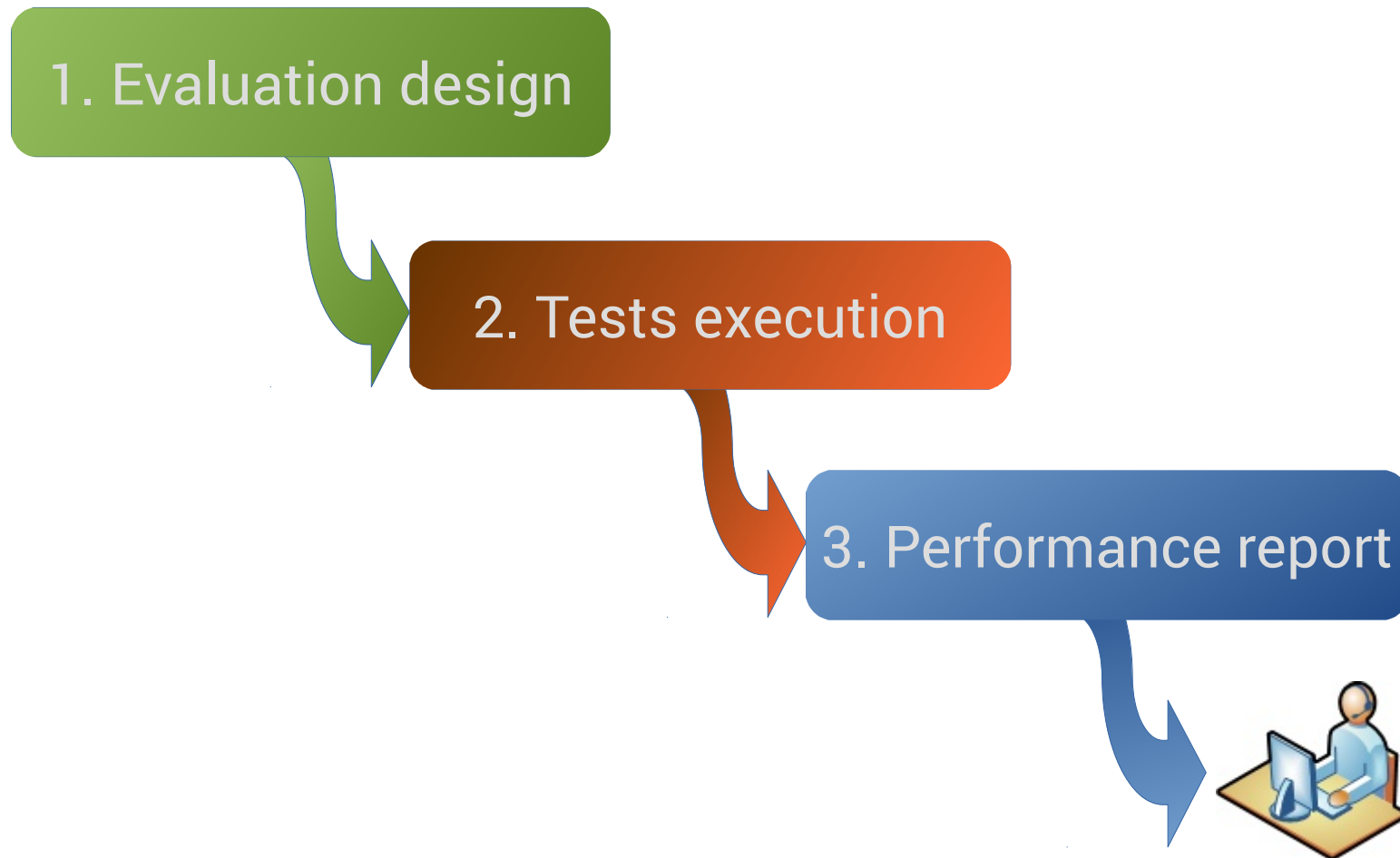
1. Introduction
2. Objectives
3. Planning for planetary rovers
- 4. Evaluating autonomous controllers**
5. OGATE Demo

An evaluation framework

- Hard to compare autonomous controllers
- Objective
 - Generation of meaningful execution data
 - Analysis integration of P&S in robotics
 - Generation of reproducible/comparable testbenchs
- Based on
 - A **methodology** to guide the testing phase
 - A set of **metrics** to assess P&S integration
 - A **software** tool to
 - Automate testbenchs
 - Improve autonomy support for users

Methodology

- Evaluation consists on 3 sequential phases



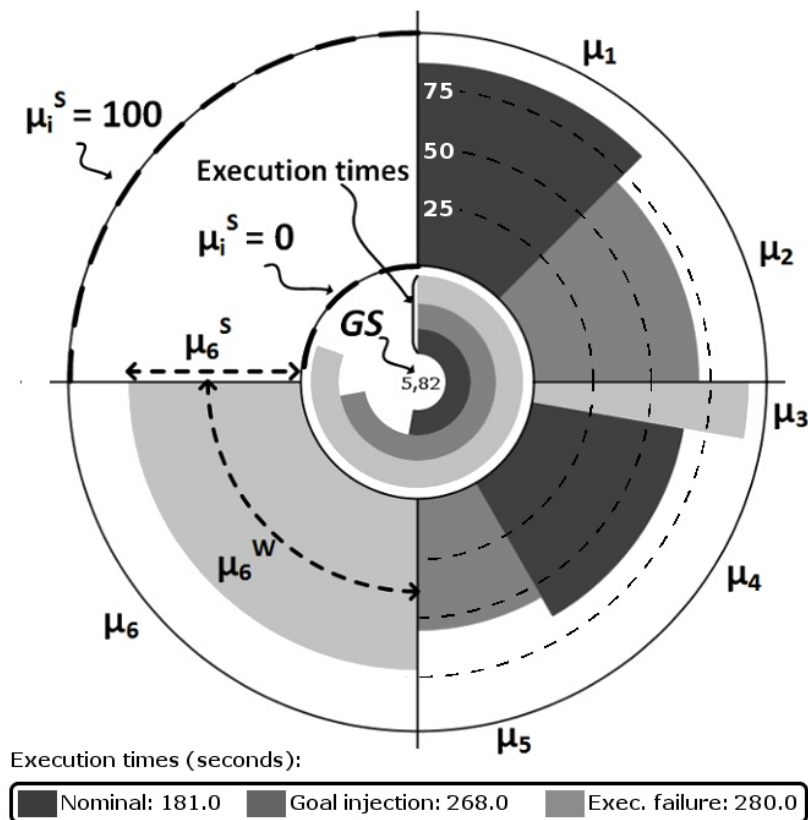
1. Evaluation design

- Objective of the test
- Application scenario and robotic platform
- Controllers configurations
- Operative conditions
 - Nominal
 - Contingency
 - Goal injection
- Normalized performance metrics

2. Tests execution

- Scenario and controller instantiation
- Controllers execution
- Monitoring of metrics data
- Collection of average behaviours

Methodology

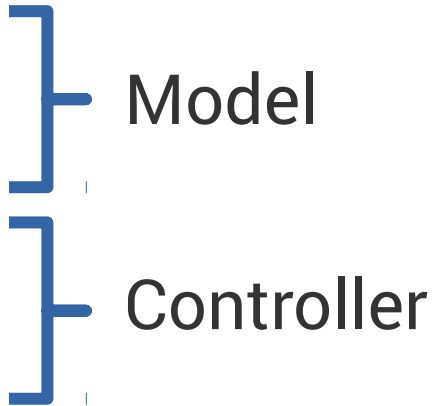


- Data synthesis
- Generation of objective evaluations
- Meaningful data representation

3. Performance report

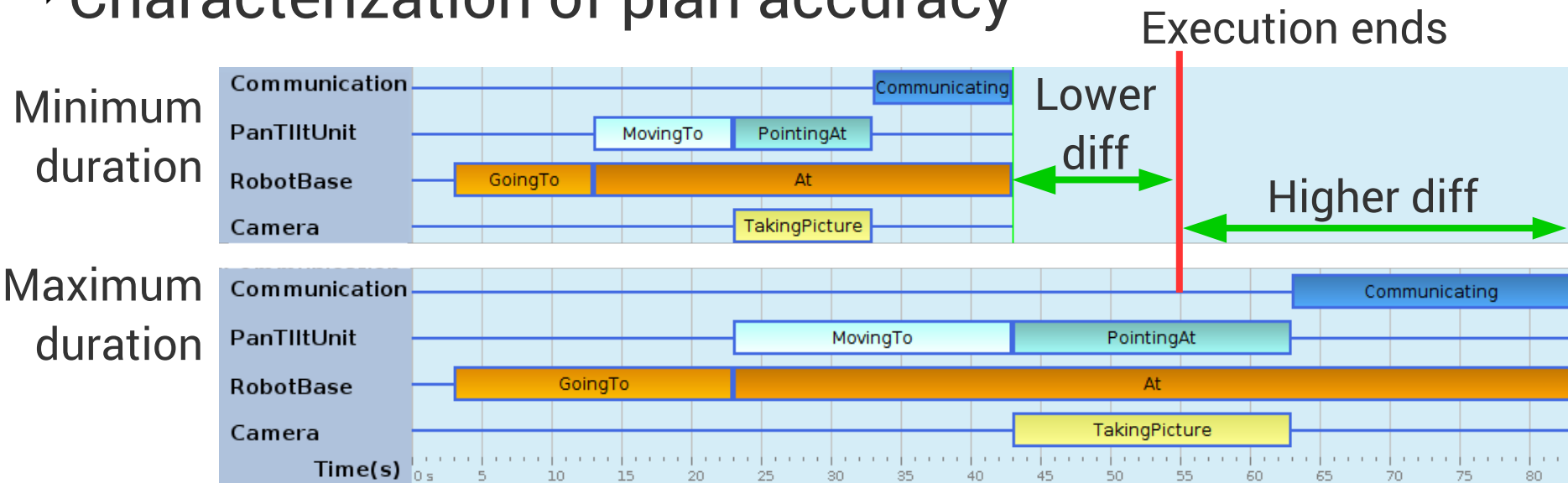


General metrics

- Characterize autonomous behaviours
 - Enable different controllers comparison
 - Four groups
 - Plan accuracy
 - Planner model adequacy
 - Planner performance
 - Planning & Execution (P&E) integration
 - These groups fit in the graphical report
 - Easy to focus on particular characteristics
- 

General metrics

Characterization of plan accuracy

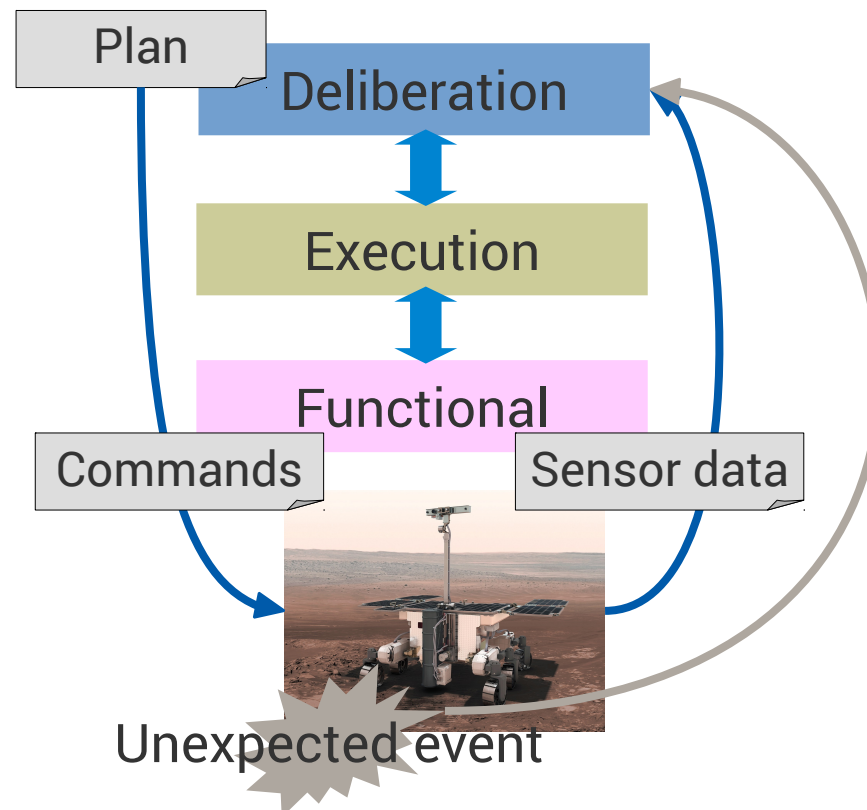


Planning performance

- Time
- Memory

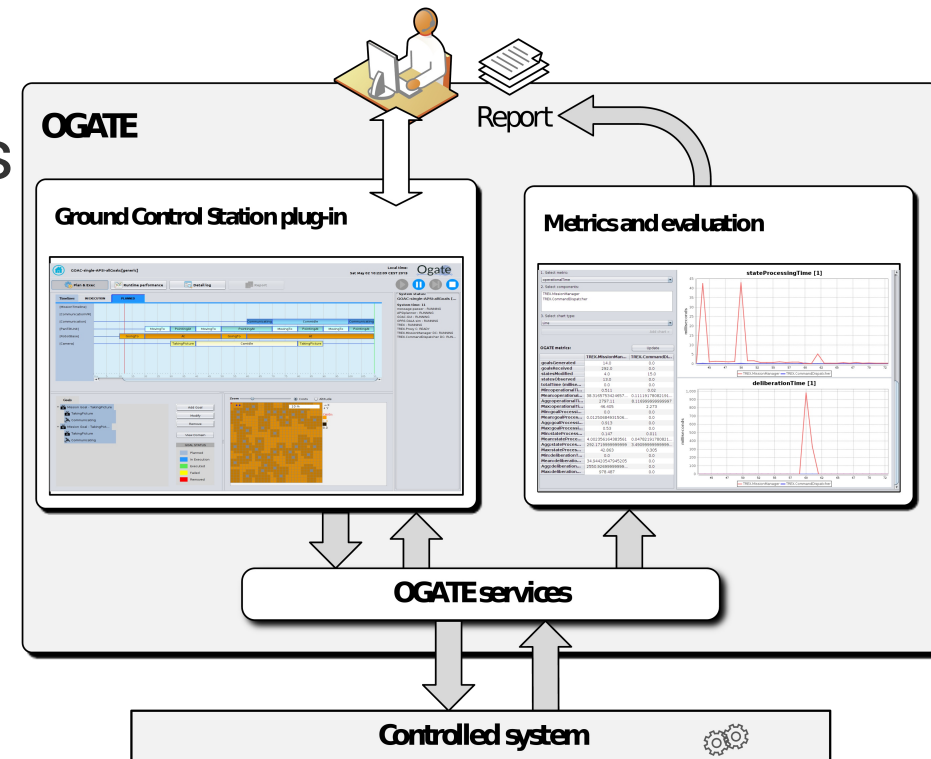
General metrics

- Integration of P&S with underlying layers of the controller
- Analysis of information flow
- Characterization of reaction time to unexpected events



The OGATE software

- ▶ OGATE (On-Ground Autonomy Test Environment)
- ▶ Designed to support autonomy
 - ▶ Simplify controllers deployment/operation
 - ▶ Monitor P&S features
 - ▶ Perform automatic testbenchs
 - ▶ Plug-ins
- ▶ Implements the methodology and metrics collection
- ▶ Allows user-defined metrics




More info:

P. Muñoz, A. Cesta, A. Orlandini and M.D. R-Moreno. First Steps on an On-Ground Autonomy Test Environment. *In procs. of the 5th IEEE Conference on Space Mission Challenges for Information Technology (2014)*

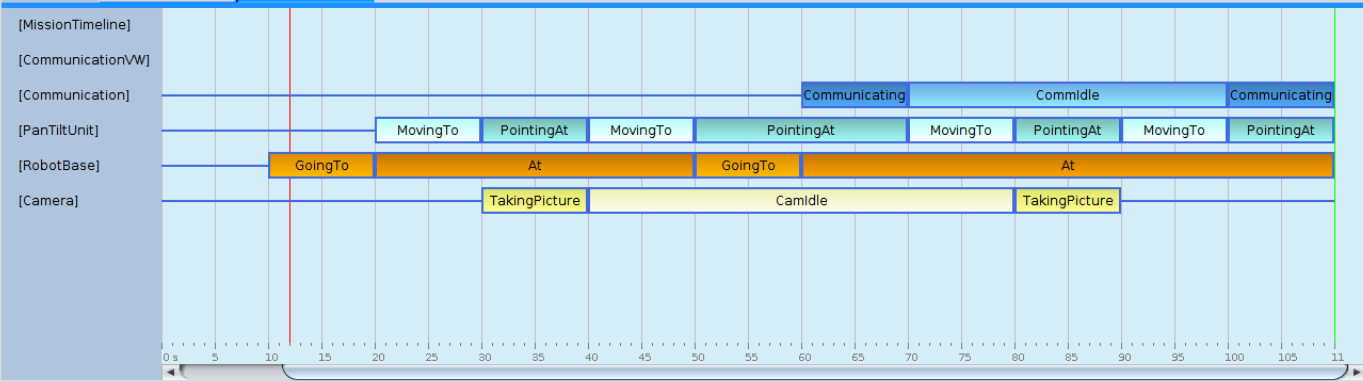
The OGATE software

▶ Current deployment: mission planning

GOAC-single-APSI-allGoals:[generic] Local time: Sat May 02 10:22:09 CEST 2015 

Plan & Exec Runtime performance Detail log Report

Timelines | IN EXECUTION | **PLANNED**



System status:
GOAC-single-APSI-allGoals [...]
System time: 11
message-passer : RUNNING
APSIplanner : RUNNING
GOAC-GUI : RUNNING
OPRS DALA sim : RUNNING
TREX : RUNNING
TREX.Proxy C: READY
TREX.MissionManager DC: RUNNING
TREX.CommandDispatcher DC: RUN...

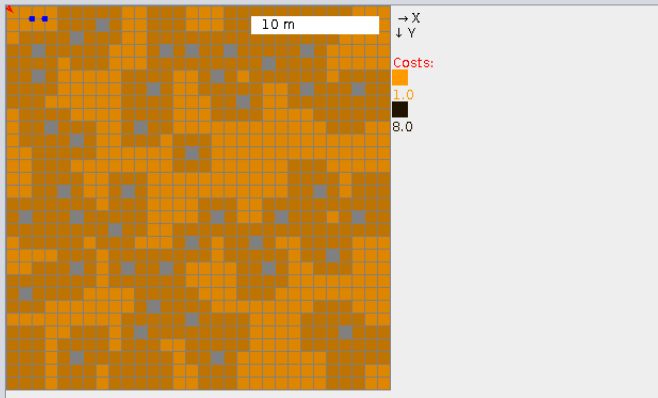
Goals

- ▼ Mission Goal - TakingPicture
 - TakingPicture
 - Communicating
- ▼ Mission Goal - TakingPict...
 - TakingPicture
 - Communicating

GOAL STATUS

- Planned
- In Execution
- Executed
- Failed
- Removed

Zoom Costs Altitude

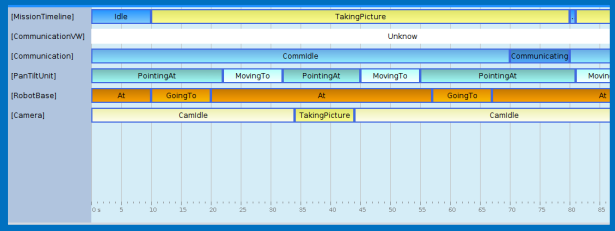


→ X
↓ Y
Costs:
1.0
8.0

The OGATE software

▶ Current deployment: mission monitoring

Past status



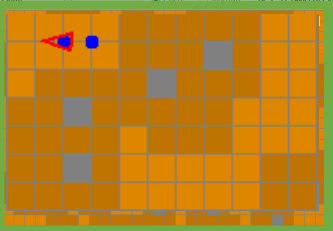
Current status

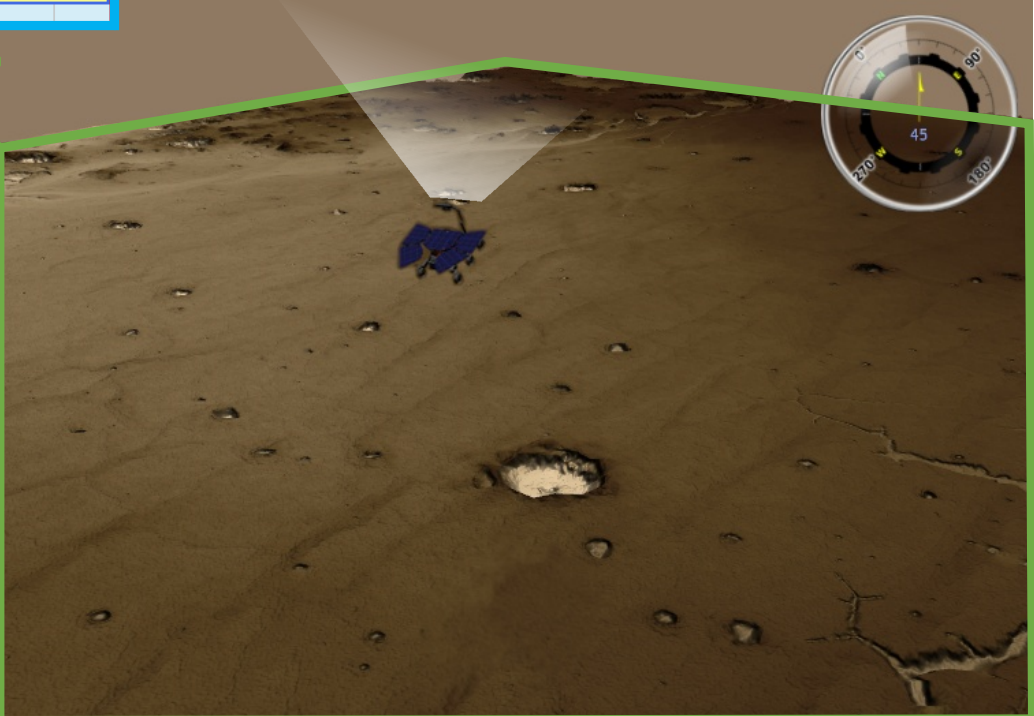
| |
|---------------|
| Commidle |
| MovingTo |
| PointingAt |
| At |
| TakingPicture |

Goals status

- ▼ Mission Goal - TakingPicture
- TakingPicture
- Communicating
- ▼ Mission Goal - TakingPict...
- TakingPicture
- Communicating


Map with rover and goals positions





The OGATE software

▶ Current deployment: performance assessment

OGATE
GOAC-single:0:[POLICY0:LATENCY0:GOALS0:WINDOWS0:MAXDURATION0:PLANNING_HORIZON_UB0] [run 3 of 10]
Local time: Thu Nov 10 19:17:38 CET 2016


Plan & Exec
Runtime performance
Detail log
Report

1. Select metric:

ControllerProcessorUsage

2. Select components:

APSIplanner
TREX
APSIplanner

3. Select chart type:

Line

OGATE metrics: Update

| | APSIplanner | TREX |
|-------------------------|-------------------|------------------|
| Min: ControllerProc... | 0.0 | 0.25 |
| Mean: ControllerPro... | 0.169889582419... | 0.56533090848... |
| Agg: ControllerProc... | 6.455804131925... | 21.4825745224... |
| Max: ControllerProc... | 1.0 | 2.5 |
| Min: ControllerMem... | 0.600000023841... | 0.0 |
| Mean: ControllerMe... | 0.982051283121... | 0.09743589888... |
| Agg: ControllerMem... | 38.30000004172... | 3.80000005662... |
| Max: ControllerMem... | 1.0 | 0.1000000149... |
| Min: ControllerDispa... | 0.0 | 0.0 |
| Mean: ControllerDis... | 0.018216216216... | 5.67567567567... |
| Agg: ControllerDisp... | 0.674 | 0.0210000000... |
| Max: ControllerDisp... | 0.293 | 0.002 |
| Min: ControllerSensi... | 0.106 | 0.011 |
| Mean: ControllerSe... | 4.711162162162... | 0.04135135135... |
| Agg: ControllerSens... | 174.313 | 1.52999999999... |
| Max: ControllerSens... | 41.49 | 0.213 |
| Min: ControllerMonit... | 0.993 | 0.016 |
| Mean: ControllerMo... | 37.53956756756... | 0.04302702702... |
| Agg: ControllerMoni... | 1388.96400000... | 1.59199999999... |
| Max: ControllerMoni... | 42.777 | 0.244 |
| ControllerReaction... | 100.0 | NaN |
| Min: PlannerDeliber... | 0.0 | NaN |
| Mean: PlannerDelib... | 12.48802702702... | NaN |
| Agg: PlannerDeliber... | 462.057 | NaN |

ControllerProcessorUsage [3]

ControllerDispatchingTime [3]

System status:

GOAC-single:0 [Running]

System time: 37

message-passer : RUNNING

APSIplanner DC : RUNNING

OPRS DALA SIM : RUNNING

GOAC-GUI C : RUNNING

TREX D : RUNNING

TREX.Proxy C : READY

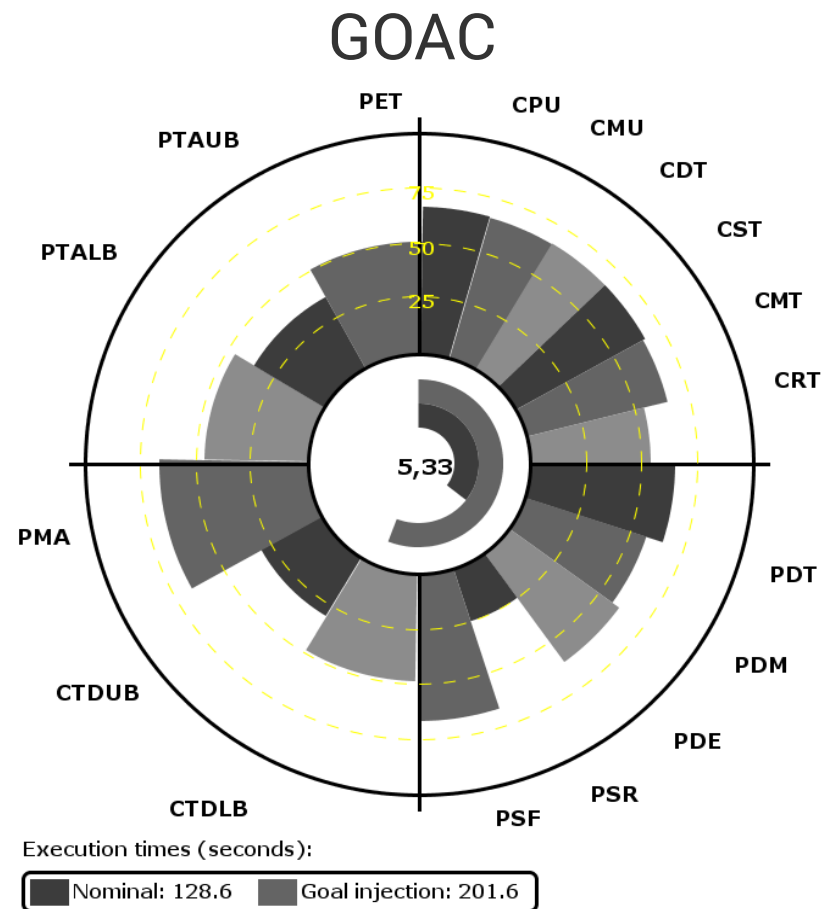
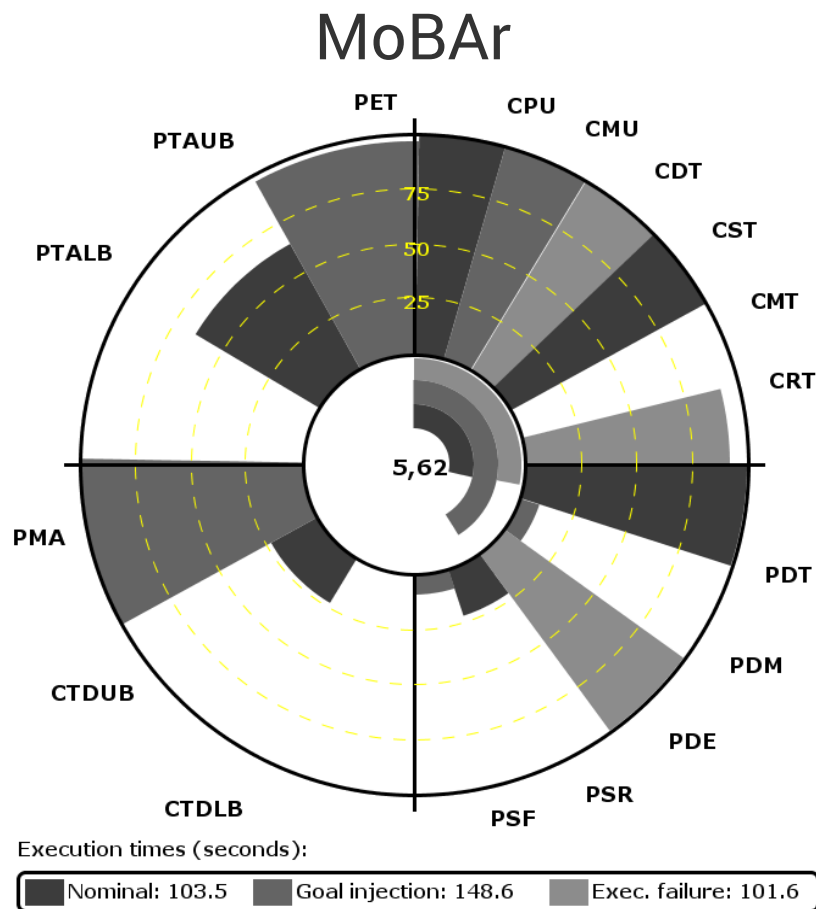
Overall test progress: 0%

A comparison testbench

- Two controllers
 - GOAC (Goal Oriented Autonomous Controller)
 - ESA effort for autonomy in space (E1-E4)
 - Timelines based planning (APSI-TRF)
 - MoBAr (Model Based Architecture)
 - UAH E4 controller
 - Predicate based planning (UP2TA)
- Exploration domain, simulated TurtleBot 2
- OGATE carries out automated tests
 - Nominal / Goal injection / Execution failure
 - Reports summarize average behaviours

A comparison testbench

Report after 30 executions



More results:
 P. Muñoz, A. Cesta, A. Orlandini and M.D. R-Moreno. A Framework for Performance Assessment of Autonomous Robotic Controllers. *In procs. of the 2nd Workshop on Planning and Robotics – ICAPS (2015)*

Contents

1. Introduction
2. Objectives
3. Planning for planetary rovers
4. Evaluating autonomous controllers
- 5. OGATE Demo**

Demo

OGATE

Please select controllers to execute and press Play button

Local time: Sun Dec 04 19:06:00 CET 2016

Plan & Exec Runtime performance Detail log Report

Load config (un)select all Advanced: Modify configuration

Configuration file: cfg/TEST.xml

Available controllers:

| | | | |
|--------------------------|--|--------------------|------------|
| <input type="checkbox"/> | Name: GOAC-single-APSI-allGoals-TurtleBot | Executions: 1 | Templates |
| | Description: The GOAC controller with a single deliberative reactor (using APSI-TRF). Objective is communicate 2 pictures using the All Goals planning policy. Using the GSI TurtleBot robot. | Timeout (sec): 300 | Metrics |
| | | | Components |
| <input type="checkbox"/> | Name: MoBAR-DALA-OPTIC-TurtleBot | Executions: 1 | Templates |
| | Description: The Model-Based Architecture from UAH. This version is specific for comparison with the GOAC controller. It uses GenOM modules connected to the OPRS-DALA simulator and the PDDL files model a very similar problem to the DDL used in the planetary exploration case study, using the OPTIC planner. Test with the GSI TurtleBot robot. | Timeout (sec): 300 | Metrics |
| | | | Components |
| <input type="checkbox"/> | Name: GOAC-single | Executions: 10 | Templates |
| | Description: The GOAC controller using a single deliberative reactor controller with the APSI-TRF as the deliberative component. You can configure different parameters by adding/removing template instances for: deliberative reactor planning policy and latency, goals, communication windows, and maximum activities duration (greater than 10; minimum is set to 10 seconds). | Timeout (sec): 425 | Metrics |
| | | | Components |

Thanks for your attention

Pablo Muñoz Martínez
e-mail: pmunoz@aut.uah.es



Universidad
de Alcalá