

OCS2 优化控制工具箱（一）安装使用 汉化

1. 前言 - 概述

OCS2 是专为切换系统优化控制（Optimal Control for Switched Systems, OCS2）定制的 C++ 工具箱。该工具箱提供以下算法的高效实现：

SLQ：连续时间域约束 DDP

iLQR：离散时域约束 DDP

SQP：基于 HPIPM 的多重打靶算法

IPM：基于非线性内点法的多重搜索算法

SLP：基于 PIPG 的顺序线性规划算法

注：DDP-微分动态规划，HPIPM是一个用于QP的开源c代码高性能框架（*hpipm*: High-performance interior-point-method QP solvers）<https://github.com/giaf/hpipm>，PIPG-Proportional-Integral Projected Gradient 基于投影梯度优化方法:<https://arxiv.org/abs/2009.06980>。

$$\begin{array}{ll} \text{minimize } \mathbf{u}(\cdot) & \sum_i \phi_i(\mathbf{x}(t_{i+1})) + \int_{t_i}^{t_{i+1}} l_i(\mathbf{x}(t), \mathbf{u}(t), t) dt \\ \text{subject to} & \mathbf{x}(t_0) = \mathbf{x}_0 \quad \text{initial state} \\ & \dot{\mathbf{x}}(t) = \mathbf{f}_i(\mathbf{x}(t), \mathbf{u}(t), t) \quad \text{system flow map} \\ & \mathbf{x}(t_{i+1}^+) = \mathbf{j}(\mathbf{x}(t_{i+1})) \quad \text{system jump map} \\ & \mathbf{g}_{1i}(\mathbf{x}(t), \mathbf{u}(t), t) = \mathbf{0} \quad \text{state - input equality constraints} \\ & \mathbf{g}_{2i}(\mathbf{x}(t), t) = \mathbf{0} \quad \text{state - only equality constraints} \\ & \mathbf{h}_i(\mathbf{x}(t), \mathbf{u}(t), t) \geq \mathbf{0} \quad \text{inequality constraints} \\ & \text{for } t_i < t < t_{i+1} \text{ and } i \in \{0, 1, \dots, I-1\} \end{array}$$

OCS2 通过增强拉格朗日法（Augmented Lagrangian）或松弛障碍法（relaxed barrier methods），处理一般路径约束。为了便于将 OCS2 应用于机器人任务，它为用户提供了额外的工具，以便根据 URDF 模型设置系统动力学（如运动学（kinematic）或动力学（dynamic）模型）和成本/约束（cost/constraints）（如避免自碰撞（self-collision avoidance）和末端执行器跟踪（end-effector tracking））。

在此框架上，如何使用性能函数映射、CBF和向量引导等，来完成人形机器人的移动操作、技能模仿等问题？

该库还提供了自动微分（automatic differentiation）工具，用于计算系统动力学、约束和成本的导数（derivatives）。为了便于在机器人平台上部署，OCS2 提供了 ROS 接口工具。该工具箱的实现高效且数值稳定，加上其友好的用户界面，为在机载计算能力有限（limited onboard computation）的众多机器人应用中使用该工具箱铺平了道路。

0.1 如何使用 OCS2 工具箱？

OCS2 可以轻松安装在 Ubuntu 上。源代码也是公开的。要开始使用控制工具箱，“开始安装”请参阅 <https://leggedrobotics.github.io/ocs2/installation.html#doxid-ocs2-doc-installation>，和 "入门" 请参阅

<https://leggedrobotics.github.io/ocs2/getting-started.html#doxid-ocs2-doc-getting-started> 页面。

0.2 许可证

OCS2 工具箱根据 BSD 3 条款许可发布。请注意源代码目录中的许可证license和注意事项文件notice files。

0.3 开发人员

项目经理：Farbod Farshidian。主要开发人员 Farbod Farshidian、Ruben Grandia、Michael Spieler、Jan Carius、Jean-Pierre Sleiman。其他开发人员 Alexander Reske、Sotaro Katayama、Mayank Mittal、Jia-Ruei Chiu、Johannes Pankert、Perry Franklin、Tom Lankhorst、David Hoeller、Asutosh Satapathy、Markus Gifftthaler、Edo Jelavic。OCS2 工具箱的开发由苏黎世联邦理工学院的 ADRL 团队发起，该项目在苏黎世联邦理工学院的 RSL 继续发展。RSL 团队现在积极支持 OCS2 的开发。

0.4 引用 OCS2

```
@misc{OCS2,  
  title = {{OCS2}: An open source library for Optimal Control of Switched Systems},  
  note = {[Online]. Available: \url{https://github.com/leggedrobotics/ocs2}},  
  author = {Farbod Farshidian and others}}
```

0.5 视频教程

OCS2 工具箱教程，Farbod Farshidian，MPC 研讨会，RSS 2021-

<https://www.youtube.com/watch?v=RymQN9GbFYg>。腿部运动和操纵的实时优化控制，Marco Hutter，MPC 研讨会，RSS 2021-<https://www.youtube.com/watch?v=sjAENmtO4bA>。对应的B站资源，请同学们补充。

0.6 相关论文

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4. Markus Gifftthaler, Farbod Farshidian, Timothy Sandy, Lukas Stadelmann, and Jonas Buchli. Efficient kinematic planning for mobile manipulators with non-holonomic constraints using optimal control. In 2017 IEEE International Conference on Robotics and Automation (ICRA), 3411–3417. IEEE, 2017.
5. Farbod Farshidian, David Hoeller, and Marco Hutter. Deep value model predictive control. In Conference on Robot Learning (CoRL), 990–1004. PMLR, 2020.
6. Ruben Grandia, Farbod Farshidian, Alexey Dosovitskiy, René Ranftl, and Marco Hutter. Frequency-aware model predictive control. IEEE Robotics and Automation Letters, 4(2):1517–1524, 2019.
7. Maria Vittoria Minniti, Farbod Farshidian, Ruben Grandia, and Marco Hutter. Whole-body mpc for a dynamically stable mobile manipulator. IEEE Robotics and Automation Letters, 4(4):3687–3694, 2019.
8. Jan Carius, Farbod Farshidian, and Marco Hutter. Mpc-net: a first principles guided policy search. IEEE Robotics and Automation Letters, 5(2):2897–2904, 2020.
9. Ruben Grandia, Farbod Farshidian, René Ranftl, and Marco Hutter. Feedback mpc for torque-controlled legged robots. In 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 4730–4737. IEEE, 2019.
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11. Jean-Pierre Sleiman, Farbod Farshidian, Maria Vittoria Minniti, and Marco Hutter. A unified mpc framework for whole-body dynamic locomotion and manipulation. IEEE Robotics and Automation Letters, 6(3):4688–4695, 2021.
12. Ruben Grandia, Andrew J Taylor, Aaron D Ames, and Marco Hutter. Multi-layered safety for legged robots via control barrier functions and model predictive control. arXiv preprint arXiv:2011.00032, 2020.
13. Magnus Gaertner, Marko Bjelonic, Farbod Farshidian, and Marco Hutter. Collision-free mpc for legged robots in static and dynamic scenes. In 2021 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2021.

14. Jean-Pierre Sleiman, Farbod Farshidian, and Marco Hutter. Constraint handling in continuous-time ddp-based model predictive control. In 2021 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2021.
15. Alexander Reske, Jan Carius, Yuntao Ma, Farbod Farshidian, and Marco Hutter. Imitation learning from mpc for quadrupedal multi-gait control. In 2021 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2021.
16. Maria Vittoria Minniti, Ruben Grandia, Kevin Fähr, Farbod Farshidian, and Marco Hutter. Model predictive robot-environment interaction control for mobile manipulation tasks. In 2021 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2021.
17. Mayank Mittal, David Hoeller, Farbod Farshidian, Marco Hutter, and Animesh Garg. Articulated object interaction in unknown scenes with whole-body mobile manipulation. arXiv preprint arXiv:2103.10534, 2021.

一、安装

1.1 前提条件

OCS2 库以 C++11 编写，在 Ubuntu 20.04 下测试，库版本与软件包源码中提供的版本一致。

1.1.1 源代码

源代码托管在 GitHub: leggedrobotics/ocs2。 <https://github.com/leggedrobotics/ocs2>

```
1 # Clone OCS2
2 git clone git@github.com:leggedrobotics/ocs2.git
```

1.1.2 依赖项

- C++ compiler with C++11 support
- Eigen (v3.3)
- Boost C++ (v1.71)
- GLPK

```
1 sudo apt install libglpk-dev
```

- catkin

```
1 sudo apt-get install catkin
```

- pybind11_catkin, ROS package, installable via

```
1 sudo apt install ros-noetic-pybind11-catkin
```

- catkin-pkg package for python3. Install with

```
1 sudo apt install python3-catkin-tools
```

- Doxygen for documentation. Install with

```
1 sudo apt install doxygen doxygen-latex
```

1.1.3 可选依赖项

- 将 [Pinocchio](#) 和 [HPP-FCL](#) 克隆到工作区，以获得刚性多体动力学库和自碰撞支持

```
1 # Clone pinocchio
2 git clone --recurse-submodules https://github.com/leggedrobotics/pinocchio.git
3 # Clone hpp-fcl
4 git clone --recurse-submodules https://github.com/leggedrobotics/hpp-fcl.git
5 # install dependencies
6 sudo apt install liburdfdom-dev liboctomap-dev libassimp-dev
```

- 对于 OCS2 单元测试和机器人示例中使用的各种机器人资产assets

```
1 # Clone ocs2_robotic_assets
2 git clone https://github.com/leggedrobotics/ocs2_robotic_assets.git
```

- [rqt_multiplot](#) 软件包可用于可视化求解器的性能指标和其他优化输出结果

```
1 sudo apt-get install ros-noetic-rqt-multiplot
```

- **RaiSim** 模拟器可用作滚动的提供者。相应的 **ocs2_raisim** 软件包有额外要求：

RaiSim 软件包需要通过克隆到工作区 **workspace** 从源代码中安装：

```
1 git clone --depth 1 https://github.com/raisimTech/raisimLib.git -b v1.1.01
```

请按照 **RaiSim** 网页上的说明进行安装。或者，为了让 **catkin** 容易找到安装程序并在将来方便卸载，可以考虑使用 **CheckInstall** 将 **RaiSim** 安装为 **debian** 软件包。为此，请替换原来的命令：

```
1 cmake .. -DCMAKE_INSTALL_PREFIX=$LOCAL_INSTALL <other options>
2 make install -j4
```

与：

```
1 cmake .. <other options> (Without INSTALL_PREFIX)
```

```
1 make -j4 && sudo checkinstall
```

这将把 **RaiSim** 安装到 **/usr/local/lib** 的默认位置，**catkin** 也会自动检测到该位置。当 **checkinstall** 提出要求时，请将软件包名称更改为合适的名称（如 "**raisim**"），以便日后进行软件包管理时查找，例如卸载（**dpkg -r <package_name>**）。

要实现可视化，请使用 **RaiSim Unity**，在 **raisimLib/raisimUnity** 目录中提供了预置的可执行文件。例如，它可用于调试目的，查看 **OCS2** 和 **RaiSim** 之间的转换是否正确。

- 网格地图 **catkin** 软件包，可使用 **sudo apt install ros-noetic-grid-map-msgs** 安装。

```
1 sudo apt install ros-noetic-grid-map-msgs
```

- **ONNX Runtime** 是一种推理和训练加速器。在这里，它用于在 C++ 代码中部署学习到的 **MPC-Net** 策略。要在本地安装它，请执行以下操作：

```
1 cd /tmp
2 wget
   https://github.com/microsoft/onnxruntime/releases/download/v1.7.0/onnxruntime-
```

```
linux-x64-1.7.0.tgz
3 tar xf onnxruntime-linux-x64-1.7.0.tgz
4 mkdir -p ~/.local/bin ~/.local/include/onnxruntime ~/.local/lib
  ~/.local/share/cmake/onnxruntime
5 rsync -a /tmp/onnxruntime-linux-x64-1.7.0/include/ ~/.local/include/onnxruntime
6 rsync -a /tmp/onnxruntime-linux-x64-1.7.0/lib/ ~/.local/lib
7 rsync -a ~/git/ocs2/ocs2_mpcnet/ocs2_mpcnet_core/misc/onnxruntime/cmake/
  ~/.local/share/cmake/onnxruntime
```

我们提供了自定义的 cmake 配置和版本文件，以便在不修改 `LIBRARY_PATH` 和 `LD_LIBRARY_PATH` 的情况下启用 `find_package(onnxruntime)`。请注意，上述最后一条命令假定您已将 OCS2 克隆到用户主目录下的 `git` 文件夹中。

- 训练 `MPC-Net` 策略时建议使用虚拟环境：

```
1 sudo apt-get install python3-venv
```

- 创建一个环境，并赋予其访问系统站点软件包的权限：

```
1 mkdir venvs && cd venvs
2 python3 -m venv mpcnet
```

- 激活环境并安装需求：

```
1 source ~/venvs/mpcnet/bin/activate
2 python3 -m pip install -r
  ~/git/ocs2/ocs2_mpcnet/ocs2_mpcnet_core/requirements.txt
```

- 激活环境并安装需求：较新的显卡可能需要 CUDA 功能，而标准 PyTorch 安装目前还不支持该功能。在这种情况下，检查 PyTorch Start Locally 是否有兼容的版本，例如，运行

```
1 pip3 install torch==1.10.2+cu113 -f
  https://download.pytorch.org/whl/cu113/torch_stable.html
```

- 可能出现的问题：

```
1 Could not find a package configuration file provided by
```

```

2 "convex_plane_decomposition" with any of the following names:
3
4 convex_plane_decompositionConfig.cmake
5 convex_plane_decomposition-config.cmake
6 Add the installation prefix of "convex_plane_decomposition" to
7 CMAKE_PREFIX_PATH or set "convex_plane_decomposition_DIR" to a directory
8 containing one of the above files. If "convex_plane_decomposition"
9 provides a separate development package or SDK, be sure it has been
10 installed."
11 CMake Error at /opt/ros/noetic/share/catkin/cmake/catkinConfig.cmake:83
   (find_package):
12 Could not find a package configuration file provided by
13 "grid_map_filters_rsl" with any of the following names:
14
15 grid_map_filters_rslConfig.cmake
16 grid_map_filters_rsl-config.cmake
17 Add the installation prefix of "grid_map_filters_rsl" to CMAKE_PREFIX_PATH
18 or set "grid_map_filters_rsl_DIR" to a directory containing one of the
19 above files. If "grid_map_filters_rsl" provides a separate development
20 package or SDK, be sure it has been installed.

```

- 解决方案:

elevation mapping cupy

```

1 git clone https://github.com/leggedrobotics/elevation_mapping_cupy.git

```

grid map

```

1 git clone https://github.com/ANYbotics/grid_map.git

```

1.2 安装

1.2.1 创建程序库

创建一个新的 catkin 工作区:

```

1 # Create the directories
2 # Do not forget to change <...> parts
3 mkdir -p <directory_to_ws>/<catkin_ws_name>/src
4 cd <directory_to_ws>/<catkin_ws_name>/

```



```
5
6 # Initialize the catkin workspace
7 catkin init
8 catkin config --extend /opt/ros/noetic
9 catkin config -DCMAKE_BUILD_TYPE=RelWithDebInfo
```

克隆 OCS2 库:

```
1 # Navigate to the directory of src
2 # Do not forget to change <...> parts
3 cd <directory_to_ws>/<catkin_ws_name>/src
4 git clone git@github.com:leggedrobotics/ocs2.git
```

构建并运行单元测试

```
1 # Build it
2 # catkin build ocs2
3 catkin build -DCMAKE_BUILD_TYPE=Release
4
5 # Source it
6 source <directory_to_ws>/<catkin_ws_name>/devel/setup.bash
7
8 # run tests
9 catkin run_tests ocs2
```

```
1 catkin build -DCMAKE_BUILD_TYPE=Release
2 -----
3 Profile:                                default
4 Extending:          [explicit] /opt/ros/noetic
5 Workspace:          /home/kuanli/ocs2_ws
6 -----
7
8 Build Space:        [exists] /home/kuanli/ocs2_ws/build
9 Devel Space:        [exists] /home/kuanli/ocs2_ws/devel
10 Install Space:     [unused] /home/kuanli/ocs2_ws/install
11 Log Space:         [exists] /home/kuanli/ocs2_ws/logs
12 Source Space:      [exists] /home/kuanli/ocs2_ws/src
13 DESTDIR:           [unused] None
14 -----
15 -
```

```
14 Devel Space Layout:      linked
15 Install Space Layout:    None
16 -----
17 Additional CMake Args:    -DCMAKE_BUILD_TYPE=RelWithDebInfo -
    DCMMAKE_BUILD_TYPE=Release
18 Additional Make Args:     None
19 Additional catkin Make Args: None
20 Internal Make Job Server: True
21 Cache Job Environments:   False
22 -----
23 Buildlisted Packages:     None
24 Skiplisted Packages:      None
25 -----
26 Workspace configuration appears valid.
27 -----
28 [build] Found 82 packages in 0.0 seconds.
29 [build] Package table is up to date.
30 Starting >>> blasfeo_catkin
31 Starting >>> cgal5_catkin
32 Starting >>> elevation_map_msgs
33 Starting >>> grid_map_core
34 Starting >>> grid_map_msgs
35 Starting >>> hpp-fcl
36 Starting >>> ocs2_msgs
37 Starting >>> ocs2_robotic_assets
38 Finished <<< blasfeo_catkin [ 0.2
    seconds ]
39 Starting >>> ocs2_thirdparty
40 Finished <<< cgal5_catkin [ 1.3
    seconds ]
41 Starting >>> semantic_sensor
42 Finished <<< grid_map_core [ 0.2
    seconds ]
43 Starting >>> grid_map_costmap_2d
44 Finished <<< ocs2_robotic_assets [ 0.2
    seconds ]
45 Starting >>> grid_map_cv
46 Finished <<< ocs2_thirdparty [ 0.2
    seconds ]
47 Starting >>> grid_map_octomap
48 Finished <<< elevation_map_msgs [ 0.6
    seconds ]
49 Starting >>> grid_map_sdf
```

```

50 Finished <<< ocs2_msgs [ 1.1
    seconds ]
51 Starting >>> ocs2_switched_model_msgs
52 Finished <<< grid_map_msgs [ 0.9
    seconds ]
53 Starting >>> convex_plane_decomposition_msgs
54 -----
55 Warnings << hpp-fcl:install /home/kuanli/ocs2_ws/logs/hpp-
    fcl/build.install.003.log
56 Error: /undefined in getenv
57 Operand stack:
58     (outfile)
59 Execution stack:
60     %interp_exit .runexec2 --nostringval-- --nostringval-- --
    nostringval-- 2 %stopped_push --nostringval-- --nostringval-- --
    nostringval-- false 1 %stopped_push 1990 1 4 %oparray_pop 1989
    1 4 %oparray_pop 1977 1 4 %oparray_pop 1833 1 4
    %oparray_pop --nostringval-- %errorexec_pop .runexec2 --nostringval--
    --nostringval-- --nostringval-- 2 %stopped_push --nostringval--
61 Dictionary stack:
62     --dict:731/1123(ro)(G)-- --dict:0/20(G)-- --dict:76/200(L)-- --
    dict:5/30(L)-- --dict:11/30(L)--
63 Current allocation mode is local
64 Current file position is 8386
65 GPL Ghostscript 9.50: Unrecoverable error, exit code 1
66 Error: /undefined in getenv
67 Operand stack:
68     (outfile)
69 Execution stack:
70     %interp_exit .runexec2 --nostringval-- --nostringval-- --
    nostringval-- 2 %stopped_push --nostringval-- --nostringval-- --
    nostringval-- false 1 %stopped_push 1990 1 4 %oparray_pop 1989
    1 4 %oparray_pop 1977 1 4 %oparray_pop 1833 1 4
    %oparray_pop --nostringval-- %errorexec_pop .runexec2 --nostringval--
    --nostringval-- --nostringval-- 2 %stopped_push --nostringval--
71 Dictionary stack:
72     --dict:731/1123(ro)(G)-- --dict:0/20(G)-- --dict:76/200(L)-- --
    dict:5/30(L)-- --dict:11/30(L)--
73 Current allocation mode is local
74 Current file position is 8386
75 GPL Ghostscript 9.50: Unrecoverable error, exit code 1
76 Error: /undefined in getenv
77 Operand stack:
78     (outfile)
79 Execution stack:
80     %interp_exit .runexec2 --nostringval-- --nostringval-- --
    nostringval-- 2 %stopped_push --nostringval-- --nostringval-- --

```

```

nostringval--  false  1  %stopped_push  1990  1  4  %oparray_pop  1989
  1  4  %oparray_pop  1977  1  4  %oparray_pop  1833  1  4
%oparray_pop  --nostringval--  %errorexec_pop  .runexec2  --nostringval--
--nostringval--  --nostringval--  2  %stopped_push  --nostringval--
81 Dictionary stack:
82  --dict:731/1123(ro)(G)--  --dict:0/20(G)--  --dict:76/200(L)--  --
  dict:5/30(L)--  --dict:11/30(L)--
83 Current allocation mode is local
84 Current file position is 8386
85 GPL Ghostscript 9.50: Unrecoverable error, exit code 1
86 Error: /undefined in getenv
87 Operand stack:
88  (outfile)
89 Execution stack:
90  %interp_exit  .runexec2  --nostringval--  --nostringval--  --
  nostringval--  2  %stopped_push  --nostringval--  --nostringval--  --
  nostringval--  false  1  %stopped_push  1990  1  4  %oparray_pop  1989
    1  4  %oparray_pop  1977  1  4  %oparray_pop  1833  1  4
%oparray_pop  --nostringval--  %errorexec_pop  .runexec2  --nostringval--
--nostringval--  --nostringval--  2  %stopped_push  --nostringval--
91 Dictionary stack:
92  --dict:731/1123(ro)(G)--  --dict:0/20(G)--  --dict:76/200(L)--  --
  dict:5/30(L)--  --dict:11/30(L)--
93 Current allocation mode is local
94 Current file position is 8386
95 GPL Ghostscript 9.50: Unrecoverable error, exit code 1
96 Error: /undefined in getenv
97 Operand stack:
98  (outfile)
99 Execution stack:
100 %interp_exit  .runexec2  --nostringval--  --nostringval--  --
  nostringval--  2  %stopped_push  --nostringval--  --nostringval--  --
  nostringval--  false  1  %stopped_push  1990  1  4  %oparray_pop  1989
    1  4  %oparray_pop  1977  1  4  %oparray_pop  1833  1  4
%oparray_pop  --nostringval--  %errorexec_pop  .runexec2  --nostringval--
--nostringval--  --nostringval--  2  %stopped_push  --nostringval--
101 Dictionary stack:
102  --dict:731/1123(ro)(G)--  --dict:0/20(G)--  --dict:76/200(L)--  --
  dict:5/30(L)--  --dict:11/30(L)--
103 Current allocation mode is local
104 Current file position is 8386
105 GPL Ghostscript 9.50: Unrecoverable error, exit code 1
106 Error: /undefined in getenv
107 Operand stack:
108  (outfile)
109 Execution stack:

```

```

110  %interp_exit  .runexec2  --nostringval--  --nostringval--  --
nostringval--  2  %stopped_push  --nostringval--  --nostringval--  --
nostringval--  false  1  %stopped_push  1990  1  4  %oparray_pop  1989
1  4  %oparray_pop  1977  1  4  %oparray_pop  1833  1  4
%oparray_pop  --nostringval--  %errorexec_pop  .runexec2  --nostringval--
--nostringval--  --nostringval--  2  %stopped_push  --nostringval--
111 Dictionary stack:
112  --dict:731/1123(ro)(G)--  --dict:0/20(G)--  --dict:76/200(L)--  --
dict:5/30(L)--  --dict:11/30(L)--
113 Current allocation mode is local
114 Current file position is 8386
115 GPL Ghostscript 9.50: Unrecoverable error, exit code 1
116 Error: /undefined in getenv
117 Operand stack:
118  (outfile)
119 Execution stack:
120  %interp_exit  .runexec2  --nostringval--  --nostringval--  --
nostringval--  2  %stopped_push  --nostringval--  --nostringval--  --
nostringval--  false  1  %stopped_push  1990  1  4  %oparray_pop  1989
1  4  %oparray_pop  1977  1  4  %oparray_pop  1833  1  4
%oparray_pop  --nostringval--  %errorexec_pop  .runexec2  --nostringval--
--nostringval--  --nostringval--  2  %stopped_push  --nostringval--
121 Dictionary stack:
122  --dict:731/1123(ro)(G)--  --dict:0/20(G)--  --dict:76/200(L)--  --
dict:5/30(L)--  --dict:11/30(L)--
123 Current allocation mode is local
124 Current file position is 8386
125 GPL Ghostscript 9.50: Unrecoverable error, exit code 1
126 Error: /undefined in getenv
127 Operand stack:
128  (outfile)
129 Execution stack:
130  %interp_exit  .runexec2  --nostringval--  --nostringval--  --
nostringval--  2  %stopped_push  --nostringval--  --nostringval--  --
nostringval--  false  1  %stopped_push  1990  1  4  %oparray_pop  1989
1  4  %oparray_pop  1977  1  4  %oparray_pop  1833  1  4
%oparray_pop  --nostringval--  %errorexec_pop  .runexec2  --nostringval--
--nostringval--  --nostringval--  2  %stopped_push  --nostringval--
131 Dictionary stack:
132  --dict:731/1123(ro)(G)--  --dict:0/20(G)--  --dict:76/200(L)--  --
dict:5/30(L)--  --dict:11/30(L)--
133 Current allocation mode is local
134 Current file position is 8386
135 GPL Ghostscript 9.50: Unrecoverable error, exit code 1
136 Error: /undefined in getenv
137 Operand stack:
138  (outfile)

```

```

139 Execution stack:
140   %interp_exit .runexec2 --nostringval-- --nostringval-- --
nostringval-- 2 %stopped_push --nostringval-- --nostringval-- --
nostringval-- false 1 %stopped_push 1990 1 4 %oparray_pop 1989
1 4 %oparray_pop 1977 1 4 %oparray_pop 1833 1 4
%oparray_pop --nostringval-- %errorexec_pop .runexec2 --nostringval--
--nostringval-- --nostringval-- 2 %stopped_push --nostringval--
141 Dictionary stack:
142   --dict:731/1123(ro)(G)-- --dict:0/20(G)-- --dict:76/200(L)-- --
dict:5/30(L)-- --dict:11/30(L)--
143 Current allocation mode is local
144 Current file position is 8386
145 GPL Ghostscript 9.50: Unrecoverable error, exit code 1
146 Error: /undefined in getenv
147 Operand stack:
148   (outfile)
149 Execution stack:
150   %interp_exit .runexec2 --nostringval-- --nostringval-- --
nostringval-- 2 %stopped_push --nostringval-- --nostringval-- --
nostringval-- false 1 %stopped_push 1990 1 4 %oparray_pop 1989
1 4 %oparray_pop 1977 1 4 %oparray_pop 1833 1 4
%oparray_pop --nostringval-- %errorexec_pop .runexec2 --nostringval--
--nostringval-- --nostringval-- 2 %stopped_push --nostringval--
151 Dictionary stack:
152   --dict:731/1123(ro)(G)-- --dict:0/20(G)-- --dict:76/200(L)-- --
dict:5/30(L)-- --dict:11/30(L)--
153 Current allocation mode is local
154 Current file position is 8386
155 GPL Ghostscript 9.50: Unrecoverable error, exit code 1
156 Error: /undefined in getenv
157 Operand stack:
158   (outfile)
159 Execution stack:
160   %interp_exit .runexec2 --nostringval-- --nostringval-- --
nostringval-- 2 %stopped_push --nostringval-- --nostringval-- --
nostringval-- false 1 %stopped_push 1990 1 4 %oparray_pop 1989
1 4 %oparray_pop 1977 1 4 %oparray_pop 1833 1 4
%oparray_pop --nostringval-- %errorexec_pop .runexec2 --nostringval--
--nostringval-- --nostringval-- 2 %stopped_push --nostringval--
161 Dictionary stack:
162   --dict:731/1123(ro)(G)-- --dict:0/20(G)-- --dict:76/200(L)-- --
dict:5/30(L)-- --dict:11/30(L)--
163 Current allocation mode is local
164 Current file position is 8386
165 GPL Ghostscript 9.50: Unrecoverable error, exit code 1
166 Error: /undefined in getenv
167 Operand stack:

```

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168     (outfile)
169 Execution stack:
170   %interp_exit .runexec2 --nostringval-- --nostringval-- --
nostringval-- 2 %stopped_push --nostringval-- --nostringval-- --
nostringval-- false 1 %stopped_push 1990 1 4 %oparray_pop 1989
1 4 %oparray_pop 1977 1 4 %oparray_pop 1833 1 4
%oparray_pop --nostringval-- %errorexec_pop .runexec2 --nostringval--
--nostringval-- --nostringval-- 2 %stopped_push --nostringval--
171 Dictionary stack:
172   --dict:731/1123(ro)(G)-- --dict:0/20(G)-- --dict:76/200(L)-- --
dict:5/30(L)-- --dict:11/30(L)--
173 Current allocation mode is local
174 Current file position is 8386
175 GPL Ghostscript 9.50: Unrecoverable error, exit code 1
176 Error: /undefined in getenv
177 Operand stack:
178     (outfile)
179 Execution stack:
180   %interp_exit .runexec2 --nostringval-- --nostringval-- --
nostringval-- 2 %stopped_push --nostringval-- --nostringval-- --
nostringval-- false 1 %stopped_push 1990 1 4 %oparray_pop 1989
1 4 %oparray_pop 1977 1 4 %oparray_pop 1833 1 4
%oparray_pop --nostringval-- %errorexec_pop .runexec2 --nostringval--
--nostringval-- --nostringval-- 2 %stopped_push --nostringval--
181 Dictionary stack:
182   --dict:731/1123(ro)(G)-- --dict:0/20(G)-- --dict:76/200(L)-- --
dict:5/30(L)-- --dict:11/30(L)--
183 Current allocation mode is local
184 Current file position is 8386
185 GPL Ghostscript 9.50: Unrecoverable error, exit code 1
186 cd /home/kuanli/ocs2_ws/build/hpp-fcl; catkin build --get-env hpp-fcl | catkin
env -si /usr/bin/make install; cd -
187
188 .....
189 Finished <<< hpp-fcl [ 4.2
seconds ]
190 Starting >>> ocs2_core
191 Finished <<< semantic_sensor [ 0.1
seconds ]
192 Starting >>> pinocchio
193 Finished <<< grid_map_costmap_2d [ 0.1
seconds ]
194 Finished <<< grid_map_octomap [ 0.2
seconds ]
195 Finished <<< grid_map_sdf [ 0.2
seconds ]

```

```
196 Finished <<< grid_map_cv [ 0.4
    seconds ]
197 Starting >>> grid_map_filters_rsl
198 Starting >>> grid_map_ros
199 Finished <<< ocs2_switched_model_msgs [ 0.5
    seconds ]
200 Finished <<< convex_plane_decomposition_msgs [ 0.5
    seconds ]
201 Finished <<< grid_map_filters_rsl [ 0.2
    seconds ]
202 Starting >>> convex_plane_decomposition
203 Finished <<< ocs2_core [ 0.5
    seconds ]
204 Starting >>> ocs2_frank_wolfe
205 Starting >>> ocs2_oc
206 Finished <<< grid_map_ros [ 0.5
    seconds ]
207 Starting >>> elevation_mapping_cupy
208 Starting >>> grid_map_filters
209 Starting >>> grid_map_loader
210 Starting >>> grid_map_pcl
211 Finished <<< pinocchio [ 2.9
    seconds ]
212 Starting >>> grid_map_rviz_plugin
213 Finished <<< ocs2_oc [ 0.2
    seconds ]
214 Finished <<< ocs2_frank_wolfe [ 0.2
    seconds ]
215 Starting >>> grid_map_visualization
216 Starting >>> ocs2_mpc
217 Finished <<< elevation_mapping_cupy [ 0.3
    seconds ]
218 Finished <<< convex_plane_decomposition [ 0.6
    seconds ]
219 Finished <<< grid_map_loader [ 0.2
    seconds ]
220 Finished <<< grid_map_rviz_plugin [ 0.4
    seconds ]
221 Starting >>> ocs2_qp_solver
222 Finished <<< grid_map_visualization [ 0.3
    seconds ]
223 Finished <<< ocs2_mpc [ 0.3
    seconds ]
224 Starting >>> ocs2_raisim_core
225 Finished <<< ocs2_qp_solver [ 0.3
    seconds ]
```



```
226 Finished <<< grid_map_filters [ 1.0
    seconds ]
227 Starting >>> grid_map_demos
228 Starting >>> hpipm_catkin
229 Starting >>> ocs2_ddp
230 Starting >>> ocs2_robotic_tools
231 Starting >>> ocs2_ros_interfaces
232 Finished <<< ocs2_raism_core [ 0.2
    seconds ]
233 Starting >>> ocs2_raism_ros
234 Finished <<< grid_map_pcl [ 1.2
    seconds ]
235 Starting >>> ocs2_slp
236 Finished <<< ocs2_ddp [ 0.2
    seconds ]
237 Starting >>> ocs2_ocs2
238 Finished <<< ocs2_robotic_tools [ 0.2
    seconds ]
239 Starting >>> ocs2_cartpole
240 Starting >>> ocs2_perceptive
241 Finished <<< hpipm_catkin [ 0.2
    seconds ]
242 Finished <<< ocs2_raism_ros [ 0.2
    seconds ]
243 Finished <<< grid_map_demos [ 0.6
    seconds ]
244 Finished <<< ocs2_slp [ 0.3
    seconds ]
245 Starting >>> grid_map
246 Finished <<< ocs2_ocs2 [ 0.2
    seconds ]
247 Starting >>> convex_plane_decomposition_ros
248 Starting >>> ocs2_ipm
249 Starting >>> ocs2_python_interface
250 Starting >>> ocs2_sqp
251 Finished <<< ocs2_ros_interfaces [ 0.7
    seconds ]
252 Starting >>> ocs2_switched_model_interface
253 Finished <<< ocs2_cartpole [ 0.3
    seconds ]
254 Starting >>> ocs2_cartpole_ros
255 Finished <<< grid_map [ 0.1
    seconds ]
256 Starting >>> ocs2_pinocchio_interface
257 Finished <<< ocs2_perceptive [ 0.3
    seconds ]
```

```
258 Finished <<< ocs2_sqp [ 0.2
    seconds ]
259 Finished <<< ocs2_ipm [ 0.3
    seconds ]
260 Finished <<< ocs2_python_interface [ 0.2
    seconds ]
261 Finished <<< convex_plane_decomposition_ros [ 1.0
    seconds ]
262 Starting >>> ocs2_double_integrator
263 Finished <<< ocs2_pinocchio_interface [ 0.4
    seconds ]
264 Starting >>> ocs2_quadrotor
265 Starting >>> ocs2_mpcnet_core
266 Starting >>> ocs2_ballbot
267 Starting >>> ocs2_centroidal_model
268 Finished <<< ocs2_cartpole_ros [ 0.7
    seconds ]
269 Starting >>> ocs2_self_collision
270 Starting >>> ocs2_sphere_approximation
271 Finished <<< ocs2_double_integrator [ 0.3
    seconds ]
272 Starting >>> ocs2_double_integrator_ros
273 Finished <<< ocs2_switched_model_interface [ 1.0
    seconds ]
274 Starting >>> ocs2_anymal_commands
275 Finished <<< ocs2_centroidal_model [ 0.2
    seconds ]
276 Starting >>> ocs2_anymal_models
277 Finished <<< ocs2_ballbot [ 0.3
    seconds ]
278 Starting >>> ocs2_ballbot_ros
279 Finished <<< ocs2_quadrotor [ 0.2
    seconds ]
280 Finished <<< ocs2_self_collision [ 0.2
    seconds ]
281 Finished <<< ocs2_sphere_approximation [ 0.3
    seconds ]
282 Finished <<< ocs2_mpcnet_core [ 0.7
    seconds ]
283 Finished <<< ocs2_double_integrator_ros [ 0.8
    seconds ]
284 Starting >>> ocs2_quadrotor_ros
285 Finished <<< ocs2_anymal_commands [ 1.0
    seconds ]
286 Starting >>> ocs2_legged_robot
287 Finished <<< ocs2_anymal_models [ 1.0
    seconds ]
```

```

288 Starting >>> ocs2_mobile_manipulator
289 Finished <<< ocs2_ballbot_ros [ 1.1
seconds ]
290 Starting >>> ocs2_ballbot_mpcnet
291 Starting >>> ocs2_self_collision_visualization
292 Starting >>> segmented_planes_terrain_model
293 Finished <<< ocs2_quadrotor_ros [ 0.7
seconds ]
294 Finished <<< ocs2_legged_robot [ 0.4
seconds ]
295 Starting >>> ocs2_legged_robot_ros
296 Finished <<< ocs2_mobile_manipulator [ 0.3
seconds ]
297 Finished <<< ocs2_ballbot_mpcnet [ 0.9
seconds ]
298 Finished <<< ocs2_self_collision_visualization [ 0.9
seconds ]
299 Starting >>> ocs2_pinocchio
300 Starting >>> ocs2_mobile_manipulator_ros
301 Finished <<< segmented_planes_terrain_model [ 1.2
seconds ]
302 Finished <<< ocs2_legged_robot_ros [ 0.9
seconds ]
303 Starting >>> ocs2_legged_robot_raisim
304 Starting >>> ocs2_quadrupe_interface
305 Finished <<< ocs2_pinocchio [ 0.2
seconds ]
306 Finished <<< ocs2_mobile_manipulator_ros [ 0.5
seconds ]
307 Finished <<< ocs2_legged_robot_raisim [ 0.7
seconds ]
308 Starting >>> ocs2_raisim
309 Starting >>> ocs2_legged_robot_mpcnet
310 Finished <<< ocs2_quadrupe_interface [ 0.9
seconds ]
311 Starting >>> ocs2_anymal_mpc
312 Starting >>> ocs2_quadrupe_loopshaping_interface
313 Finished <<< ocs2_raisim [ 0.1
seconds ]
314 Finished <<< ocs2_legged_robot_mpcnet [ 0.6
seconds ]
315 Starting >>> ocs2_mpcnet
316 Finished <<< ocs2_mpcnet [ 0.2
seconds ]
317 Finished <<< ocs2_quadrupe_loopshaping_interface [ 1.0
seconds ]

```

```

318 Finished <<< ocs2_anymal_mpc [ 1.0
    seconds ]
319 Starting >>> ocs2_anymal_loopshaping_mpc
320 Finished <<< ocs2_anymal_loopshaping_mpc [ 0.3
    seconds ]
321 Starting >>> ocs2_anymal
322 Finished <<< ocs2_anymal [ 0.1
    seconds ]
323 Starting >>> ocs2_robotic_examples
324 Finished <<< ocs2_robotic_examples [ 0.1
    seconds ]
325 Starting >>> ocs2
326 Starting >>> ocs2_doc
327 Finished <<< ocs2 [ 0.1
    seconds ]
328 Finished <<< ocs2_doc [ 1.5
    seconds ]
329 [build] Summary: All 82 packages succeeded!
330 [build] Ignored: None.
331 [build] Warnings: 1 packages succeeded with warnings.
332 [build] Abandoned: None.
333 [build] Failed: None.
334 [build] Runtime: 20.5 seconds total.

```

```

1 source devel/setup.bash
2 catkin run_tests ocs2
3 ==> Expanding alias 'run_tests' from 'catkin run_tests ocs2' to 'catkin test
    ocs2'
4 Starting >>> ocs2
5 Output << ocs2:results /home/kuanli/ocs2_ws/logs/ocs2/test.results.000.log
6 Summary: 0 tests, 0 errors, 0 failures, 0 skipped
7 cd /home/kuanli/ocs2_ws/build/ocs2; catkin test --get-env ocs2 | catkin env -
    si catkin_test_results; cd -
8
9 Finished <<< ocs2 [ 0.2 seconds ]
10 [test] Summary: All 1 packages succeeded!
11 [test] Ignored: None.
12 [test] Warnings: None.
13 [test] Abandoned: None.
14 [test] Failed: None.
15 [test] Runtime: 0.4 seconds total.

```

1.2.2 构建本文档

假设已安装 python catkin 工具，请运行以下命令：

```
1 # Navigate to the directory of ocs2_doc
2 # Do not forget to change <...> parts
3 cd <directory_to_ws>/<catkin_ws_name>/src/ocs2/ocs2_doc
4
5 # make build directory
6 mkdir -p build
7 # Navigate to the build folder
8 cd build
9
10 # build docs
11 cmake ..
12 make
```

这将生成文档并将其放在 **build/output/sphinx** 文件夹中。在浏览器中打开 **index.html**。

