# Run all cells

**Look for instructions below**

In [1]:

```
!apt-get install clang-9
!git clone https://github.com/RumblingTurtle/SrdPy.git
!pip install git+https://github.com/rdeits/meshcat-python.git@master
!pip install ./SrdPy
```

```
Reading package lists... Done
Building dependency tree
Reading state information... Done
The following package was automatically installed and is no longer required:
  libnvidia-common-460
Use 'apt autoremove' to remove it.
The following additional packages will be installed:
  binfmt-support libclang-common-9-dev libclang-cpp9 libclang1-9 libffi-dev
  libllvm9 libomp-9-dev libomp5-9 libpfm4 llvm-9 llvm-9-dev llvm-9-runtime
  llvm-9-tools python-chardet python-pkg-resources python-pygments python-yaml
  python3-pkg-resources python3-pygments python3-yaml
Suggested packages:
  clang-9-doc libomp-9-doc llvm-9-doc python-setuptools ttf-bitstream-vera
  python3-setuptools
The following NEW packages will be installed:
  binfmt-support clang-9 libclang-common-9-dev libclang-cpp9 libclang1-9
  libffi-dev libllvm9 libomp-9-dev libomp5-9 libpfm4 llvm-9 llvm-9-dev
  llvm-9-runtime llvm-9-tools python-chardet python-pkg-resources
  python-pygments python-yaml python3-pkg-resources python3-pygments
  python3-yaml
0 upgraded, 21 newly installed, 0 to remove and 34 not upgraded.
Need to get 85.9 MB of archives.
After this operation, 511 MB of additional disk space will be used.
Get:1 http://archive.ubuntu.com/ubuntu bionic/main amd64 python3-yaml amd64 3.12-1build2
[109 kB]
Get:2 http://archive.ubuntu.com/ubuntu bionic/main amd64 binfmt-support amd64 2.1.8-2 [51
.6 kB]
Get:3 http://archive.ubuntu.com/ubuntu bionic-updates/main amd64 libllvm9 amd64 1:9-2~ubu
ntu18.04.2 [14.8 MB]
Get:4 http://archive.ubuntu.com/ubuntu bionic-updates/universe amd64 libclang-cpp9 amd64
1:9-2~ubuntu18.04.2 [25.1 MB]
Get:5 http://archive.ubuntu.com/ubuntu bionic-updates/universe amd64 libclang-common-9-de
v amd64 1:9-2~ubuntu18.04.2 [3,861 kB]
Get:6 http://archive.ubuntu.com/ubuntu bionic-updates/universe amd64 libclang1-9 amd64 1:
9-2~ubuntu18.04.2 [6,701 kB]
Get:7 http://archive.ubuntu.com/ubuntu bionic-updates/universe amd64 clang-9 amd64 1:9-2~
ubuntu18.04.2 [1,109 kB]
Get:8 http://archive.ubuntu.com/ubuntu bionic-updates/universe amd64 libomp5-9 amd64 1:9-
2~ubuntu18.04.2 [299 kB]
Get:9 http://archive.ubuntu.com/ubuntu bionic-updates/universe amd64 libomp-9-dev amd64 1
:9-2~ubuntu18.04.2 [58.6 kB]
Get:10 http://archive.ubuntu.com/ubuntu bionic-updates/universe amd64 llvm-9-runtime amd6
4 1:9-2~ubuntu18.04.2 [176 kB]
Get:11 http://archive.ubuntu.com/ubuntu bionic/main amd64 libpfm4 amd64 4.9.0-2 [225 kB]
Get:12 http://archive.ubuntu.com/ubuntu bionic-updates/universe amd64 llvm-9 amd64 1:9-2~
ubuntu18.04.2 [4,874 kB]
Get:13 http://archive.ubuntu.com/ubuntu bionic/main amd64 libffi-dev amd64 3.2.1-8 [156 k
B]
Get:14 http://archive.ubuntu.com/ubuntu bionic-updates/main amd64 python-pygments all 2.2
.0+dfsg-1ubuntu0.2 [576 kB]
Get:15 http://archive.ubuntu.com/ubuntu bionic/main amd64 python-yaml amd64 3.12-1build2
[115 kB]
Get:16 http://archive.ubuntu.com/ubuntu bionic-updates/main amd64 python3-pygments all 2.
2.0+dfsg-1ubuntu0.2 [574 kB]
Get:17 http://archive.ubuntu.com/ubuntu bionic-updates/universe amd64 llvm-9-tools amd64
1:9-2~ubuntu18.04.2 [250 kB]
```

```
Get:18 http://archive.ubuntu.com/ubuntu bionic-updates/universe amd64 libllvm-9-dev amd64 1:
9-2~ubuntu18.04.2 [26.6 MB]
Get:19 http://archive.ubuntu.com/ubuntu bionic/main amd64 python-pkg-resources all 39.0.1
-2 [128 kB]
Get:20 http://archive.ubuntu.com/ubuntu bionic/main amd64 python-chardet all 3.0.4-1 [80.
3 kB]
Get:21 http://archive.ubuntu.com/ubuntu bionic/main amd64 python3-pkg-resources all 39.0.
1-2 [98.8 kB]
Fetched 85.9 MB in 5s (16.0 MB/s)
Selecting previously unselected package python3-yaml.
(Reading database ... 160706 files and directories currently installed.)
Preparing to unpack .../00-python3-yaml_3.12-1build2_amd64.deb ...
Unpacking python3-yaml (3.12-1build2) ...
Selecting previously unselected package binfmt-support.
Preparing to unpack .../01-binfmt-support_2.1.8-2_amd64.deb ...
Unpacking binfmt-support (2.1.8-2) ...
Selecting previously unselected package libllvm9:amd64.
Preparing to unpack .../02-libllvm9_1%3a9-2~ubuntu18.04.2_amd64.deb ...
Unpacking libllvm9:amd64 (1:9-2~ubuntu18.04.2) ...
Selecting previously unselected package libclang-cpp9.
Preparing to unpack .../03-libclang-cpp9_1%3a9-2~ubuntu18.04.2_amd64.deb ...
Unpacking libclang-cpp9 (1:9-2~ubuntu18.04.2) ...
Selecting previously unselected package libclang-common-9-dev.
Preparing to unpack .../04-libclang-common-9-dev_1%3a9-2~ubuntu18.04.2_amd64.deb ...
Unpacking libclang-common-9-dev (1:9-2~ubuntu18.04.2) ...
Selecting previously unselected package libclang1-9.
Preparing to unpack .../05-libclang1-9_1%3a9-2~ubuntu18.04.2_amd64.deb ...
Unpacking libclang1-9 (1:9-2~ubuntu18.04.2) ...
Selecting previously unselected package clang-9.
Preparing to unpack .../06-clang-9_1%3a9-2~ubuntu18.04.2_amd64.deb ...
Unpacking clang-9 (1:9-2~ubuntu18.04.2) ...
Selecting previously unselected package libomp5-9:amd64.
Preparing to unpack .../07-libomp5-9_1%3a9-2~ubuntu18.04.2_amd64.deb ...
Unpacking libomp5-9:amd64 (1:9-2~ubuntu18.04.2) ...
Selecting previously unselected package libomp-9-dev.
Preparing to unpack .../08-libomp-9-dev_1%3a9-2~ubuntu18.04.2_amd64.deb ...
Unpacking libomp-9-dev (1:9-2~ubuntu18.04.2) ...
Selecting previously unselected package llvm-9-runtime.
Preparing to unpack .../09-llvm-9-runtime_1%3a9-2~ubuntu18.04.2_amd64.deb ...
Unpacking llvm-9-runtime (1:9-2~ubuntu18.04.2) ...
Selecting previously unselected package libpfm4:amd64.
Preparing to unpack .../10-libpfm4_4.9.0-2_amd64.deb ...
Unpacking libpfm4:amd64 (4.9.0-2) ...
Selecting previously unselected package llvm-9.
Preparing to unpack .../11-llvm-9_1%3a9-2~ubuntu18.04.2_amd64.deb ...
Unpacking llvm-9 (1:9-2~ubuntu18.04.2) ...
Selecting previously unselected package libffi-dev:amd64.
Preparing to unpack .../12-libffi-dev_3.2.1-8_amd64.deb ...
Unpacking libffi-dev:amd64 (3.2.1-8) ...
Selecting previously unselected package python-pygments.
Preparing to unpack .../13-python-pygments_2.2.0+dfsg-1ubuntu0.2_all.deb ...
Unpacking python-pygments (2.2.0+dfsg-1ubuntu0.2) ...
Selecting previously unselected package python-yaml.
Preparing to unpack .../14-python-yaml_3.12-1build2_amd64.deb ...
Unpacking python-yaml (3.12-1build2) ...
Selecting previously unselected package python3-pygments.
Preparing to unpack .../15-python3-pygments_2.2.0+dfsg-1ubuntu0.2_all.deb ...
Unpacking python3-pygments (2.2.0+dfsg-1ubuntu0.2) ...
Selecting previously unselected package llvm-9-tools.
Preparing to unpack .../16-llvm-9-tools_1%3a9-2~ubuntu18.04.2_amd64.deb ...
Unpacking llvm-9-tools (1:9-2~ubuntu18.04.2) ...
Selecting previously unselected package llvm-9-dev.
Preparing to unpack .../17-llvm-9-dev_1%3a9-2~ubuntu18.04.2_amd64.deb ...
Unpacking llvm-9-dev (1:9-2~ubuntu18.04.2) ...
Selecting previously unselected package python-pkg-resources.
Preparing to unpack .../18-python-pkg-resources_39.0.1-2_all.deb ...
Unpacking python-pkg-resources (39.0.1-2) ...
Selecting previously unselected package python-chardet.
Preparing to unpack .../19-python-chardet_3.0.4-1_all.deb ...
Unpacking python-chardet (3.0.4-1) ...
Selecting previously unselected package python3-pkg-resources.
Preparing to unpack .../20-python3-pkg-resources_39.0.1-2_all.deb ...
Unpacking python3-pkg-resources (39.0.1-2) ...
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Unpacking python3-pkg-resources (39.0.1-2) ...
Setting up python3-yaml (3.12-1build2) ...
Setting up binfmt-support (2.1.8-2) ...
Created symlink /etc/systemd/system/multi-user.target.wants/binfmt-support.service → /lib
/systemd/system/binfmt-support.service.
invoke-rc.d: could not determine current runlevel
invoke-rc.d: policy-rc.d denied execution of start.
Setting up python-yaml (3.12-1build2) ...
Setting up libffi-dev:amd64 (3.2.1-8) ...
Setting up python3-pkg-resources (39.0.1-2) ...
Setting up python-pkg-resources (39.0.1-2) ...
Setting up libomp5-9:amd64 (1:9-2~ubuntu18.04.2) ...
Setting up libpfm4:amd64 (4.9.0-2) ...
Setting up python-pygments (2.2.0+dfsg-1ubuntu0.2) ...
Setting up libllvm9:amd64 (1:9-2~ubuntu18.04.2) ...
Setting up libomp-9-dev (1:9-2~ubuntu18.04.2) ...
Setting up python3-pygments (2.2.0+dfsg-1ubuntu0.2) ...
Setting up libclang-common-9-dev (1:9-2~ubuntu18.04.2) ...
Setting up python-chardet (3.0.4-1) ...
Setting up libclang1-9 (1:9-2~ubuntu18.04.2) ...
Setting up libclang-cpp9 (1:9-2~ubuntu18.04.2) ...
Setting up llvm-9-runtime (1:9-2~ubuntu18.04.2) ...
Setting up llvm-9-tools (1:9-2~ubuntu18.04.2) ...
Setting up clang-9 (1:9-2~ubuntu18.04.2) ...
Setting up llvm-9 (1:9-2~ubuntu18.04.2) ...
Setting up llvm-9-dev (1:9-2~ubuntu18.04.2) ...
Processing triggers for systemd (237-3ubuntu10.47) ...
Processing triggers for man-db (2.8.3-2ubuntu0.1) ...
Processing triggers for libc-bin (2.27-3ubuntu1.2) ...
/sbin/ldconfig.real: /usr/local/lib/python3.7/dist-packages/ideep4py/lib/libmkldnn.so.0 i
s not a symbolic link

Cloning into 'SrdPy'...
remote: Enumerating objects: 1067, done.
remote: Counting objects: 100% (1067/1067), done.
remote: Compressing objects: 100% (509/509), done.
remote: Total 1067 (delta 587), reused 994 (delta 531), pack-reused 0
Receiving objects: 100% (1067/1067), 20.34 MiB | 21.28 MiB/s, done.
Resolving deltas: 100% (587/587), done.
Collecting git+https://github.com/rdeits/meshcat-python.git@master
  Cloning https://github.com/rdeits/meshcat-python.git (to revision master) to /tmp/pip-r
eq-build-hiwkuwnh
  Running command git clone -q https://github.com/rdeits/meshcat-python.git /tmp/pip-req-
build-hiwkuwnh
  Running command git submodule update --init --recursive -q
Requirement already satisfied: ipython>=5 in /usr/local/lib/python3.7/dist-packages (from
meshcat==0.1.1) (5.5.0)
Collecting u-msgpack-python>=2.4.1
  Downloading https://files.pythonhosted.org/packages/a3/54/0400a3a22ff133633d343371821bf
81010455fa3a981a93d7ff3e27a554e/u_msgpack_python-2.7.1-py2.py3-none-any.whl
Requirement already satisfied: numpy>=1.14.0 in /usr/local/lib/python3.7/dist-packages (f
rom meshcat==0.1.1) (1.19.5)
Requirement already satisfied: tornado>=4.0.0 in /usr/local/lib/python3.7/dist-packages (
from meshcat==0.1.1) (5.1.1)
Requirement already satisfied: pyzmq>=17.0.0 in /usr/local/lib/python3.7/dist-packages (f
rom meshcat==0.1.1) (22.0.3)
Collecting pyngrok>=4.1.6
  Downloading https://files.pythonhosted.org/packages/6b/4e/a2fe095bbe17cf26424c4abcd22a0
490e22d01cc628f25af5e220ddbf6f0/pyngrok-5.0.5.tar.gz (745kB)
     |████████████████████████████████| 747kB 7.8MB/s
Requirement already satisfied: simplegeneric>0.8 in /usr/local/lib/python3.7/dist-package
s (from ipython>=5->meshcat==0.1.1) (0.8.1)
Requirement already satisfied: setuptools>=18.5 in /usr/local/lib/python3.7/dist-packages
(from ipython>=5->meshcat==0.1.1) (56.1.0)
Requirement already satisfied: traitlets>=4.2 in /usr/local/lib/python3.7/dist-packages (
from ipython>=5->meshcat==0.1.1) (5.0.5)
Requirement already satisfied: pygments in /usr/local/lib/python3.7/dist-packages (from i
python>=5->meshcat==0.1.1) (2.6.1)
Requirement already satisfied: pexpect; sys_platform != "win32" in /usr/local/lib/python3
.7/dist-packages (from ipython>=5->meshcat==0.1.1) (4.8.0)
Requirement already satisfied: decorator in /usr/local/lib/python3.7/dist-packages (from
ipython>=5->meshcat==0.1.1) (4.4.2)
Requirement already satisfied: pickleshare in /usr/local/lib/python3.7/dist-packages (fro
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Requirement already satisfied: picklesnare in /usr/local/lib/python3.7/dist-packages (fro
m ipython>=5->meshcat==0.1.1) (0.7.5)
Requirement already satisfied: prompt-toolkit<2.0.0,>=1.0.4 in /usr/local/lib/python3.7/d
ist-packages (from ipython>=5->meshcat==0.1.1) (1.0.18)
Requirement already satisfied: PyYAML in /usr/local/lib/python3.7/dist-packages (from pyn
grok>=4.1.6->meshcat==0.1.1) (3.13)
Requirement already satisfied: ipython-genutils in /usr/local/lib/python3.7/dist-packages
(from traitlets>=4.2->ipython>=5->meshcat==0.1.1) (0.2.0)
Requirement already satisfied: ptyprocess>=0.5 in /usr/local/lib/python3.7/dist-packages
(from pexpect; sys_platform != "win32"->ipython>=5->meshcat==0.1.1) (0.7.0)
Requirement already satisfied: six>=1.9.0 in /usr/local/lib/python3.7/dist-packages (from
prompt-toolkit<2.0.0,>=1.0.4->ipython>=5->meshcat==0.1.1) (1.15.0)
Requirement already satisfied: wcwidth in /usr/local/lib/python3.7/dist-packages (from pr
ompt-toolkit<2.0.0,>=1.0.4->ipython>=5->meshcat==0.1.1) (0.2.5)
Building wheels for collected packages: meshcat, pyngrok
  Building wheel for meshcat (setup.py) ... done
  Created wheel for meshcat: filename=meshcat-0.1.1-cp37-none-any.whl size=627107 sha256=
3a6e3d8154006a48fd6f6b411fee0b9b7621a82d62c7fe254744f2fc9e795f14
  Stored in directory: /tmp/pip-ephem-wheel-cache-87sbtvdd/wheels/c2/57/90/f09f46ded98f6e
a0f4dd05029529fe8d24d936a520786a60e0
  Building wheel for pyngrok (setup.py) ... done
  Created wheel for pyngrok: filename=pyngrok-5.0.5-cp37-none-any.whl size=19246 sha256=d
bc52f134072b9af2e6440ff3e87507d284f52ddf1c82e1b8a71bae3df3cca4f
  Stored in directory: /root/.cache/pip/wheels/0c/13/64/5ebbcc22eaf53fdf5766b397c1fb17c83
f5775fdccf0ea1b88
Successfully built meshcat pyngrok
Installing collected packages: u-msgpack-python, pyngrok, meshcat
Successfully installed meshcat-0.1.1 pyngrok-5.0.5 u-msgpack-python-2.7.1
Processing ./SrdPy
Requirement already satisfied: numpy in /usr/local/lib/python3.7/dist-packages (from SrdP
y==0.1) (1.19.5)
Collecting casadi
  Downloading https://files.pythonhosted.org/packages/d7/41/abb53746924c0669cc597d18d9fa7
7c51682f225222d130fec8217fbd256/casadi-3.5.5-cp37-none-manylinux1_x86_64.whl (34.2MB)
     |████████████████████████████████| 34.3MB 115kB/s
Collecting control
  Downloading https://files.pythonhosted.org/packages/88/87/ee6cb7cdcf4efe5634231bd688b30
7773629a100ec4c83b0c3eb03edd39d/control-0.9.0.tar.gz (339kB)
     |████████████████████████████████| 348kB 42.8MB/s
Collecting slycot
  Downloading https://files.pythonhosted.org/packages/85/21/4e7110462f3529b2fbcff8a519b61
bf64e0604b8fcbe9a07649c9bed9d7a/slycot-0.4.0.0.tar.gz (1.5MB)
     |████████████████████████████████| 1.6MB 31.5MB/s
  Installing build dependencies ... done
  Getting requirements to build wheel ... done
    Preparing wheel metadata ... done
Collecting urdf-parser-py
  Downloading https://files.pythonhosted.org/packages/96/08/76bc3f7fc9a0345d45527c0054fbe
c8479d74649d6accb5c1ec174e5098c/urdf_parser_py-0.0.3.tar.gz
Requirement already satisfied: pyngrok in /usr/local/lib/python3.7/dist-packages (from Sr
dPy==0.1) (5.0.5)
Collecting qpsolvers
  Downloading https://files.pythonhosted.org/packages/d2/84/4775a9d3497fed47d77a1996baee4
09c8f67b670a00b75ac375036875168/qpsolvers-1.6.1-py3-none-any.whl
Collecting pybullet
  Downloading https://files.pythonhosted.org/packages/73/6d/60b97ffc579db665bdd87f2cb47fe
1215ae770fbbc1add84ebf36ddca63b/pybullet-3.1.7.tar.gz (79.0MB)
     |████████████████████████████████| 79.0MB 48kB/s
Requirement already satisfied: scipy in /usr/local/lib/python3.7/dist-packages (from cont
rol->SrdPy==0.1) (1.4.1)
Requirement already satisfied: matplotlib in /usr/local/lib/python3.7/dist-packages (from
control->SrdPy==0.1) (3.2.2)
Requirement already satisfied: pyyaml in /usr/local/lib/python3.7/dist-packages (from urd
f-parser-py->SrdPy==0.1) (3.13)
Requirement already satisfied: lxml in /usr/local/lib/python3.7/dist-packages (from urdf-
parser-py->SrdPy==0.1) (4.2.6)
Collecting quadprog>=0.1.8
  Downloading https://files.pythonhosted.org/packages/31/c7/833d7b5b53fff5b9042803aa80962
07d8e038ca42052f074d4ad8cddbfc5/quadprog-0.1.8.tar.gz (269kB)
     |████████████████████████████████| 276kB 36.4MB/s
Requirement already satisfied: cycler>=0.10 in /usr/local/lib/python3.7/dist-packages (fr
om matplotlib->control->SrdPy==0.1) (0.10.0)
Requirement already satisfied: kiwisolver>=1.0.1 in /usr/local/lib/python3.7/dist-package
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Requirement already satisfied: kiwisolver>=1.0.1 in /usr/local/lib/python3.7/dist-package
s (from matplotlib->control->SrdPy==0.1) (1.3.1)
Requirement already satisfied: pyparsing!=2.0.4,!=2.1.2,!=2.1.6,>=2.0.1 in /usr/local/lib
/python3.7/dist-packages (from matplotlib->control->SrdPy==0.1) (2.4.7)
Requirement already satisfied: python-dateutil>=2.1 in /usr/local/lib/python3.7/dist-pack
ages (from matplotlib->control->SrdPy==0.1) (2.8.1)
Requirement already satisfied: Cython in /usr/local/lib/python3.7/dist-packages (from qua
dprog>=0.1.8->qpsolvers->SrdPy==0.1) (0.29.23)
Requirement already satisfied: six in /usr/local/lib/python3.7/dist-packages (from cycler
>=0.10->matplotlib->control->SrdPy==0.1) (1.15.0)
Building wheels for collected packages: slycot
  Building wheel for slycot (PEP 517) ... done
  Created wheel for slycot: filename=slycot-0.4.0-cp37-cp37m-linux_x86_64.whl size=141783
3 sha256=e69401fb8318d913a69cc4168b46392e60e0a9c7de331a978273ec28d1d1580b
  Stored in directory: /root/.cache/pip/wheels/a2/46/56/f82cbb2fd06556f4f3952a2eb2396e8fd
29264fffecbaad3cf
Successfully built slycot
Building wheels for collected packages: SrdPy, control, urdf-parser-py, pybullet, quadpro
g
  Building wheel for SrdPy (setup.py) ... done
  Created wheel for SrdPy: filename=SrdPy-0.1-cp37-none-any.whl size=65602 sha256=8a51399
536cc1e43edaca62919a4304589b76d5fbe32e1ec8321b7aeec182ca7
  Stored in directory: /tmp/pip-ephem-wheel-cache-6utzwg6e/wheels/f8/a7/cf/bd93c0f0858d9b
8af946b5a7d08f2ee154ff8598b8672efd36
  Building wheel for control (setup.py) ... done
  Created wheel for control: filename=control-0.9.0-py2.py3-none-any.whl size=344920 sha2
56=2de4ea89f4c1bfa3f3193d9c2e3c3c186ef412ac892b588d923d0226398df161
  Stored in directory: /root/.cache/pip/wheels/35/be/ee/081b68ca3e4b2d253fba2f7f7e5196037
3903fb7b6d13c5532
  Building wheel for urdf-parser-py (setup.py) ... done
  Created wheel for urdf-parser-py: filename=urdf_parser_py-0.0.3-cp37-none-any.whl size=
13122 sha256=392848264e977b4259c4698510be938b588ce174d1019aae999343d70a62c66f
  Stored in directory: /root/.cache/pip/wheels/61/30/cb/440cedefdba99ee2fa968bbf5bfcadc33
e7433239b34b8fa88
  Building wheel for pybullet (setup.py) ... done
  Created wheel for pybullet: filename=pybullet-3.1.7-cp37-cp37m-linux_x86_64.whl size=89
750795 sha256=e1beacfeb3a4f21cb513d9f30dbf1aeafc14f90126334164efcf16c7c5191007
  Stored in directory: /root/.cache/pip/wheels/30/56/e6/fce8276a2f30165f7ac31089bb72f390f
a16b87328651e1a5a
  Building wheel for quadprog (setup.py) ... done
  Created wheel for quadprog: filename=quadprog-0.1.8-cp37-cp37m-linux_x86_64.whl size=33
6639 sha256=b939fb22cc397ac7e084950757a65210119f3f79d70e1b5cb2c05bb48affd2e5
  Stored in directory: /root/.cache/pip/wheels/0c/39/5f/c712b0e462439dec9b30080cf34622f16
7929b39bd964d8baf
Successfully built SrdPy control urdf-parser-py pybullet quadprog
Installing collected packages: casadi, control, slycot, urdf-parser-py, quadprog, qpsolve
rs, pybullet, SrdPy
Successfully installed SrdPy-0.1 casadi-3.5.5 control-0.9.0 pybullet-3.1.7 qpsolvers-1.6.
1 quadprog-0.1.8 slycot-0.4.0 urdf-parser-py-0.0.3
```

In [2]:

```
from SrdPy.URDFUtils import getLinkArrayFromURDF

from SrdPy.TableGenerators import generateConstraiedLinearModelTable
from SrdPy.TableGenerators import generateLinearModelTable
from SrdPy.LinksAndJoints import *
from SrdPy.Handlers import *
from SrdPy.InverseKinematics import *
from SrdPy.SymbolicUtils import *
from SrdPy.Loggers import *
from SrdPy.DynamicSolvers import *
from SrdPy.Controllers import *

from SrdPy.Visuals import Visualizer
from SrdPy import SymbolicEngine
from SrdPy import plotGeneric
from copy import deepcopy
from casadi import *

from SrdPy.TableGenerators import *
from SrdPy import Chain
```

```
from SrdPy import Profiler
import numpy as np
from scipy.integrate import solve_ivp
import os
```

In [3]:

```
p = Profiler()
iiwaLinks = getLinkArrayFromURDF(os.path.abspath("./SrdPy/examples/iiwa/iiwa14.urdf"),Tru
e)
iiwaChain = Chain(iiwaLinks)


print(iiwaChain)
initialPosition = np.array([0.1701584,  -0.07586424,  0.42323069, -0.41380217,  0.011959
43,  0.07095069,
  0.])
blank_chain = deepcopy(iiwaChain)
blank_chain.update(initialPosition)

engine = SymbolicEngine(iiwaChain.linkArray)

deriveJacobiansForlinkArray(engine)
H = deriveJSIM(engine)

iN, dH = deriveGeneralizedInertialForces_dH(engine, H)
g = deriveGeneralizedGravitationalForces(engine)
d = deriveGeneralizedDissipativeForcesUniform(engine, 1)
T = deriveControlMap(engine)


description_gen_coord_model = generateDynamicsGeneralizedCoordinatesModel(engine,
                                                                           H=H,
                                                                           c=(iN + g + d
),
                                                                           T=T,
                                                                           functionName_
H="g_dynamics_H",
                                                                           functionName_
c="g_dynamics_c",
                                                                           functionName_
T="g_dynamics_T",
                                                                           casadi_cCodeF
ilename="g_dynamics_generalized_coordinates",
                                                                           path="./iiwa/
Dynamics")

handlerGeneralizedCoordinatesModel = GeneralizedCoordinatesModelHandler(description_gen_c
oord_model)

description_linearization = generateDynamicsLinearization(engine,
                                                           H=H,
                                                           c=(iN + g + d),
                                                           T=T,
                                                           functionName_A="g_linearizati
on_A",
                                                           functionName_B="g_linearizati
on_B",
                                                           functionName_c="g_linearizati
on_c",
                                                           casadi_cCodeFilename="g_dynam
ics_linearization",
                                                           path="./iiwa/Linearization")

handlerLinearizedModel = LinearizedModelHandler(description_linearization)

constraint6 = engine.links["iiwa_link_6"].absoluteFollower[0]

task = constraint6[:2]
print("task size is: ", task.size)
```

```
description_IK = generateSecondDerivativeJacobians(engine,
                                                   task=task,
                                                   functionName_Task="g_InverseKinematics_
Task",
                                                   functionName_TaskJacobian="g_InverseKine
matics_TaskJacobian",
                                                   functionName_TaskJacobianDerivative="g_I
nverseKinematics_TaskJacobian_derivative",
                                                   casadi_cCodeFilename="g_InverseKinematic
s",
                                                   path="./iiwa/InverseKinematics")

ikModelHandler = IKModelHandler(description_IK, engine.dof, task.shape[0])
```

```
Unknown tag: material
Unknown tag: self_collision_checking
Unknown tag: material
Unknown tag: material
Unknown tag: material
Unknown tag: material
Unknown tag: material
Unknown tag: material
Unknown tag: material
Unknown tag: hardwareInterface
Unknown tag: hardwareInterface
Unknown tag: hardwareInterface
Unknown tag: hardwareInterface
Unknown tag: hardwareInterface
Unknown tag: hardwareInterface
Unknown tag: hardwareInterface
```

```
Parsing URDF:/content/SrdPy/examples/iiwa/iiwa14.urdf
Root node: base
Chain
Links:
0. Ground
1. iiwa_link_0
2. iiwa_link_1
3. iiwa_link_2
4. iiwa_link_3
5. iiwa_link_4
6. iiwa_link_5
7. iiwa_link_6
8. iiwa_link_7

Starting writing function for the g_dynamics_H
Starting writing function for the g_dynamics_c
Starting writing function for the g_dynamics_T
Running gcc
Generated C code!
Starting writing function for the g_linearization_A
Starting writing function for the g_linearization_B
Running gcc
Generated C code!
task size is:  2
Starting writing function for the g_InverseKinematics_Task
Starting writing function for the g_InverseKinematics_Task task jacobian
Starting writing function for the derivative of g_InverseKinematics_Task
Generated C code!
```

In [4]:

```
IC_task = ikModelHandler.getTask(initialPosition)

task_1 = np.array([[0.1],  [0.3]])
# task_2 = np.array([[0.3],  [0.3]])
# task_3 = np.array([[0.3],  [0.1]])

# zeroOrderDerivativeNodes = np.hstack((IC_task, task_1, task_2, task_3))
zeroOrderDerivativeNodes = np.hstack((IC_task, task_1))
```

```
firstOrderDerivativeNodes = np.zeros(zeroOrderDerivativeNodes.shape)

secondOrderDerivativeNodes = np.zeros(zeroOrderDerivativeNodes.shape)

timeOfOneStage = 2
timeEnd = (len(zeroOrderDerivativeNodes[1]) - 1) * timeOfOneStage + 1
nodeTimes = np.arange(start=0, stop=timeEnd, step=timeOfOneStage)

handlerIK_taskSplines = IKtaskSplinesHandler(nodeTimes,
                                             zeroOrderDerivativeNodes,
                                             firstOrderDerivativeNodes,
                                             secondOrderDerivativeNodes)

timeTable = np.arange(handlerIK_taskSplines.timeStart, handlerIK_taskSplines.timeExpirat
ion + 0.01, 0.01)

IKTable = generateIKTable(ikModelHandler, handlerIK_taskSplines, initialPosition, timeTa
ble, method="lsqnonlin")
plotIKTable(ikModelHandler, timeTable, IKTable)

ikSolutionHandler = IKSolutionHandler(ikModelHandler, handlerIK_taskSplines, timeTable,
IKTable, "linear")

tf = ikSolutionHandler.timeExpiration

n = handlerGeneralizedCoordinatesModel.dofConfigurationSpaceRobot

A_table, B_table, c_table, x_table, u_table, dx_table = generateLinearModelTable(handler
GeneralizedCoordinatesModel,handlerLinearizedModel,ikSolutionHandler,timeTable)
```

```
Calculating  0.0%
Calculating  0.0%
Calculating  1.0%
Calculating  2.0%
Calculating  3.0%
Calculating  4.0%
Calculating  5.0%
Calculating  6.0%
Calculating  7.0%
Calculating  8.0%
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```

```
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Calculating  95.0%
Calculating  96.0%
Calculating  97.0%
Calculating  98.0%
Calculating  99.0%
```
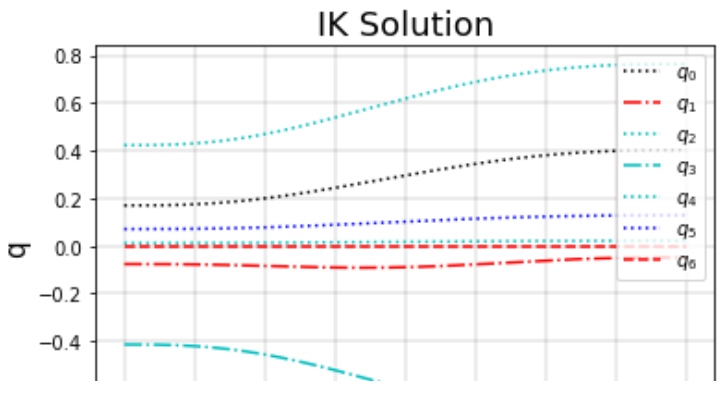
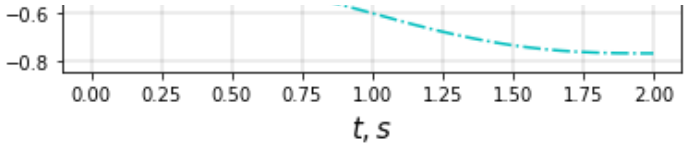
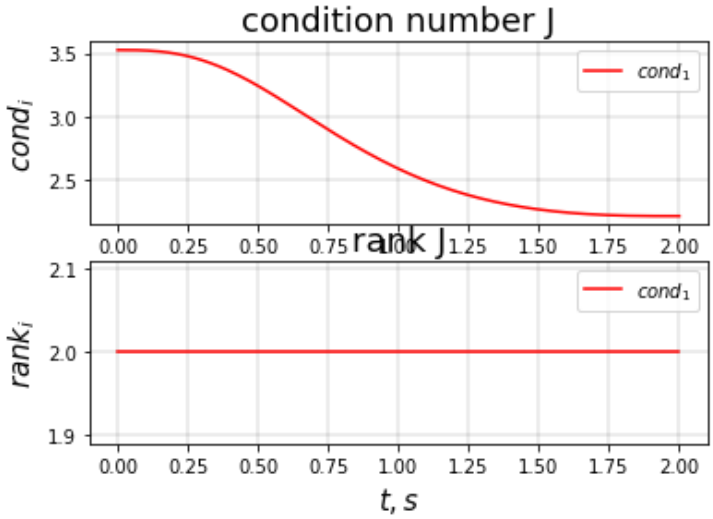






# Task

1. **Implement control, but state observer (x can't be used by the controller, but $y = Cx$ can be)**
2. **Simulate the system with the observer and the controller**
3. **Simulate from different initial positions**

## To solve this task we start by deriving the required equation:

**Initially we have been given the system:**

$$\begin{cases} \dot{x} = Ax + Bu + c, \quad (1) \\ \dot{\hat{x}} = A\hat{x} + Bu + L(y - C\hat{x}) + c, \quad (2) \\ y = Cx, \quad (3) \\ u = -K(\hat{x} - x^*(t)) + u^*(t). \quad (4) \end{cases}$$

**\ To find the designated values, substituting eqn(3) into eqn(2), and eqn(4) into eqn(1) and eqn(2):**

$$\begin{cases} \dot{x} = Ax - BK(\hat{x} - x^*(t)) + u^*(t) + c, \quad (5) \\ \dot{\hat{x}} = A\hat{x} - BK(\hat{x} - x^*(t)) + u^*(t) + L(Cx - C\hat{x}) + c \quad . \quad (6) \end{cases}$$

**\ Let us assume $e = x - \hat{x}$, $\hat{x} = x - e$ and therefore we get $\dot{e} = \dot{x} - \dot{\hat{x}}$.**

****

1. **Substituting $\hat{x} = x - e$ into eqn $(5)$:**

$$\dot{x} = Ax - BK(x - e - x^*(t))$$

$$+u^*(t)+c$$
$$\dot{x}=Ax-BKx$$
$$+BKe+BKx^*(t)$$
$$+u^*(t)+c$$
$$\dot{x}=(A-BK)x$$
$$+BKe+BKx^*(t)$$
$$+u^*(t)+c$$

\

1. **Subtracting eqn$(6)$ from eqn$(5)$:**

$$\dot{x}-\dot{\hat{x}}=A(x-\hat{x})$$
$$-BK(\hat{x}-x^*(t))$$
$$+u^*(t)+c$$
$$+BK(\hat{x}-x^*(t))$$
$$-u^*(t)-L(Cx$$
$$-C\hat{x})-c$$

$$\dot{e}=Ae-LC(x$$
$$-\hat{x})$$
$$\dot{e}=Ae-LCe$$
$$\dot{e}=(A-LC)e$$

**\ After this following arithmetics, the simplified final system looks like this:**

$$\begin{cases}\dot{x}=(A-BK)x\\+BKe+BKx^*(t)\\+u^*(t)+c,\\\dot{e}=(A-LC)e.\end{cases}$$

**\ Rewriting in the matrix form:**

$$\begin{bmatrix}\dot{x}\\\dot{e}\end{bmatrix}=\begin{bmatrix}A-BK & BK\\0 & A-LC\end{bmatrix}\begin{bmatrix}x\\e\end{bmatrix}+\begin{bmatrix}BKx^*(t)+u^*(t)\\+c\\0\end{bmatrix}$$

In [5]:

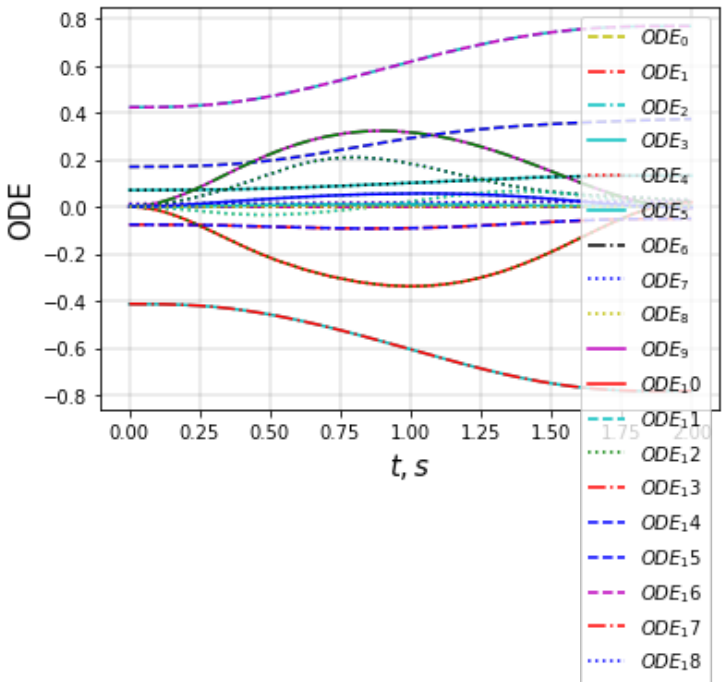
```
from control import lqr


# a function for generating the K table
def my_generateLQRTable_K(A_table, B_table, Q_table, R_table):
    count = A_table.shape[0]
    n = A_table.shape[2]
    m = B_table.shape[2]

    K_table = np.zeros((count,m,n))
```

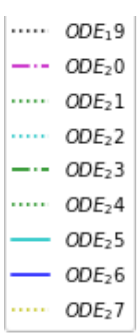
```
    for i in range(count):
        K, S, CLP =  lqr(A_table[i], B_table[i], Q_table[i], R_table[i])
        K_table[i] = K

    return K_table


# a function for calculating the L_table using LQR
def my_generateLQRTable_L(A_table, C_table, Q_table, R_table):
    count = A_table.shape[0]
    n = A_table.shape[2]
    m = C.shape[0]

    L_table = np.zeros((count,n,m))

    for i in range(count):
        L_t, S, CLP =  lqr(np.transpose(A_table[i]), np.transpose(C_table[i]), Q_table[i
], R_table[i])
        L_table[i] = np.transpose(L_t)

    return L_table

# I created a new function i.e my own generateCloseLoopTable function using the observer
to control the trajectory
# this will help us to understand the change caused by changing any of the given paramete
rs and observe the trajectory
def my_generateCloseLoopTable(A_table, B_table, c_table, C_table, K_table, L_table, x_ta
ble, u_table):
    count = A_table.shape[0]
    n = A_table.shape[1]

    AA_table = np.zeros((count,n*2, n*2))
    cc_table = np.zeros((count,n*2))

    for i in range(count):

        # here we calculate the matrices
        AA_table[i] = np.block([[A_table[i], -B_table[i]@K_table[i]  ],[L_table[i]@C_tab
le[i], A_table[i] - B_table[i]@K_table[i] - L_table[i]@C_table[i] ]])


        row_cc = B_table[i] @ (K_table[i] @ x_table[i] + u_table[i]) + c_table[i]

        cc_table[i] = np.block([row_cc, row_cc])

    return AA_table, cc_table


# a function to return the AA_table and cc_table for the ODE that represents the observat
ion error
def error_system(A_table, L_table, C_table):
  count = A_table.shape[0]
  n = A_table.shape[1]
  m = A_table.shape[2]

  AA_table = np.zeros((count,n,m))
  cc_table = np.zeros((count,n))

  for i in range(count):
    AA_table[i] = A_table[i] - L_table[i]@ C_table[i]

  return AA_table, cc_table
```

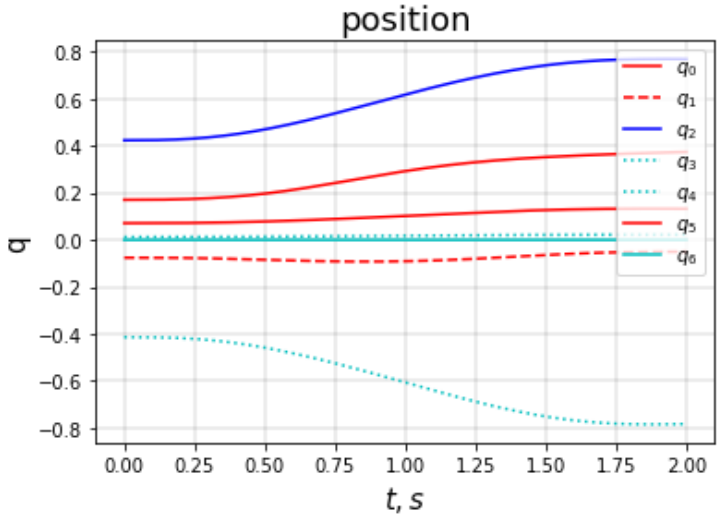
In [9]:

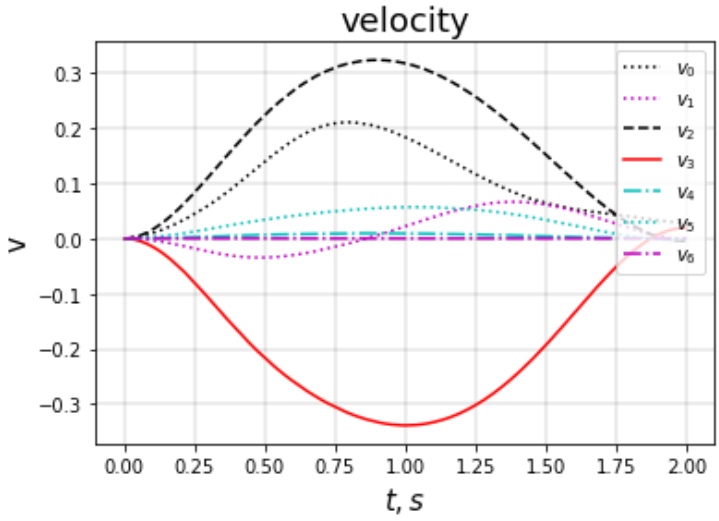
```
C = np.concatenate((np.eye(n), np.zeros((n, n))), axis=1) #y = C*x

Q = 10*np.eye(2 * n)
R = 0.1*np.eye(handlerGeneralizedCoordinatesModel.dofControl)
count = A_table.shape[0]
```

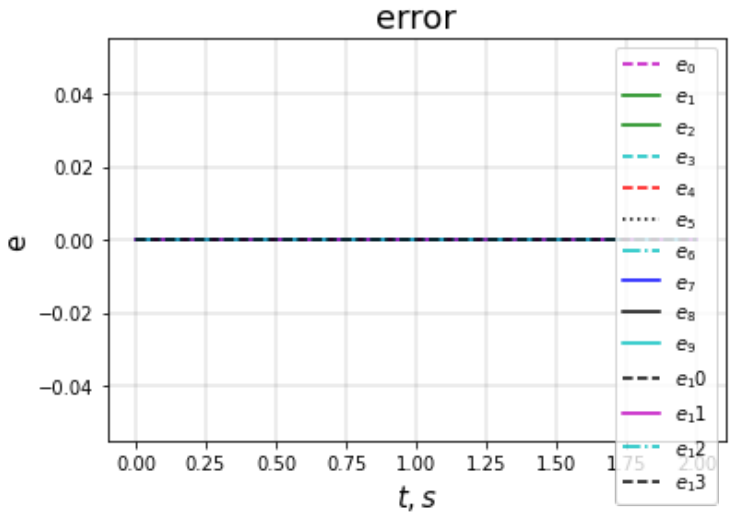
```
#Controller gains
K_table = my_generateLQRTable_K(A_table, B_table, np.tile(Q, [count,1, 1]), np.tile(R, [
count, 1, 1]))
# Find the matrix L
L_table = my_generateLQRTable_L(A_table, np.tile(C, [count,1, 1]), np.tile(Q, [count,1,
1]), np.tile(R, [ count, 1, 1]))

# Closed-loop using the observer
AA_table, cc_table = my_generateCloseLoopTable(A_table, B_table, c_table, np.tile(C, [co
unt,1, 1]) , K_table, L_table, x_table, u_table)


#Initial positions
x0 = np.hstack((np.hstack((initialPosition, np.zeros(initialPosition.shape[0]))),np.hsta
ck((initialPosition, np.zeros(initialPosition.shape[0])))))

#Simulation
ode_fnc_handle = ClosedLoopLinearSystemOdeFunctionHandler(AA_table, cc_table, timeTable)
sol = solve_ivp(ode_fnc_handle, [0, tf], x0) #, t_eval=timeTable,method="RK45")

# plot graphs
time_table_0 = sol.t
solution_tape = sol.y.T
ax = plotGeneric(time_table_0,solution_tape,figureTitle="",ylabel="ODE")
ax = plotGeneric(time_table_0,solution_tape[:,:n],figureTitle="position",ylabel="q", plo
t=True)
ax = plotGeneric(time_table_0,solution_tape[:,n:2*n],figureTitle="velocity",ylabel="v",
plot=True)



# Calculating error
# from here onwards we start to calculate the error



# Find the ODE for the error
error_AA_table, error_cc_table = error_system(A_table,L_table, np.tile(C, [count,1, 1]))

# Error simulation
e0 = np.zeros((n*2))
error_fnc_handle = ClosedLoopLinearSystemOdeFunctionHandler(error_AA_table, error_cc_tabl
e, timeTable)
error = solve_ivp(error_fnc_handle, [0, tf], e0)
error_tape = error.y.T

ax = plotGeneric(error.t,error_tape,figureTitle="error",ylabel="e", plot=True)
```





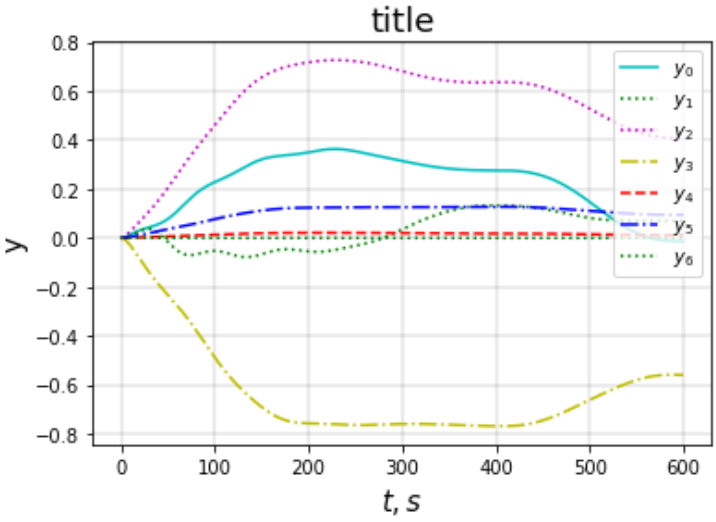

# Animations

In [10]:

```
chainLinks = getLinkArrayFromURDF(os.path.abspath("./SrdPy/examples/iiwa/iiwa14.urdf"),T
rue)
chain = Chain(chainLinks)

print(chain)
blank_chain = deepcopy(chain)
blank_chain.update(initialPosition)
with open('anim_array.npy', 'rb') as f:
    q = np.load(f)

blank_chain.update(q[0])
plotGeneric(np.arange(q.shape[0]),q,plot=True)
vis = Visualizer()
vis.animate(blank_chain,q,framerate=0.1,showMeshes=True)
```

```
Unknown tag: material
Unknown tag: self_collision_checking
Unknown tag: material
Unknown tag: material
Unknown tag: material
Unknown tag: material
Unknown tag: material
Unknown tag: material
Unknown tag: material
Unknown tag: hardwareInterface
Unknown tag: hardwareInterface
Unknown tag: hardwareInterface
Unknown tag: hardwareInterface
Unknown tag: hardwareInterface
Unknown tag: hardwareInterface
Unknown tag: hardwareInterface
```

```
Parsing URDF:/content/SrdPy/examples/iiwa/iiwa14.urdf
Root node: base
Chain
Links:
0. Ground
1. iiwa_link_0
2. iiwa_link_1
3. iiwa_link_2
4. iiwa_link_3
5. iiwa_link_4
6. iiwa_link_5
7. iiwa_link_6
8. iiwa_link_7
```




```
You can open the visualizer by visiting the following URL:
http://cf62da1a0082.ngrok.io/static/
No mesh: Ground
```

**Click the link above to see animation ^^^**

**Do not forget to add the "anim_array.npy" file to check out the animations else it will show some error**

**Do not forget to add the "anim_array.npy" file to check out the animations else it will show some error.**

**Lastly, I would say that the system looks stable and everything seems fine as the graphs are converging. It can also be noted that my special function can help to analyse the results and also the effect of the matrices Q, R on the observer design can change the transient process of state estimation, and ideally may add some noise to the observed part of state.**