pyCub

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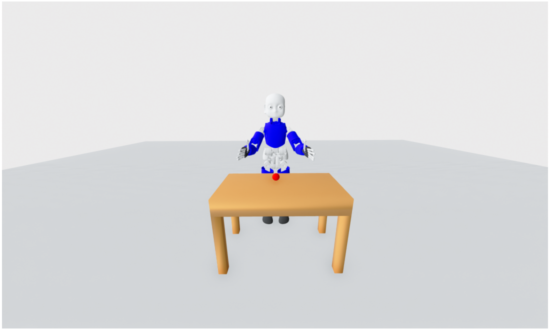
Introduction

- iCub Humanoid Robot
- pure Python3
    - 3.8 and higher; tested in 3.11
- physics from PyBullet[1]
- visualization in Open3D[2]



[1] https://pybullet.org
[2] https://www.open3d.org

Installation

Clone the repository: `git clone https://github.com/rustlluk/pyCub.git`, and then use one of the following options.

Python only

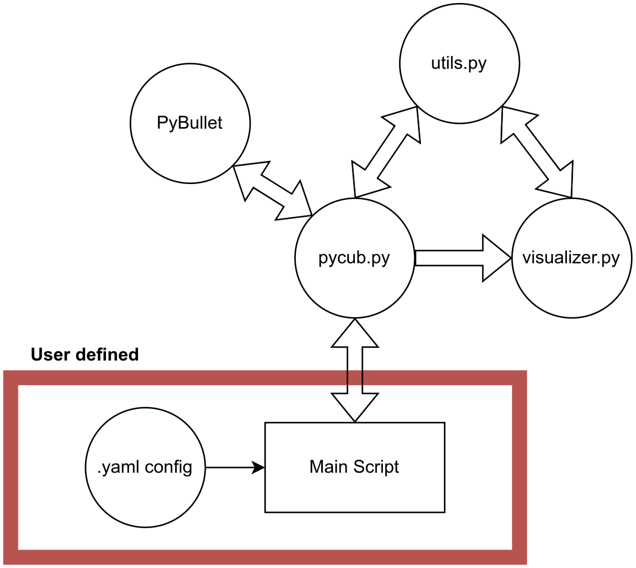
- install Python3.8 or newer
- install dependencies (using venv is recommended)
  - `python3 -m pip install pybullet numpy scipy open3d`
    - open3d version 0.16.0 or newer is required
    - you may need to upgrade pip: `python3 -m pip install --upgrade pip`

Docker (Linux only)

- Install docker-engine
- Go to `PATH_TO_REPO/Docker` and `./deploy.py -c pycub -p PATH_TO_REPO -b`

The same steps are written either in *README* at the GitHub repository or in documentation at: https://lukasrustler.cz/pycub.

Components


utils.py
PyBullet
pycub.py
visualizer.py
User defined
.yaml config
Main Script

Config

Important options:

- `gui`: whether to show GUI; True/False; default: True
- `end_effector`: which link is used as EE in Cartesian control; string; default: "r_hand"
- `initial_joint_angles`: dictionary with initial angles (in degrees) for joints. Can be empty.
- `log`: logging settings
  - log: whether to log; True/False; default: True
  - period: period of logging; float; default: 0.01; 0 for logging at each step
- `simulation_step`: the simulation advances for 1/simulation_step; float; default: 240; low value can break the simulation
- `self_collisions`: whether to detect self-collisions of robot links; True/False; default: True

Config - Objects

- way how to load other objects then the robot
- can load *.urdf* or *.obj* files
    - URDF from *.obj* file is created automatically with: `mass` = 0.2 kg; `lateral_friction` = 1; `rolling_friction` = 0

Structure:

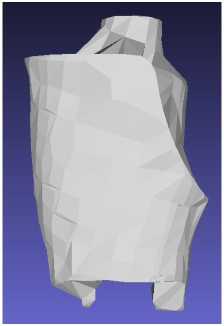
- `urdfs:`
    - paths: list of paths to the files; relative to *other_meshes* directory
    - positions: list of 1x3 lists of positions of the files in world frame
    - fixed: list of bools; True when the object is not movable, i.e., it is not influenced by gravity
    - color: list of 1x3 lists of 0-1 float to specify RGB color; can be an empty list when URDF is used

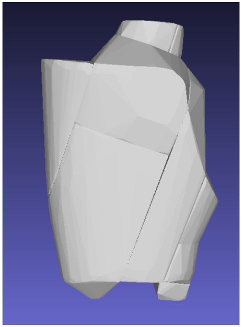
Example:

```
urdfs:
  paths: [plane/plane.urdf, ball/ball.obj, table/table.obj]
  positions: [[0, 0, 0]], [-0.35, 0, -0.1], [-0.6, -0.4, -0.225]]
  fixed: [True, False, True]
  color: [[], [1, 0, 0], [0.825, 0.41, 0.12]]
```

Collision Meshes

To simplify collision detection, PyBullet uses convex hulls of collision geometries. That means that collisions for concave meshes are not precise. From that reason, V-HACD is used to decompose collision geometries to convex parts. Everything is done automatically inside `pyCub`[3].


(a) Original forearm mesh.


(b) Decomposed forearm mesh.

[3]First run with new meshes takes more time as the meshes are decomposed.

User Scripts

The most simple example that loads the world and waits until the GUI is closed is shown below.

```python
import sys
import os
# add needed packages to path
sys.path.insert(0, os.path.dirname(os.path.dirname(os.path.abspath(__file__))))
from pycub import pyCub

if __name__ == "__main__":
    # load the robot with correct world/config
    client = pyCub(config="with_ball.yaml")

    # wait until the gui is closed
    while client.is_alive():
        client.update_simulation()
```

Python Path

When running the code from terminal (and not some clever IDE), it is important to add the necessary modules to python path. There are several ways how to do it:

1. Add absolute path to *icub_pybullet* to *PYTHONPATH*. In Docker:
   export PYTHONPATH=$PYTHONPATH:/home/docker/pycub_ws/icub_pybullet
   - you can it to *~/.bashrc* , so you do not need to call it every time you open new terminal
2. Add the absolute path to *icub_pybullet* folder in the code as `sys.path.insert(0, PATH)`. For example, when using Docker it can be `sys.path.insert(0, "/home/docker/pycub_ws/icub_pybullet")`
3. Use `sys.path.insert(0, os.path.dirname(os.path.dirname(os.path.abspath(__file__))))` in the code
   - this works for codes in the *examples* directory. You need to add proper number of `os.path.dirname()` to get to *icub_pybullet*

Simulation Control

- The simulation is not updating by itself, i.e., users have to call `pyCub.update_simulation()` to do one step.
- By default, a simulation step is performed only if the last step was done more than 0.01 second ago, no matter how often you call `pyCub.update_simulation()`.
    - This is usefull mainly to make visualization slower
    - you can control it with parameter in `pyCub.update_simulation()`. For example, to make the visualization run as fast as possible use `pyCub.update_simulation(None)`
- Some function (e.g., moving) can update the simulation automatically

Joints and Links

- There are two list for joints and links, `pyCub.joints` and `pyCub.links`. The lists include instances of Joint and Link classes.
- The lists include only joints that are not fixed and links that contain collision geometry.

Important Joint variables:

- `name`: string name of the joint; can be used for Joint Space Movement
- `robot_joint_id`: index of the joint in URDF; used by PyBullet
- `joints_id`: index of the joint in `pyCub.joints` list; can be used for Joint Space Movement

The reason to have two sets of indexes is that iCub URDF contains a lot of fixed joints, and it is easier for users to care only about the moveable ones.

To find a joint index by joint name or vice versa, there is a function `pyCub.find_joint_id()`.

Joint Space Movement

Movement in joint space can be achieved with function
`pyCub.move_position(self, joints, positions, wait=True, velocity=1, set_col_state=True, check_collision=True)`.

- `joints` can be an integer (index of the joint), string (name of the joint) or list of integers or strings
- `positions` can be a float or list of floats with the same size as `joints`
- if `wait` is set to True then the command is blocking, i.e., the main script will wait until the motion is done (all joints are the desired position or collision occured)
  - if `wait` is False, then you can check for the end of the movement in the main script with `pyCub.wait_motion_done()` or `pyCub.motion_done()`
- `velocity` sets the maximum joint velocity. **The robot may still go slower if the trajectory does not allow for higher velocity.**
- if `check_collision` is True and `wait` is also True, then the robot stops even if a collision occurs.

Cartesian Movement

Movement in Cartesian space can be achieved with `pyCub.move_cartesian(self, pose, wait=True, velocity=1, check_collision=True)`.

- `pose` as 6D end-effector pose of type `utils.Pose`; it contains two attributes `pos` and `ori` that lists of position (1x3) and orientation (1x4, x, y, z, w quaternion)
- other arguments are the same as for Joint Space movement

End-effector of the robot can changed by changing `pyCub.end_effector` of your `pyCub` instance with a different instance of `pyCub.EndEffector` class.

The movement itself is achieved by computing the inverse kinematics of the input pose and running the joint space movement.
There is no planner included. The resulting trajectories will be mostly random, and collisions are checked only during movement.

Waiting for Motion

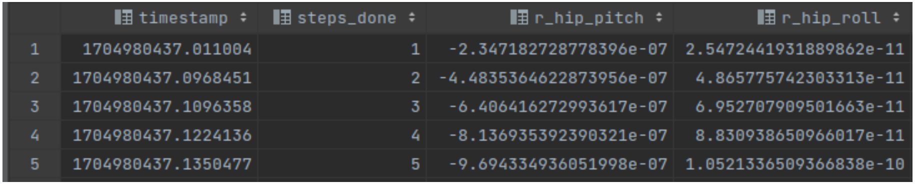
There are three main ways to wait for motion completion.

1. setting `wait` parameter of `move_position()` or `move_cartesian` to True
2. using `pyCub.wait_motion_done(sleep_duration=0.01, check_collision=True)`
    - this way you can change visualization speed
    - the function will return in moment when all joints are at the desired position or when collision occures
        - in case of collision, `pyCub.collision_during_motion` is set to True
3. use `pyCub.motion_done(joints=None, check_collision=True)`
    - this way you can do other things while waiting

```
while not client.motion_done(): # while motion
    # DO SOMETHING
    client.update_simulation(0.1) # update simulation
```

Logging

- things in the terminal can be logged using `pyCub.logger`
  - it uses python `logging` library
  - there is 5 levels (debug, info, warning, error, critical); debug is not showing by default
  - e.g., `pyCub.logging.info("Information message")`
- if you set `log.log` in `.yaml` config to True, then the state of the robot is also saved to .csv file
  - it can be used to "replay" the simulation later
  - the structure is `timestamp;steps_done;joint_0;...;joint_n`
    - in case of skin, there is also comma-separated output of each enabled skin part



	timestamp	steps_done	r_hip_pitch	r_hip_roll
1	1704980437.011004	1	-2.347182728778396e-07	2.5472441931889862e-11
2	1704980437.0968451	2	-4.4835364622873956e-07	4.865775742303313e-11
3	1704980437.1096358	3	-6.406416272993617e-07	6.952707909501663e-11
4	1704980437.1224136	4	-8.136935392390321e-07	8.830938650966017e-11
5	1704980437.1350477	5	-9.694334936051998e-07	1.0521336509366838e-10