pyCub

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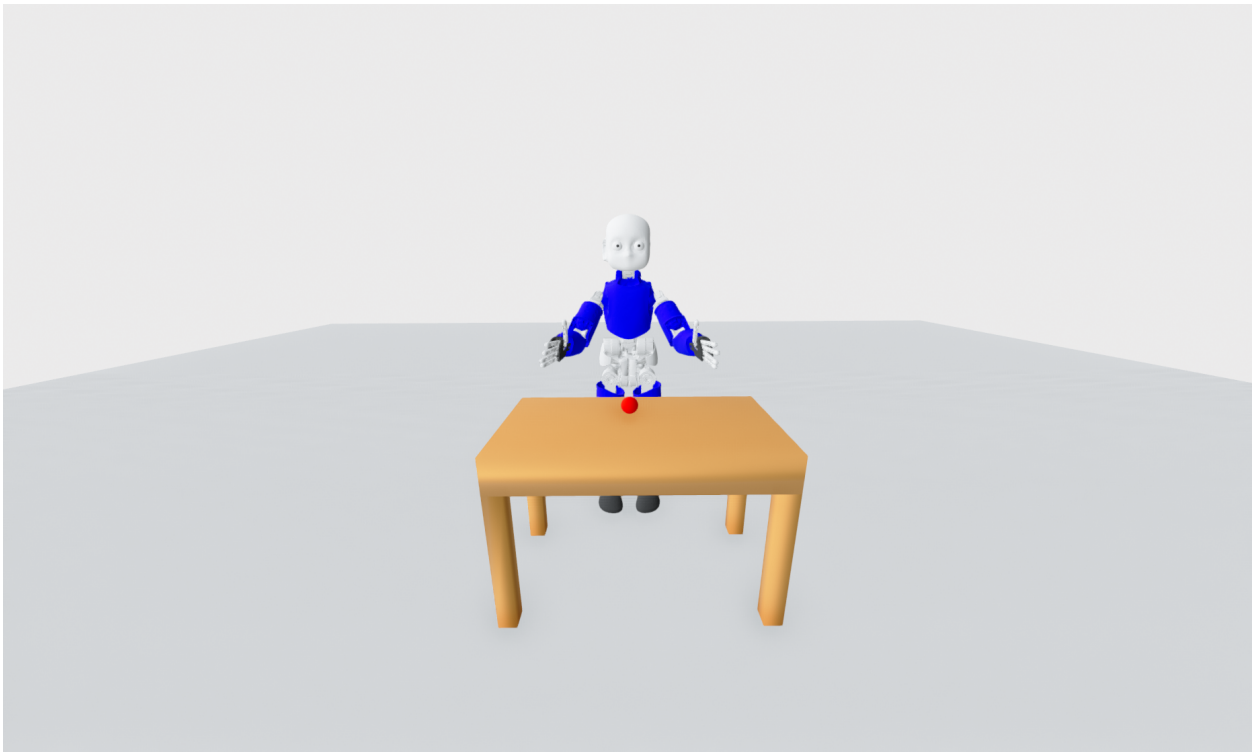

CONTENTS:

CHAPTER

ONE

README

pyCub is iCub humanoid robot simulator written in Python. It uses PyBullet for simulation and Open3D for visualization.

1.1 Known bugs

- visualization with skin dies after ~65k steps
  - e.g., https://github.com/isl-org/Open3D/issues/4992

1.2 Installation

1. Install dependencies
   - use Docker
     - see *Docker* section
   - or install python3 (3.8 and higher; tested in 3.11) and `python3 -m pip install pybullet numpy scipy open3d`
     - open3d 0.16.0 and higher is required
       - you may need to upgrade pip first: `python3 -m pip install --upgrade pip`
2. Pull this repository
3. try run some example, e.g., `python3 PATH_TO_THE_REPOSITORY/icub_pybullet/examples/push_the_ball_cartesian.py`
4. (optional, but recommended) add `export PYTHONPATH=$PYTHONPATH:PATH_TO_THE_REPOSITORY/icub_pybullet` to your `~/.bashrc` file
   - this will allow you to run scripts from any location

1.3 Examples

- push_the_ball_pure_joints.py contains an example that shows how to control the robot in joint space
- push_the_ball_cartesian.py contains an example that shows how to control the robot in Cartesian space
- skin_test.py contains an example with balls falling the robot and skin should turn green on the places where contact occurs. You may want to slow the simulation a little bit to see that :)

1.4 Information

- documentation can be found at lukasrustler.cz/pycub or in pyCub.pdf
- presentation with description of functionality can be found at pyCub presentation
- simulator code is in pycub.py
  - it uses PyBullet for simulation and provides high-level interface
- visualization code in visualizer.py
  - it uses Open3D for visualization as it is much more customizable than PyBullet default GUI
- movement is done using position control. You can either use position control directly (pycub.move_position()) or use cartesian control (pycub.move_cartesian())
  - **Neither of these check for collision before movement!**
  - Function pycub.motion_done() check whether all joints reached the target or whether collision ocurred. If collision, the variable pycub.collision_during_movement is set. You can also run pycub.motion_done() with check_collision=False to ignore collision checks, e.g., to get out of collision state
- until you add `export PYTHONPATH=$PYTHONPATH:PATH_TO_THE_REPOSITORY/icub_pybullet` to your `~/.bashrc` file (or change PYTHONPATH everytime you open a new terminal) you have to add something like `sys.path.append(0, "PATH_TO_THE_REPOSITORY/icub_pybullet")` to every file you want to run
  - scripts in examples folder already contain such line, so the examples can be run easily

1.5 Docker

https://github.com/rustlluk/easy-docker is utilized to use Docker

1.5.1 Installation

- install docker-engine (**DO NOT INSTALL DOCKER DESKTOP**), do post-installation steps and (optional) install nvidia-docker for GPU support
- For ubuntu (and Mint, but you have) users:
  - if you are a mint user, change VERSION_CODENAME to UBUNTU_CODENAME

```
sudo apt-get update
sudo apt-get install ca-certificates curl gnupg
sudo install -m 0755 -d /etc/apt/keyrings
curl -fsSL https://download.docker.com/linux/ubuntu/gpg | sudo gpg --dearmor -o /
```

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```
↪etc/apt/keyrings/docker.gpg
sudo chmod a+r /etc/apt/keyrings/docker.gpg

echo \
  "deb [arch="$(dpkg --print-architecture)" signed-by=/etc/apt/keyrings/docker.gpg]␣
↪https://download.docker.com/linux/ubuntu \
  "$(. /etc/os-release && echo "$VERSION_CODENAME")" stable" | \
  sudo tee /etc/apt/sources.list.d/docker.list > /dev/null
sudo apt-get update
sudo apt-get install docker-ce docker-ce-cli containerd.io docker-buildx-plugin␣
↪docker-compose-plugin
```

  - and post-installation to use docker without sudo:

```
sudo groupadd docker
sudo usermod -aG docker $USER
```

  - and restart your computer

- clone this repository

```
cd SOME_PATH
git clone https://github.com/rustlluk/pyCub.git
```

- (optionally) rename it to be called the same as in docker

```
mv PATH_TO_THE_REPOSITORY/pycub SOME_PATH/pycub_ws
```

- build the docker (see *Parameters* for more parameters)

```
cd SOME_PATH/pycub_ws/Docker
./deploy.py -b -p PATH_TO_THE_REPOSITORY/pycub_ws -c pycub
```

- after you built the container, you can run it next time as

```
./deploy.py -e -c pycub
```

- if you want to open new terminal in existing container, run

```
./deploy.py -c pycub -t
```

1.5.2 Docker + PyCharm

You have two option:

1. Either run pycharm from docker
2. Open your pycharm on your host machine:
   - add ssh interpreter
     - user docker
     - ip can be localhost or ip where you run the docker
     - port 2222

- uncheck automatic upload to remote folder
- change remote path to /home/docker/pycub_ws

Common steps:

- mark all folder icub_pybullet as Source Root
- for X11 forwarding:
  - Click on configurations drop menu -> Edit Configurations -> Edit configuration templates -> Python -> Edit environment variables -> add DISPLAY with the same value as in docker and uncheck 'Include system environment variables'. Every new configuration will have that settings from now
    - if you already have configuration created before doing the above -> delete it and create again, or change it manually

1.5.3 Deploy Parameters

- `cd` to folder with Dockerfile
- `./deploy.py`
  - `-b` or `--build` when building
    - default: False
  - `-nv` or `--nvidia` when you want to use your Nvidia card
    - you have to use it when creating a new container
    - default: False
  - `-e` if you just want to run existing docker without building
    - default: False
  - `-p` or `--path` with path to current folder
    - default: ""
  - `c` or `--container` with desired name of the new, created container
    - default: my_new_docker
  - `t` or `--terminal` to run new terminal in running docker session
    - default: False
  - `-pv` or `--python-version` to specify addition python version to install
    - default: 3.11
  - `-pcv` or `--pycharm-version` to specify version of pycharm to use
    - default: 2023.2.3
  - `-bi` or `--base-image` to specify base image that will be used
    - default: nvidia/cuda:11.0.3-devel-ubuntu20.04
    - other can be found at hub.docker.com

  Do this on computer where you will run the code. If you have a server you have to run it on the server over SSH to make things work properly.

1.5.4 FAQ

- **applications do not run on your screen** (or you have some strange screen related errors)
  - in another terminal run `xhost local:docker`
    - if it does not work, try `xhost +`
      - if this does not work, nothing can be done
- **you get error of not being in sudo group when running image**
  - check output of `id -u` command. If the output is not 1000 you have to build the image by yourself and can not pull it
    - this happens when your account is not the first one created on your computer
- **``sudo apt install something`` does not work**
  - you need to run `sudo apt update` first after you run the container for the first time
    - apt things are removed in Dockerfile, so it does not take unnecessary space in the image

CHAPTER

TWO

PRESENTATION

View the Presentation with description of functionality.

CHAPTER

THREE

ICUB_PYBULLET

3.1 pyCub

class pycub.**EndEffector**(*name*, *client*)

Bases: object

Help function for end-effector encapsulaation

Parameters

- **name** (*str*) – name of the end-effector
- **client** (*pointer to pyCub instance*) – parent client

get_position()

Function to get current position of the end-effector

class pycub.**Joint**(*name*, *robot_joint_id*, *joints_id*, *lower_limit*, *upper_limit*, *max_force*, *max_velocity*)

Bases: object

Help class to encapsulate joint information

Parameters

- **name** (*str*) – name of the joint
- **robot_joint_id** (*int*) – id of the joint in pybullet
- **joints_id** (*int*) – id of the joint in pycub.joints
- **lower_limit** (*float*) – lower limit of the joint
- **upper_limit** (*float*) – upper limit of the joint
- **max_force** (*float*) – max force of the joint
- **max_velocity** (*float*) – max velocity of the joint

class pycub.**Link**(*name*, *robot_link_id*, *urdf_link*)

Bases: object

Help function to encapsulate link information

Parameters

- **name** (*str*) – name of the link
- **robot_link_id** (*int*) – id of the link in pybullet
- **urdf_link** (*int*) – id of the link in pycub.urdfs[“robot”].links

class pycub.**pyCub**(*config='default.yaml'*)

Bases: BulletClient

Client class which inherits from BulletClient and contains the whole simulation functionality

Parameters
config (*str, optional, default="default.yaml"*) – path to the config file

static bbox_overlap(*b1_min*, *b1_max*, *b2_min*, *b2_max*)

compute_skin()

Function to emulate skin activations using ray casting.

contactPoints = {'DISTANCE': 8, 'FLAG': 0, 'FORCE': 9, 'FRICTION1': 10, 'FRICTION2': 12, 'FRICTIONDIR1': 11, 'FRICTIONDIR2': 13, 'IDA': 1, 'IDB': 2, 'INDEXA': 3, 'INDEXB': 4, 'NORMAL': 7, 'POSITIONA': 5, 'POSITIONB': 6}

create_urdf(*object_path*, *fixed*, *color*, *suffix=''*)

Creates a URDF for the given .obj file

Parameters

- **object_path** (*str*) – path to the .obj
- **fixed** (*bool*) – whether the object is fixed in space
- **color** (*list of 3 floats*) – color of the object

dynamicsInfo = {'BODYTYPE': 10, 'DAMPING': 8, 'FRICTION': 1, 'INERTIAOR': 4, 'INERTIAPOS': 3, 'INTERTIADIAGONAL': 2, 'MARGIN': 11, 'MASS': 0, 'RESTITUTION': 5, 'ROLLINGFRICTION': 6, 'SPINNINGFRICTION': 7, 'STIFFNESS': 9}

find_joint_id(*joint_name*)

Help function to get indexes from joint name of joint index in self.joints list

Parameters
joint_name (*str or int*) – name or index of the link

Returns
joint id in pybullet and pycub space

Return type
int, int

find_link_id(*mesh_name*, *robot=None*, *urdf_name='robot'*)

Help function to find link id from mesh name

Parameters

- **mesh_name** (*str*) – name of the mesh (only basename with extension)
- **robot** (*int, optional, default=None*) – robot pybullet id
- **urdf_name** (*str, optional, default="robot"*) – name of the object in pycub.urdfs

Returns
id of the link in pybullet space

Return type
int

get_camera_images()

Gets the images from enabled eye cameras

Returns
list of numpy arrays

Return type
list

get_joint_state(*joints=None*)

Get the state of the specified joints

Parameters
joints (*int or list, optional, default=None*) – joint or list of joints to get the state of

Returns
list of states of the joints

Return type
list

init_robot()

Load the robot URDF and get its joints' information

Returns
robot and its joints

Return type
int or list

is_alive()

Checks whether the engine is still running

Returns
True when running

Return type
bool

jointInfo = {'AXIS': 13, 'DAMPING': 6, 'FLAGS': 5, 'FRICTION': 7, 'INDEX': 0, 'LINKNAME': 12, 'LOWERLIMIT': 8, 'MAXFORCE': 10, 'MAXVELOCITY': 11, 'NAME': 1, 'PARENTINDEX': 16, 'PARENTORN': 15, 'PARENTPOS': 14, 'QINDEX': 3, 'TYPE': 2, 'UINDEX': 4, 'UPPERLIMIT': 9}

jointStates = {'FORCES': 2, 'POSITION': 0, 'TORQUE': 3, 'VELOCITY': 1}

kill_open3d()

linkInfo = {'ANGVEL': 7, 'INERTIAORI': 3, 'INERTIAPOS': 2, 'LINVEL': 6, 'URDFORI': 5, 'URDFPOS': 4, 'WORLDORI': 1, 'WORLDPOS': 0}

motion_done(*joints=None*, *check_collision=True*)

Checks whether the motion is done.

Parameters

- **joints** (*int or list, optional, default=None*) – joint or list of joints to get the state of
- **check_collision** (*bool, optional, default=True*) – whether to check for collision during motion

Returns
True when motion is done, false otherwise

Return type
bool

move_cartesian(*pose*, *wait=True*, *velocity=1*, *check_collision=True*)

Move the robot in cartesian space by computing inverse kinematics and running position control

Parameters

- **pose** (utils.Pose) – desired pose of the end effector
- **wait** (*bool, optional, default=True*) – whether to wait for movement completion
- **velocity** (*float, optional, default=1*) – joint velocity to move with
- **check_collision** (*bool, optional, default=True*) – whether to check for collisions during motion

move_position(*joints*, *positions*, *wait=True*, *velocity=1*, *set_col_state=True*, *check_collision=True*)

Move the specified joints to the given positions

Parameters

- **joints** (*int, list, str*) – joint or list of joints to move
- **positions** (*float or list*) – position or list of positions to move the joints to
- **wait** (*bool, optional, default=True*) – whether to wait until the motion is done
- **velocity** (*float, optional, default=1*) – velocity to move the joints with
- **set_col_state** (*bool, optional, default=True*) – whether to reset collision state
- **check_collision** (*bool, optional, default=True*) – whether to check for collision during motion

move_velocity(*joints*, *velocities*)

Move the specified joints with the specified velocity IT IS HERE, BUT NOT IN WORKING STATE

Parameters

- **joints** (*int or list*) – joint or list of joints to move
- **velocities** (*float or list*) – velocity or list of velocities to move the joints to

prepare_log()

Prepares the log string

Returns
log string

Return type
str

print_collision_info(*c=None*)

Help function to print collision info

Parameters
c (*list, optional, default=None*) – one collision

run_vhacd()

Function to run VHACD on all objects in loaded URDFs, and to create new URDFs with changed collision meshes

static scale_bbox(*bbox*, *scale*)

stop_robot()

Stops the robot

toggle_gravity()

Toggles the gravity

update_simulation(*sleep_duration=0.01*)

Updates the simulation

Parameters

sleep_duration (*float, optional, default=0.01*) – duration to sleep before the next simulation step

visualShapeData = {'COLOR': 7, 'DIMS': 3, 'FILE': 4, 'GEOMTYPE': 2, 'ID': 0, 'LINK': 1, 'ORI': 6, 'POS': 5, 'TEXTURE': 8}

wait_motion_done(*sleep_duration=0.01*, *check_collision=True*)

Help function to wait for motion to be done. Can sleep for a specific duration

Parameters

- **sleep_duration** (*float, optional, default=0.01*) – how long to sleep before running simulation step
- **check_collision** (*bool, optional, default=True*) – whether to check for collisions during motion

3.2 utils

class utils.**Config**(*config_path*)

Bases: object

Class to parse and keep the config loaded from yaml file

Parameters

config_path (*str*) – path to the config file

set_attribute(*attr*, *value*, *reference*)

Function to recursively fill the instance variables from dictionary. When value is non-dict, it is directly assigned to a variable. Else, the dict is recursively parsed.

Parameters

- **attr** (*str*) – name of the attribute
- **value** (*str, float, int, dict, list, ... - and other that can be loaded from yaml*) – value of the attribute
- **reference** (*pointer or whatever it is called in Python*) – reference to the parent class. "self" for the upper attributes, pointer to namedtuple for inner attributes

Returns

0

Return type

int

class utils.**CustomFormatter**(*fmt=None*, *datefmt=None*, *style='%'*, *validate=True*, *, *defaults=None*)

Bases: Formatter

Custom formatter that assigns colors to logs From https://stackoverflow.com/a/56944256

Initialize the formatter with specified format strings.

Initialize the formatter either with the specified format string, or a default as described above. Allow for specialized date formatting with the optional datefmt argument. If datefmt is omitted, you get an ISO8601-like (or RFC 3339-like) format.

Use a style parameter of '%', '{' or '$' to specify that you want to use one of %-formatting, `str.format()` ({}) formatting or `string.Template` formatting in your format string.

Changed in version 3.2: Added the `style` parameter.

```
FORMATS = {10:  '\x1b[38;20m%(module)s %(levelname)s:  %(message)s\x1b[0m', 20:
'\x1b[38;20m%(module)s %(levelname)s:  %(message)s\x1b[0m', 30:
'\x1b[33;20m%(module)s %(levelname)s:  %(message)s\x1b[0m', 40:
'\x1b[31;20m%(module)s %(levelname)s:  %(message)s\x1b[0m', 50:
'\x1b[31;1m%(module)s %(levelname)s:  %(message)s\x1b[0m'}
```

```
bold_red = '\x1b[31;1m'
```

format(*record*)

Format the specified record as text.

The record's attribute dictionary is used as the operand to a string formatting operation which yields the returned string. Before formatting the dictionary, a couple of preparatory steps are carried out. The message attribute of the record is computed using LogRecord.getMessage(). If the formatting string uses the time (as determined by a call to usesTime(), formatTime() is called to format the event time. If there is exception information, it is formatted using formatException() and appended to the message.

```
grey = '\x1b[38;20m'
```

```
red = '\x1b[31;20m'
```

```
reset = '\x1b[0m'
```

```
yellow = '\x1b[33;20m'
```

class utils.**Pose**(*pos*, *ori*)

Bases: object

Mini help class for Pose representation

Init function that takes position and orientation and saves them as attributes

Parameters

- **pos** (*list*) – x,y,z position
- **ori** (*list*) – rpy orientation

class utils.**URDF**(*path*)

Bases: object

Class to parse URDF file

Parameters

path (*str*) – path to the URDF file

ROOT_TAGS = []

dereference()

Make parent/child again as names to allow urdf write

find_root_tags()

Finds tags that are 'root', i.e., they have child 'inside'

fix_urdf()

Fix the URDF file by converting non-mesh geometries to mesh and saving them as .obj files. If changes were made, write the new URDF to a file.

make_references()

Make parent/child in joint list as references to the given link

read(*el*, *parent*)

Recursive function to read the URDF file. When there are no children, it reads the attributes and saves them.

Parameters

- **el** (*xml.etree.ElementTree.Element*) – The current element in the XML tree.
- **parent** (*xml.etree.ElementTree.Element*) – The parent element in the XML tree.

write_attr(*attr_name*, *attr*, *level=1*, *skip_header=False*)

Write an attribute to the new URDF string.

Parameters

- **attr_name** (*str*) – The name of the attribute.
- **attr** (*any*) – The attribute value.
- **level** (*int, optional, default=1*) – The indentation level for the attribute.
- **skip_header** (*bool, optional, default=False*) – Whether to skip writing the attribute header.

write_urdf()

Write the URDF object to a string.

3.3 visualizer

class visualizer.**Visualizer**(*client=None*)

Bases: object

Class to help with custom rendering

Parameters

client (*int, optional, default=None*) – The client to be used for the visualizer.

class **EyeWindow**(*eye*, *parent*)

Bases: object

Class to handle windows for eye rendering

Parameters

- **eye** (*str*) – name of the eye

- **parent** (*int*) – The parent class (Visualizer).

MENU_IDS = {'l_eye': [2, 3, 8], 'r_eye': [4, 5, 9]}

POSITIONS = {'l_eye': [320, 560], 'r_eye': [0, 560]}

get_image()

on_close()

Small function to delete the window from the parent class

on_mouse(*event*)

Small function to ignore mouse events

Parameters

event (*gui.MouseEvent*) – Mouse event

save_image(*im*)

Callback to get images from open3d

Parameters

im (*o3d.geometry.Image*) – the image to be saves

save_images()

Function to save stream of images to file

class MenuCallback(*menu_id*, *parent*)

Bases: object

Class to handle menu callbacks.

Initialize the MenuCallback class.

Parameters

- **menu_id** (*int*) – The id of the menu.
- **parent** (*pointer to the class of visualizer.Visualizer type*) – The parent class (Visualizer).

input_completed(*text=None*)

save_image(*im*, *mode*)

Save the image. It shows FileDialog to find path for image save. It saves it with the current resolution of the window.

Parameters

- **im** (*open3d.geometry.Image*) – The image to be saved.
- **mode** (*int*) – The mode of the image. 0 for RGB, 1 for depth.

wait_for_dialog_completion()

Help function to keep the gui loop running

find_xyz_rpy(*mesh_name*, *urdf_name='robot'*)

Find the xyz, rpy and scales values.

Parameters

- **mesh_name** (*str*) – The name of the mesh.
- **urdf_name** (*str, optional, default="robot"*) – The name of the urdf.

Returns

The xyz, rpy, and scales, link_name

read_info(*obj_id*)

Read info from PyBullet

Parameters
obj_id (*int*) – id of the object; given by pybullet

Returns
0 for success

Return type
int

render()

Render all the things

show_first(*urdf_name='robot'*)

Show the first batch of meshes in the visualizer. It loads the meshes and saves the to dict for quicker use later

Parameters
urdf_name (*str, optional, default="robot"*) – The name of the urdf to be used.

show_mesh()

Function to parse info about meshes from PyBullet

CHAPTER

FOUR

EXAMPLES

4.1 push_the_ball_cartesian

Example of moving the robot in cartesian space to push the ball. It is more robust than the pure joint control.

Author
Lukas Rustler

push_the_ball_cartesian.**push_the_ball**()

Function to move the ball with cartesian control. The robot is moved 15cm lower and 10cm closer and the moved left to push the ball.

4.2 push_the_ball_pure_joints

Example of how to push the ball from the table using only pure joint control. It works without planner of collisions detection/avoidance. It is not very robust, and it is laborious, but it is a good starting point for your own experiments.

Author
Lukas Rustler

push_the_ball_pure_joints.**push_the_ball**()

Function to push the ball from the table

4.3 skin_test

Script to the test the skin sensors.

Author
Lukas Rustler

PYTHON MODULE INDEX

INDEX

R

S

T

U

V

W

Y