Task Space, Workspace and Introduction to ROS

CS 6301 Special Topics: Introduction to Robot Manipulation and Navigation
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Configuration Space of a Robot

• The configuration of a robot is a complete specification of the position of every point of the robot.

• The minimum number $n$ of real-valued coordinates needed to represent the configuration is the number of degrees of freedom (DOF) of the robot.

• The $n$-dimensional space containing all possible configurations of the robot is called the configuration space (C-space).

• The configuration of a robot is represented by a point in its C-space.

- 4 revolute joints
- 4 DOFs
Task Space

• The task space is a space in which the robot’s task can be naturally expressed

• Task examples
  • Draw on a piece of paper: $\mathbb{R}^2$
  • Manipulate a rigid body: C-space of the rigid body

• Task space is driven by the task, independently of the robot
Workspace

• The workspace is a specification of the configurations that the end-effector of the robot can reach.
• Depends on the robot structure, independent of the task

a planar 2R open chain  

a planar 3R open chain  

a spherical 2R open chain
SCARA Robot

- End-effector configuration
  \[(x, y, z, \phi)\]
- Task space \(\mathbb{R}^3 \times S^1\)
- Workspace
  - Reachable \((x, y, z, \phi)\)
A 6R Robot

A spray-painting robot

- End-effector configuration
  \[(x, y, z) \quad (\theta, \phi)\]
  
  Cartesian position of the nozzle
  Spherical coordinates to describe the direction in which the nozzle is pointing

- Task space \(\mathbb{R}^3 \times S^2\)

- Workspace
  - Reachable
    \[(x, y, z) \quad (\theta, \phi)\]
https://www.rnaautomation.com/case-study/robotic-spray-booth/
Robot Programming

• Sensing
  • How to receive data from sensors on the robot?
  • RGB image, depth image, lidar scan, odometry, joint state

• Computation
  • Use the sensor data for computation
  • Object recognition, motion planning, compute control command, etc.

• Control
  • How to send the control command to the robot?
Robot Operating System (ROS)

- ROS is a set of software libraries and tools that can be used to build robot applications
  - Drivers, algorithms, developer tools, etc.

- Goal of ROS: support code reuse in robotics research and development

- Operating systems: Unix-based platforms (Ubuntu)

https://www.ros.org/
https://wiki.ros.org/
Robot Operating System (ROS)

https://www.ros.org/
ROS Computation Graph

• The computation graph is the peer-to-peer network of ROS processes that are processing data together

• Computation graph concepts
  • Nodes: processes that perform computation
  • ROS Master: provides name registration and lookup, nodes can find each other via ROS master
  • Messages: nodes communicate by passing messages, a data structure with type fields (integer, floating, arrays, etc.)
ROS Message Example

File: `sensor_msgs/Image.msg`

**Raw Message Definition**

```plaintext
# This message contains an uncompressed image
# (0, 0) is at top-left corner of image

Header header
    # Header timestamp should be acquisition time of image
    # Header frame_id should be optical frame of camera
    # origin of frame should be optical center of camera
    # +x should point to the right in the image
    # +y should point down in the image
    # +z should point into plane of the image
    # If the frame_id here and the frame_id of the CameraInfo
    # message associated with the image conflict
    # the behavior is undefined

uint32 height
    # image height, that is, number of rows

uint32 width
    # image width, that is, number of columns

# The legal values for encoding are in file src/image_encodings.cpp
# If you want to standardize a new string format, join
# ros-users@lists.sourceforge.net and send an email proposing a new encoding.

string encoding
    # Encoding of pixels -- channel meaning, ordering, size
    # taken from the list of strings in include/sensor_msgs/image_encodings.h

uint8 is_big endian
    # is this data big endian?

uint32 step
    # full row length in bytes

uint8[] data
    # actual matrix data, size is (step * rows)
```

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**std_msgs/Header Message**

File: `std_msgs/Header.msg`

**Raw Message Definition**

```plaintext
# Standard metadata for higher-level stamped data types.
# This is generally used to communicate timestamped data
# in a particular coordinate frame.
#
# sequence ID: consecutively increasing ID
uint32 seq
    # Two integer timestamp that is expressed as:
    # * stamp.sec: seconds (stampsecs) since epoch (in Python the variable is called 'secs')
    # * stamp.nsec: nanoseconds since stampsecs (in Python the variable is called 'nsecs')
    # time-handling sugar is provided by the client library

time stamp
    # frame this data is associated with

string frame_id
```
ROS Computation Graph

• Topics: a node publishes messages to a topic. The topic is the name to identify the content of the message

Node: Head camera
Topic: /rgb_image
Message: sensor_msgs/Image

Node: Object detection
ROS Computation Graph

- Service: request and reply interactions

Node: Motion Planner

File: control_msgs/FollowJointTrajectoryGoal.msg

```plaintext
# DO NOT MODIFY! AUTOGENERATED FROM AN ACTION DEFINITION

trajectory_msg/FollowJointTrajectoryGoal

- tolerance for the trajectory. If the measured joint values fail to
- be within tolerance of the trajectory within the given time, the
- trajectory is terminated and the node aborts, setting return_code to
- FAILURE and res to the default for the action server (often taken from
- the parameter server).

- tolerance applied to the joints as the trajectory is executed. If
- violated, the goal aborts with return_code set to
- FAILURE

- # To report success, the joints must be within goal/timeout of the
- final trajectory value. The goal must be achieved by the time the
- trajectory ends plus goal/timeout. (goal/timeout is equal to
- traj/monitoring_time plus traj/complete_time.) If the goal is not
- achieved in this time, the node aborts and return_code is set to
- FAILURE.

- If the joints are not within goal/timeout of the trajectory within
- traj/complete_time, the goal aborts with return_code set to
- FAILURE

- status values are defined in actionlib_msgs/GoalStatus

- goal/timeout
- traj/complete_time
```

Node: Arm Controller

File: control_msgs/FollowJointTrajectoryAction.msg

```plaintext
# DO NOT MODIFY! AUTOGENERATED FROM AN ACTION DEFINITION

FollowJointTrajectoryActionGoal action_goal
FollowJointTrajectoryActionResult action_result
FollowJointTrajectoryActionFeedback action_feedback
```

Compact Message Definition

```plaintext
control_msgs/FollowJointTrajectoryActionGoal action_goal
custom_msgs/FollowJointTrajectoryActionResult action_result
custom_msgs/FollowJointTrajectoryActionFeedback action_feedback
```
ROS Computation Graph

• ROS bags
  • A format for saving and playing back ROS message data
  • We can save sensor data into a ros bag, and use it for development

```bash
rosbag record --duration=30 --output-name=/tmp/mybagfile.bag
/topic1 /topic2 /topic3
```
Docker

• An open platform that enables you to separate your applications from your infrastructure

• Container
  • A lightweight environment that contains everything to run an application
  • A container is a runnable instance of an image

• Image
  • A read-only template with instructions for creating a docker container
Ubuntu in Docker

• Download the ubuntu docker image
  https://hub.docker.com/_/ubuntu

```
docker pull ubuntu:20.04
```

Command  Docker image name  Docker image tag
Docker

docker run -i -t ubuntu:20.04 /bin/bash

• Run an **ubuntu container**
• You need to have an **ubuntu image** locally, if not, the command will pull an ubuntu image as by `docker pull ubuntu`
• Docker creates a new container as though you had run `docker container create`
• Docker starts the container and execute `/bin/bash`
• `-i, -t` the container is running interactively and attached to your terminal
• When exit, the container stops but is not removed
ROS in Docker

• Install Docker Desktop [https://docs.docker.com/get-docker/](https://docs.docker.com/get-docker/)
• Start the Docker Desktop
• Ubuntu images [https://hub.docker.com/_/ubuntu](https://hub.docker.com/_/ubuntu)
• Run command “docker run –i –t ubuntu:20.04 /bin/bash”
• No need to use sudo in docker, do an “apt update” first
ROS in Docker

• Install X server
  • Windows: VcXsrv Windows X Server [https://sourceforge.net/projects vcxsrv/]
  • Mac: Xquartz [https://www.xquartz.org/]

• Start the X server
• Check IP address
• In Ubuntu terminal
  
  Export DISPLAY=my_ip:0.0

[https://medium.com/@potatowagon/how-to-use-gui-apps-in-linux-docker-container-from-windows-host-485d3e1c64a3]
ROS in Docker

- Test ROS installation

- In one terminator terminal, start roscore
  - source /opt/ros/noetic/setup.bash
  - roscore

- In another terminator terminal, start rviz
  - source /opt/ros/noetic/setup.bash
  - rosrush rviz rviz
Commit Your Docker Image

- After you exit the docker container

- Run the command “docker container list -a” to see all the containers. Find the container ID of the latest one

- Run the command “docker container commit <CONTAINER_ID>”

- Run the command “docker image list -a” to see the latest image ID

- Run the command “docker image tag <IMAGE_ID> TAG”. Give a name to this image such as “ubuntu:ros”
ROS in Docker

• After install all needed packages, exit
• docker container commit CONTAINER_ID
• docker image tag <IMAGE_ID> TAG

• Useful commands
  • docker container list –a
  • docker image list -a

• The new tagged image will have all the installed packages
Summary

• Task space

• Workspace

• ROS

• Docker
Further Reading

  http://hades.mech.northwestern.edu/images/7/7f/MR.pdf

• ROS wiki https://wiki.ros.org/

• Docker document https://docs.docker.com/get-started/overview/