# sorotraj

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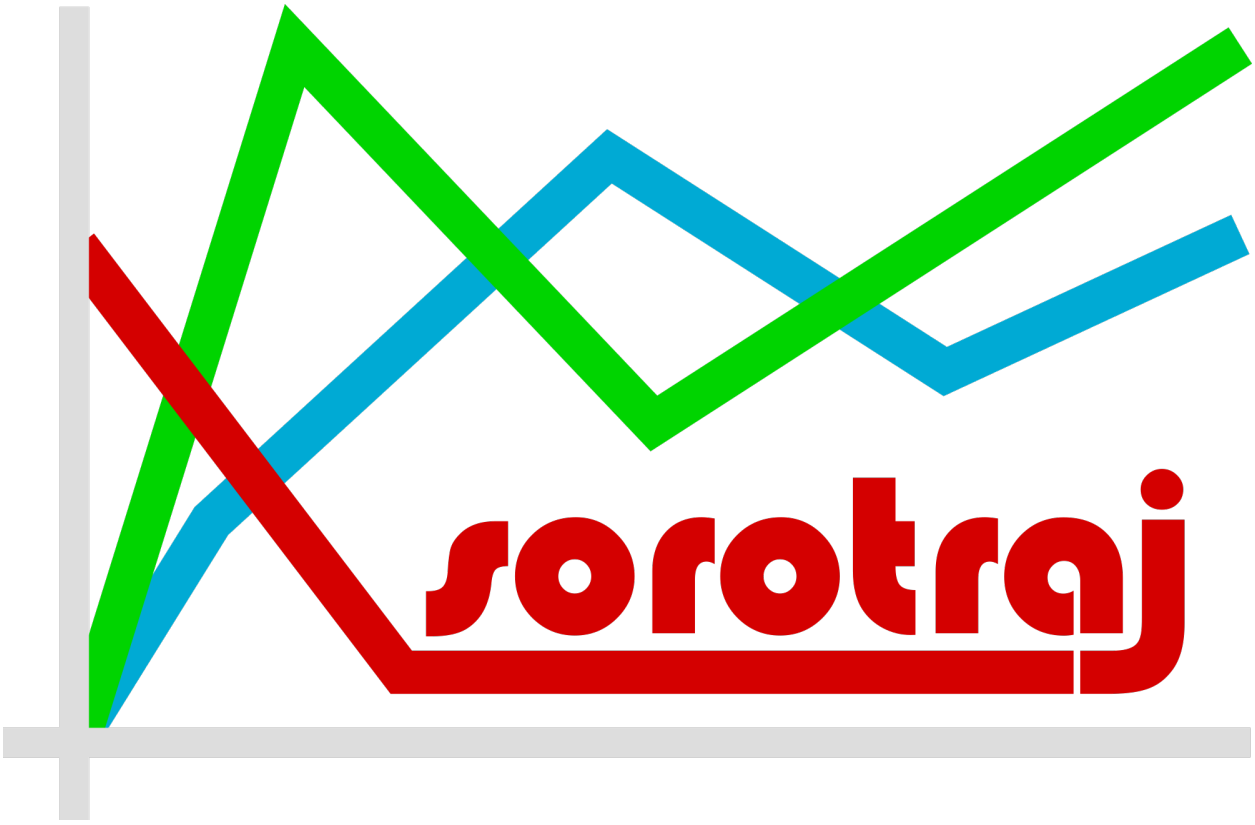
# DOCUMENTATION




Sorotraj allows you to generate trajectory functionsto control soft robots. Trajectories are defined in a simple, human-readable yaml file, and are designed for compatibillity with both with Ctrl-P pressure controllers (for real-world soft robots) and SoMo simulations (for virtual soft robots).

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ONE

# QUICKSTART GUIDE

*(from "README.md" in github repo)*

## 1.1 sorotraj

Generate trajectories for soft robots from yaml files (accompanies the Ctrl-P project)

### 1.1.1 Installation

#### Install the release version

This package is on pypi, so anyone can install it with pip: `pip install sorotraj`

#### Install the most-recent development version

1. Clone the package from the github repo
2. Navigate into the main folder
3. `pip install .`

### 1.1.2 Usage

#### Minimal Example

```
import sorotraj

file_to_use = 'traj_setup/setpoint_traj_demo.yaml'

traj = sorotraj.TrajBuilder()
traj.load_traj_def(file_to_use)
trajectory = traj.get_trajectory()
interp = sorotraj.Interpolator(trajectory)
actuation_fn = interp.get_interp_function(
                num_reps=1,
                speed_factor=2.0,
                invert_direction=False)
print(actuation_fn(2.155))
```

**Check out the *examples* folder for more detailed usage examples**

### 1.1.3 Set Up Trajectories:

Trajectories are made of three parts:

1. **main**: used in a looping trajectory
2. **prefix**: happens once before the main part
3. **suffix**: happens once after the main part

Here's an example of what that might look like defined in a yaml file:

```yaml
config:
    setpoints:
        # [time, finger1, finger2, n/c, n/c]
        main:
            - [0.0,   10, 12, 14,  16]
            - [1.0,    20, 0, 0,  0]
            - [2.0,   0, 20, 0,  0]
            - [3.0,     0, 0, 20, 0]
            - [4.0,     0, 0, 0, 20]
            - [5.0,    10, 12, 14, 16]

        prefix:
            - [0.000,   0, 0, 0,  0]
            - [1.0,    10, 12, 14,  16]

        suffix:
            - [2.000,   10, 12, 14,  16]
            - [3.0,  0, 0, 0,  0]
```

There are currently three types of ways to generate the **main** part of a trajectory:

1. **direct**: You enter waypoints directly
    - Define waypoints as a list of lists of the form: `[time in sec], [a_1], [a_2], ..., [a_n]`
2. **interp**: Interpolate between waypoints
    - Define waypoints as a list of lists of the form: `[time in sec], [a_1], [a_2], ..., [a_n]`
    - Set a few more parameters:
        - **interp_type**: (`string`) The type of interpolation to use. right now types include: `'linear'`, `'cubic'`, and `'none'`
        - **subsample_num**: (`int`) The total number of subsamples over the whole trajectory
3. **waveform**: Generate waveforms (very basic, still just in-phase waveforms across all channels)
    - Set up the waveform:
        - **waveform_type**: (`string`) Types include: square-sampled, square, sin, cos-up, cos-down, triangle, sawtooth-f, and sawtooth-r
        - **waveform_freq**: (`float`) Frequency in Hertz
        - **waveform_max**: (`float`) A list of the maximum values for the waveform, in the form: `[20, 0, 15, 5]`

  - **waveform_min**: (`float`) A list of the minimum values for the waveform, in the form: `[0, 20, 0, 15]`

- Set a few more parameters:
  - **subsample_num**: (`int`) The total number of subsamples over the whole trajectory
  - **num_cycles**: (`int`) The number of cycles of the waveform
  - **channels**: (`bool`) Flags to turn channels on and off. A list of the form: `[1,1,0,0]`

### 1.1.4 Convert Trajectories Line-by-Line

Check out the _build_convert*trajectories.py* example.

1. Set up a conversion function
   - Inputs: one original trajectory line (`list`)
   - Outputs: one new trajectory line (`list`)
2. Load the trajectory like normal
   - `traj.load_traj_def(file_to_use)`
3. Convert the trajectory by passing the conversion function
   - `traj.convert_traj(conversion_function)`
4. This conversion overwrites the original trajectory. Now you can save it like normal
   - `traj.save_traj(file_to_save)`
5. Convert the trajectory definition by passing the conversion function
   - `traj.convert_definition(conversion_function)`
6. This conversion overwrites the original trajectory definition and reguilds the trajectory. Now you can save the definition like normal
   - `traj.save_definition(file_to_save)`

### 1.1.5 Build an interpolator

```
interp = sorotraj.Interpolator(trajectory)
```

- **trajectory**: A trajectory object generated by `sorotraj.TrajBuilder`

```
actuation_fn, final_time = interp.get_traj_function(
                num_reps=1,
                speed_factor=1.0,
                invert_direction=False)
```

- **num_reps**: (`int`, default=1) Number of times to repeat the main looping trajectory
  - Must be positive, nonzero
- **speed_factor**: (`float`, default=1.0) A speed multiplier that is applied to the main loop (but not the prefix or suffix)
  - Must be positive, nonzero

- **invert_direction**: (`bool`, default=False) Negate the whole trajectory (useful if actuators have different directionalities)
  - (`bool`): Negate all channels
  - (`list of ints`): Choose which channels to negate with a list of channel indices

```
cycle_fn = interp.get_cycle_function(
                num_reps=1,
                speed_factor=1.0,
                invert_direction=False)
```

- Same inputs as `get_interp_function()`, but returns a cycle function (returns the current cycle as a function of time)
- cycle_fn takes these values:
  - -2 = Prefix
  - -1 = Suffix
  - 0-N = Main loop index

CHAPTER

TWO

# EXAMPLES

Several examples of how sorotraj is used in the Ctrl-P system as well as SoMo simulations are shown here. You can find them in the examples folder in the github repo.

## 2.1 Build One Trajectory

build_one_trajectory.py

```
import sorotraj
import numpy as np
import matplotlib.pyplot as plt

#file_to_use = 'traj_setup/setpoint_traj_demo.yaml'      # Basic demo
#file_to_use = 'traj_setup/setpoint_traj_demo_err0.yaml' # duplicate time (will throw␣
↪exception)
#file_to_use = 'traj_setup/setpoint_traj_demo_err1.yaml' # non-monotonic time (will throw␣
↪exception)
#file_to_use = 'traj_setup/setpoint_traj_demo_0.yaml'    # empty prefix
file_to_use = 'traj_setup/setpoint_traj_demo_1.yaml'    # single line prefix
#file_to_use = 'traj_setup/waveform_traj_demo.yaml'    # single prefix line

# Build the trajectory from the definition file
builder = sorotraj.TrajBuilder()
builder.load_traj_def(file_to_use)
traj = builder.get_trajectory()
for key in traj:
        print(key)
        print(traj[key])

# Plot the trajectory
builder.plot_traj()

# Make an interpolator from the trajectory
interp = sorotraj.Interpolator(traj)

# Get the actuation function for the specified run parameters
actuation_fn, final_time = interp.get_traj_function(
                num_reps=2,
                speed_factor=1.0,
                invert_direction=[1,3])
```

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```
print("Final Interpolation Time: %f"%(final_time))

# Get the cycle function for the specified run parameters
cycle_fn = interp.get_cycle_function(
                num_reps=2,
                speed_factor=1.0,
                invert_direction=[1,3])

# Plot the actuation function vs. time
times = np.linspace(-1,20,2000)
vals = actuation_fn(times)

plt.plot(times, vals)
plt.show()
```

## 2.2 Build and Save Trajectories

build_save_trajectories.py

```
import sorotraj
import os

setup_location = 'traj_setup'
build_location = 'traj_built'

files_to_use = ['waveform_traj_demo','interp_setpoint','setpoint_traj_demo']

# Build a trajectory builder
traj = sorotraj.TrajBuilder()
for file in files_to_use:
        # Load, build, and save each trajectory
        traj.load_traj_def(os.path.join(setup_location,file))
        traj.save_traj(os.path.join(build_location,file))
```

## 2.3 Convert Trajectories

build_convert_trajectories.py

```
import sorotraj
import os

setup_location = 'traj_setup'
build_location = 'traj_built'

files_to_use = ['waveform_traj_demo','interp_setpoint','setpoint_traj_demo']

# Define a line-by-line conversion function to use
```

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```
#   This example converts from orthogonal axes to differential actuation.
def linear_conversion(traj_line, weights):
    traj_length=len(traj_line)-1

    traj_line_new = [0]*(traj_length+1)
    traj_line_new[0]=traj_line[0] # Use the same time point

    for idx in range(int(traj_length/2)):
        idx_list = [2*idx+1, 2*idx+2]
        traj_line_new[idx_list[0]] = weights[0]*traj_line[idx_list[0]] + weights[1]*traj_
↪line[idx_list[1]]
        traj_line_new[idx_list[1]] = weights[0]*traj_line[idx_list[0]] - weights[1]*traj_
↪line[idx_list[1]]

    return traj_line_new


# Set up the specific version of the conversion function to use
weights = [1.0, 0.5]
conversion_fun = lambda line: linear_conversion(line, weights)

# Test the conversion
traj_line_test = [0.00,  5,15,  5,15  ,-10,0,  -10,0]
print(traj_line_test)
print(conversion_fun(traj_line_test))

# Build the trajectories, convert them , and save them
traj = sorotraj.TrajBuilder()
for file in files_to_use:
    traj.load_traj_def(os.path.join(setup_location,file))
    traj.convert_traj(conversion_fun)
    traj.save_traj(os.path.join(build_location,file+'_convert'))

# Convert the definitions if possible
traj = sorotraj.TrajBuilder(graph=False)
for file in files_to_use:
    traj.load_traj_def(os.path.join(setup_location,file))
    traj.convert_definition(conversion_fun)
    traj.save_definition(os.path.join(setup_location,file+'_convert'))
```

## 2.4 Advanced Examples

Getting a bit into the weeds, here are some examples that showcase some advanced functionality

### 2.4.1 Wrapped Interpolator

wrapped_interp.py

```
import sorotraj
import numpy as np
import matplotlib.pyplot as plt

file_to_use = 'traj_setup/setpoint_traj_demo.yaml'

# Build the trajectory from the definition file
builder = sorotraj.TrajBuilder()
builder.load_traj_def(file_to_use)
traj = builder.get_traj_components()

# Make a wrapped interpolator with the looping part
# of the trajectory
interp = sorotraj.interpolator.WrappedInterp1d(
                        traj['setpoints']['time'],
                        traj['setpoints']['values'],
                        axis=0)

interp_fun = interp.get_function()

# Plot the values over a ridiculous range of times
times = np.linspace(-10,20,2000)
vals = interp_fun(times)

plt.plot(times, vals)
plt.show()
```

CHAPTER

# THREE

# CLASS REFERENCE

Each page contains details and full API reference for all the classes in sorotraj.

For an explanation of how to use all of it together, see *Quickstart Guide*.

## 3.1 Trajectory Builder

Build trajectories from a definition (either from a yaml file or directly via python dictionary).

**class** sorotraj.build_traj.**TrajBuilder**(*verbose=False*)

Trajectory builder

**verbose**

Flag used to turn on verbose printing

**Type** bool

### Examples

```
>>> def_file = 'examples/traj_setup/setpoint_traj_demo.yaml'
... builder = TrajBuilder()
... builder.load_traj_def(def_file)
... traj = builder.get_trajectory()
... out_file = 'examples/traj_built/setpoint_traj_demo.traj'
... builder.save_traj(out_file)
```

**build_traj**()

Build the current trajectory

**Raises** **RuntimeError** – If the trajectory definition has not been set

**convert_definition**(*conversion_fun*)

Convert a trajectory definition line-by-line using a conversion function.

Trajectory definition of type 'direct' and 'interp' can be converted, but waveform trajectory definitions cannot.

**Parameters** **conversion_fun** (*function*) – Conversion function taking in one waypoint (list) and returning waypoint (list)

**Raises**

- **RuntimeError** – If the trajectory definition is not set
- **RuntimeError** – If the trajectory type is incompatible (not direct or interp)

convert_traj(*conversion_fun*)
Convert a trajectory line-by-line using a conversion function

**Parameters** **conversion_fun** (*function*) – Conversion function taking in one trajectory line (list) and returning one line (list)

**Raises** **RuntimeError** – If the trajectory has not been built

get_definition(*use_copy=False*)
Get the trajectory definition.

**Parameters** **use_copy** (*bool*) – Decide whether to pass the trajectory by referece. If True, the actual trajectory object is returned, otherwise a copy of the trajectory is returned.

**Returns** **trajectory_definition** – The trajectory definition

**Return type** dict

**Raises** **RuntimeError** – If the trajectory definition is not set set

get_traj_components()
Get trajectory split into compoenents rather than in vector form

This generates a dictionary with the same trajectory components as a usual trajectory, but the values of each component are dictionaries with 'time' and 'values' rather than the usual list of lists.

**Raises** **RuntimeError** – If the trajectory has not been built

get_trajectory(*use_copy=False*)
Get the built trajectory.

**Parameters** **use_copy** (*bool*) – Decide whether to pass the trajectory by referece. If True, the actual trajectory object is returned, otherwise a copy of the trajectory is returned.

**Returns** **trajectory** – The full trajectory

**Return type** dict

**Raises** **RuntimeError** – If the trajectory has not been built

load_traj_def(*filename*)
Load a trajectory definition from a file.

Once lodaed, the trajectory definition is set, and the trajectory is built.

**Parameters** **filename** (*str*) – The file to load

**Raises** **ValueError** – If the filename is not of type 'str'

plot_traj()
Plot the current trajectory (assuming 1 rep of the main segment)

**Raises** **RuntimeError** – If the trajectory has not been built

save_definition(*filename*)
Save the trajectory definition to a file.

**Parameters** **filename** (*str*) – The file to save

**Raises**

- **ValueError** – If the filename is not of type 'str'
- **RuntimeError** – If the trajectory definition is not set

save_traj(*filename*)
Save the trajectory to a file.

**Parameters** **filename** (*str*) – The file to save

**Raises**

- **ValueError** – If the filename is not of type 'str'
- **RuntimeError** – If the trajectory has not been built

**set_definition**(*definition*)

Set the trajectory definition manually.

The trajectory definition is set, and the trajectory is rebuilt.

**Parameters** **definition** (*dict*) – The trajectory definition to set

**Raises** **ValueError** – If the trajectory definition is not of type 'dict'

## 3.2 Trajectory Interpolation

Use interpolators to obtain trajectory functions where you input a time (or array of times) and return the trajectory at that timepoint (or timepoints).

### 3.2.1 Interpolator Class

This is the primary way to create an interpolation function. This handles many edge-cases to ensure behavior is the same as the real-life Ctrl-P control system.

**class** sorotraj.interpolator.**Interpolator**(*trajectory*)

Trajectory interpolator

**trajectory**

Trajectory to interpolate

**Type** dict

#### Examples

```
>>> interp = sorotraj.Interpolator(traj)
... actuation_fn = interp.get_interp_function(
...     num_reps=1,
...     speed_factor=1.0,
...     invert_direction=False)
... interp.get_final_time()
8.0
```

**get_cycle_function**(*num_reps=1*, *speed_factor=1.0*, *invert_direction=False*, *as_list=None*)

Get a function to return the current cycle number given time as an input

**Parameters**

- **num_reps** (*int*) – Number of times to repeat the "main" trajectory segment
- **speed_factor** (*float*) – Speed multiplier (times are multiplied by inverse of this)
- **invert_direction** (*Union[bool, list]*) – Invert the sign of the interpolated values. If True, all signs are flipped. If list, invert_direction is treated as a list of indices.

**Returns**

- **cycle_function** (*function*) – The cycle function
- **final_time** (*float*) – The end time of the trajectory

`get_final_time`()
Get the final time of the most-recent interpolator

(This function exists for backward compatibillity. In the future, obtain the final time from the "get_traj_function" instead.)

`get_interp_function`(*num_reps=1*, *speed_factor=1.0*, *invert_direction=False*, *as_list=None*)
Get a trajectory interpolation function with the specified parameters

(This function exists for backward compatibillity. In the future, use "get_traj_function" instead.)

**Parameters**

- **num_reps** (*int*) – Number of times to repeat the "main" trajectory segment
- **speed_factor** (*float*) – Speed multiplier (times are multiplied by inverse of this)
- **invert_direction** (*Union[bool, list]*) – Invert the sign of the interpolated values. If True, all signs are flipped. If list, invert_direction is treated as a list of indices.

**Returns** The trajectory interpolation function

**Return type** traj_function

**Raises** **ValueError** – If num_reps is less than 0, or if speed_factor is 0 or less

`get_traj_function`(*num_reps=1*, *speed_factor=1.0*, *invert_direction=False*)
Get a trajectory interpolation function with the specified parameters

**Parameters**

- **num_reps** (*int*) – Number of times to repeat the "main" trajectory segment
- **speed_factor** (*float*) – Speed multiplier (times are multiplied by inverse of this)
- **invert_direction** (*Union[bool, list]*) – Invert the sign of the interpolated values. If True, all signs are flipped. If list, invert_direction is treated as a list of indices.

**Returns**

- **traj_function** (*function*) – The trajectory interpolation function
- **final_time** (*float*) – The end time of the trajectory

### 3.2.2 Custom Back-End Interpolators

Several custom interpolation classes are used under the hood to make the functions behave like the physical control system. Below you can find documentation for these classes

`class sorotraj.interpolator.TrajectoryInterpolator`(*traj_unpacked*, *num_reps=1*, *speed_factor=1.0*, *invert_direction=False*, *fill_value=None*)
A trajectory interpolator based on specified parameters

**Parameters**

- **traj_unpacked** (*dict*) – Unpacked trajectory object (dict where keys are trajectory components with fields "time" and ""values")
- **num_reps** (*int, optional*) – Number of times to repeat the "main" trajectory segment
- **speed_factor** (*float, optional*) – Speed multiplier (times are multiplied by inverse of this)

- **invert_direction** (*Union[bool, list], optional*) – Invert the sign of the interpolated values. If True, all signs are flipped. If list, invert_direction is treated as a list of indices.
- **fill_value** (*Union[list, np.ndarray], optional*) – Default value of signals (only used when prefix and main are empty in the trajectory)

**Raises** **ValueError** – If all trajectory components are empty

**get_final_time**()
Get the final time of the trajectory

**Returns** **final_time** – The final time

**Return type** float

**get_traj_function**()
Get the trajectory function

**Returns** **traj_function** – The trajectory interpolation meta-function.

**Return type** function

**traj_function**(*x0*)
The trajectory interpolation function

**Parameters** **x0** (*Union[float, list, np.ndarray]*) –

**Returns** **output** – The trajectory at the given time point(s)

**Return type** np.ndarray

**Raises**

- **ValueError** – If input is not a 1D array-like object
- **RuntimeError** – If the length of the output does not equal the length of the input

**class** sorotraj.interpolator.**WrappedInterp1d**(*x*, *y*, ***kwargs*)
Create a wrapping 1D interpolator

**Parameters**

- **x** (*dict*) – x points to use in interpolation
- **y** (*int, optional*) – Values to use for interpolation
- ****kwargs** (*optional*) – kwargs to pass to scipy.interpolate.interp1d().

**get_function**()
Get the wrapped interpolation function

**Returns** **wrapped_interp1d** – The wrapped interpolator function

**Return type** function

**max_wrap**(*x0*)
Calculate wrapped x values when x is greater than the wrapping bounds

**Parameters** **x0** (*np.ndarray*) – Values of x

**Returns** **wrapped_x0** – Values of x wrapped.

**Return type** np.ndarray

**min_wrap**(*x0*)
Calculate wrapped x values when x is less than the wrapping bounds

**Parameters** **x0** (*np.ndarray*) – Values of x

**Returns** **wrapped_x0** – Values of x wrapped.

**Return type** np.ndarray

**wrapped_interp1d**(*x0*)
The wrapped interp1d function. Input x0, return interpolated cyclic values

**Parameters** **x0** (*Union[float, list, np.ndarray]*) – Values of x where you want to interpolate

**Returns** **output** – The interpolated values of y at the given time point(s)

**Return type** np.ndarray

**Raises** **ValueError** – If the input is not 1D

sorotraj.interpolator.**interp1d_patched**(*x*, *y*, ***kwargs*)
Get a 1D interpolation function where single-length input data are handled

When the length of x and y is greater than 1, interp1d is used. When the legnth of x and y is 1, use the value of y for all values of x0.

**Parameters** **x0** (*Union[float, list, np.ndarray]*) – Values of x where you want to interpolate

**Returns** **patched_interp1d** – The patched interp1d function (same way the regular interp1d works)

**Return type** function

CHAPTER

FOUR

# CONTRIBUTING

Contributing Checklist

- only through a new branch and reviewed PR (no pushes to master!)
- always bump the version of your branch by increasing the version number listed in setup.py

CHAPTER

# FIVE

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CHAPTER

SIX

# QUICK INSTALL

```
pip install sorotraj
```

CHAPTER

SEVEN

# EXPLORE THE EXAMPLES

Check out the *Examples*, or run any of the files in the examples folder. The "*Build One Trajectory*" example is a great place to start!

CHAPTER

# EIGHT

# LINKS

- **Documentation:** Read the Docs
- **pip install:** View on PyPi
- **Source code:** Github

CHAPTER

NINE

# CONTACT

If you have questions, or if you've done something interesting with this package, get in touch with Clark Teeple, or the Harvard Microrobotics Lab!

If you find a problem or want something added to the library, open an issue on Github.

CHAPTER

# TEN

# USED IN...

Sorotraj has enabled several published works:

- [Graule *et al.*, 2021]
- [Teeple *et al.*, 2021]
- [Teeple *et al.*, 2021]

## 10.1 References

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# PYTHON MODULE INDEX

## S

# INDEX

## W