Example to plot directly into latex

19-10-2019

1 Introduction

2 Genetic Algorithm Performance

To illustrate how the python code exports the figures directly into the report, this second ”hw2” is included. Below are the pictures that are created by the code listed in **??** and **??**.

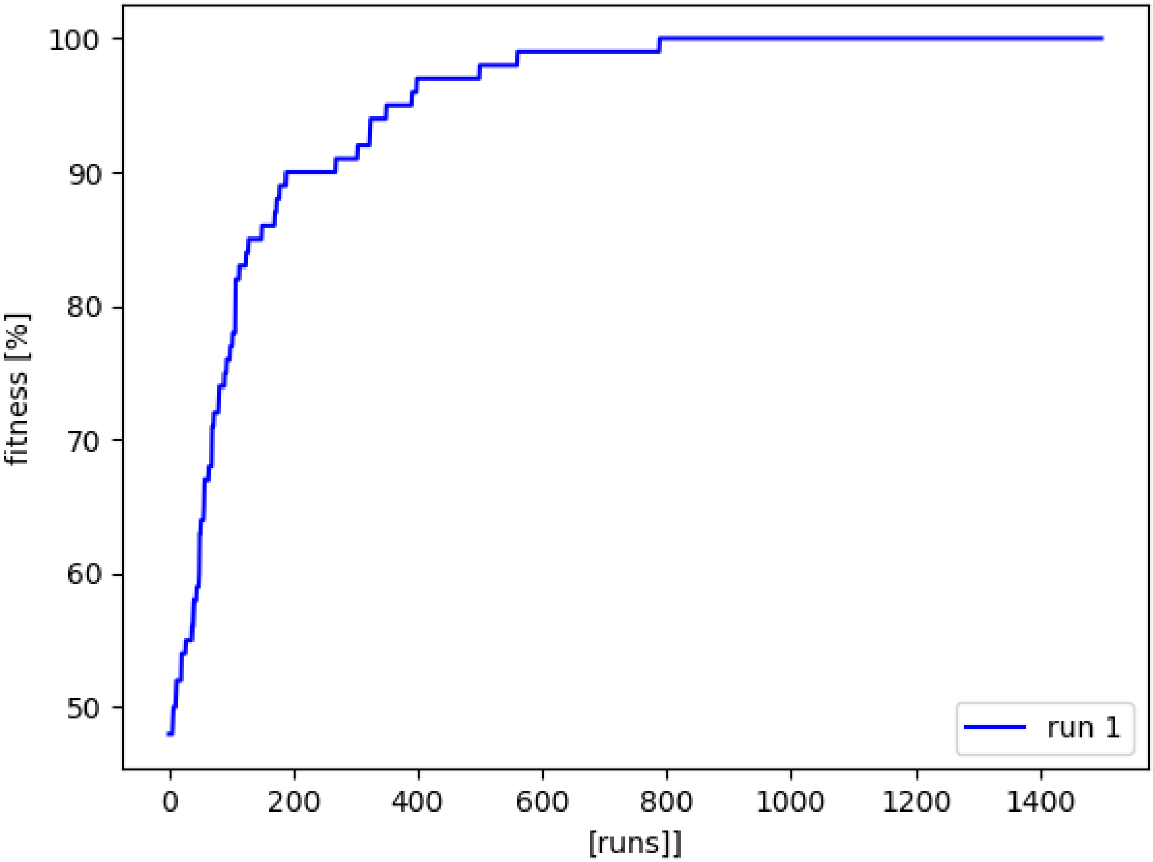


Figure 1: Performance of some genetic algorithm

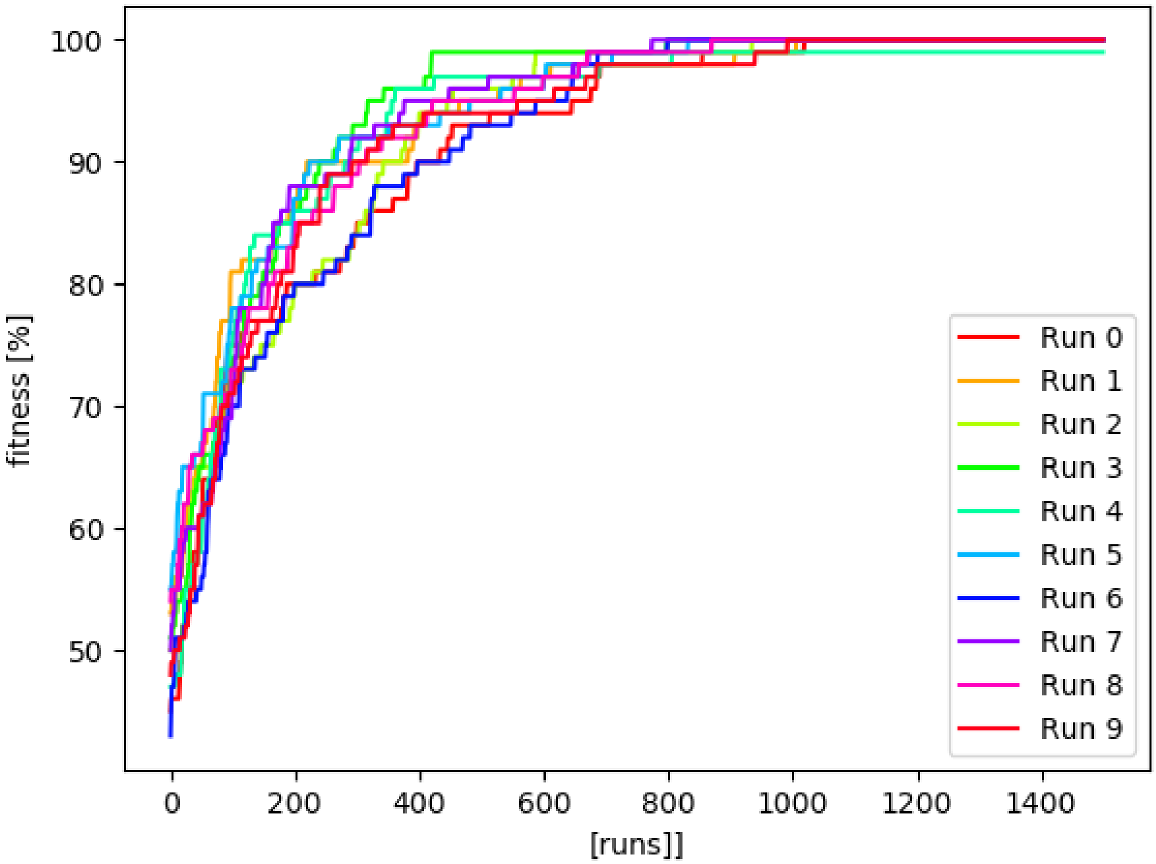


Figure 2: Performance of some genetic algorithm

A Appendix __main__.py

```
import os
from .Main import Main

print(f'Hi, I\'ll be running the main code, and I\'ll let you know when I\'m done.')
project_nr = 1
main = Main()

notebook_names = ['AE4868_example_notebook_update20201025.ipynb']
notebook_names = []# TODO: re-enable

# run the jupyter notebooks for assignment 1
main.run_jupyter_notebooks(project_nr,notebook_names)

# convert jupyter notebook for assignment 1 to pdf
main.convert_notebooks_to_pdf(project_nr,notebook_names)

# export the code to latex
main.export_code_to_latex(project_nr)

# compile the latex report
main.compile_latex_report(project_nr)

################################################################
```

```
###########example code to illustrate python-latex  image sync
    ↪ #########
#############runs arbitrary genetic algorithm, can be deleted
    ↪ ###########
################################################################
# run a genetic algorithm to create some data for a plot.
print("now running a")
res = main.do_run_a()

# plot some graph with a single line, general form is:
# plt_tex.plotSingleLines(plt_tex,x,y,"x-axis label","y-axis label",
    ↪ lineLabels,"filename",legend_position,project_nr)
# main.plt_tex.plotSingleLine(plt_tex,range(0, len(res)),res,"[runs
    ↪ ]]","fitness [%]","run 1","4a",4,project_nr)

# run a genetic algorithm to create some data for another plot.
print("now running b")
main.do4b(project_nr)

# run a genetic algorithm to create some data for another plot.
print("now running 4c")
main.do4c(project_nr)

print(f'Done.')
```

B Appendix Main.py

```python
# Example code that creates plots directly in report
# Code is an implementation of a genetic algorithm
import random
from matplotlib import pyplot as plt
from matplotlib import lines
import matplotlib.pyplot as plt
import numpy as np

from .Compile_latex import Compile_latex
from .Plot_to_tex import Plot_to_tex as plt_tex
from .Run_jupyter_notebooks import Run_jupyter_notebook
from .Export_code_to_latex import export_code_to_latex

# define global variables for genetic algorithm example
string_length = 100
mutation_chance= 1.0/string_length
max_iterations = 1500

class Main:

    def __init__(self):
        self.run_jupyter_notebook = Run_jupyter_notebook()
        pass


    def run_jupyter_notebooks(self,project_nr,notebook_names):
        '''runs a jupyter notebook'''
        notebook_path = f'code/project{project_nr}/src/'

        for notebook_name in notebook_names:
            self.run_jupyter_notebook.run_notebook(f'{notebook_path}{notebook_name}')

    def convert_notebooks_to_pdf(self,project_nr,notebook_names):
        '''converts a jupyter notebook to pdf'''
        notebook_path = f'code/project{project_nr}/src/'

        for notebook_name in notebook_names:
            self.run_jupyter_notebook.convert_notebook_to_pdf(f'{notebook_path}{notebook_name}')

    def export_code_to_latex(self, project_nr):
        export_code_to_latex(project_nr, 'main.tex')

    def compile_latex_report(self,project_nr):
        '''compiles latex code to pdf'''
        compile_latex =Compile_latex(project_nr ,'main.tex')

    ################################################################
    ############example code to illustrate python-latex  image sync #########
    ##############runs arbitrary genetic algorithm, can be deleted ###########
    ################################################################
    def count(self,bits):
        count = 0
        for bit in bits:
            if bit:
                count = count + 1
        return count

    def gen_bit_sequence(self):
        bits = []
        for _ in range(string_length):
            bits.append(True if random.randint(0, 1) == 1 else False)
        return bits

    def mutate_bit_sequence(self,sequence):
        retval = []
        for bit in sequence :
            do_mutation = random.random() <= mutation_chance
            if(do_mutation):
                retval.append(not bit)
            else:
                retval.append(bit)
        return retval

    #execute a run a
    def do_run_a(self):

        seq = self.gen_bit_sequence()
        fitness = self.count(seq)
        results = [fitness]
        for run in range(max_iterations-1):
            new_seq = self.mutate_bit_sequence(seq)
            new_fitness = self.count(new_seq)
            if new_fitness > fitness:
                seq = new_seq
                fitness = new_fitness
            results.append(max(results[-1],fitness))
        return results


    #execute a run c
    def do_run_c(self):
        seq = self.gen_bit_sequence()
        fitness = self.count(seq)
        results = [fitness]
        for run in range(max_iterations):
            new_seq = self.mutate_bit_sequence(seq)
            new_fitness = self.count(new_seq)
            seq = new_seq
            fitness = new_fitness
            results.append(max(results[-1], fitness))
        return results

    def do4b(self,project_nr):
        optimum_found = 0

        # generate plot data
        plotResult = np.zeros((10,max_iterations), dtype=int);
        lineLabels = []

        # perform computation
        for run in range(10):
            res = self.do_run_a()
            if res[-1] == string_length:
                optimum_found +=1

            # store computation data for plotting
            lineLabels.append(f'Run {run}')
            plotResult[run,:]=res;
```

```python

        # plot multiple lines into report (res is an array of dataseries (representing the lines))
        # plt_tex.plotMultipleLines(plt_tex,x,y,"x-axis label","y-axis label",lineLabels,"filename",legend_position,project_nr)
        plt_tex.plotMultipleLines(plt_tex,range(0, len(res)),plotResult,"[runs]]","fitness [%]",lineLabels,"4b",4,project_nr)
        print("total optimum found: {} out of {} runs".format(optimum_found,10))

    def do4c(self,project_nr):
        optimum_found = 0

        # generate plot data
        plotResult = np.zeros((10,max_iterations+1), dtype=int);
        lineLabels = []

        # perform computation
        for run in range(10):
            res = self.do_run_c()
            if res[-1] == string_length:
                optimum_found +=1

            # Store computation results for plot
            lineLabels.append(f'Run {run}')
            plotResult[run,:]=res;

        # plot multiple lines into report (res is an array of dataseries (representing the lines))
        # plt_tex.plotMultipleLines(plt_tex,x,y,"x-axis label","y-axis label",lineLabels,"filename",legend_position,project_nr)
        plt_tex.plotMultipleLines(plt_tex,range(0, len(res)),plotResult,"[runs]]","fitness [%]",lineLabels,"4c",4,project_nr)

        print("total optimum found: {} out of {} runs".format(optimum_found, 10))

    def addTwo(self,x):
        ''' adds two to the incoming integer and returns the result of the computation.'''
        return x+2

if __name__ == '__main__':
    # initialize main class
    main = Main()
```

C Appendix Compile_latex.py

```
# runs a jupyter notebook and converts it to pdf

import os
import shutil
import nbformat
from nbconvert.preprocessors import ExecutePreprocessor

class Compile_latex:

    def __init__(self,project_nr,latex_filename):
        self.script_dir = self.get_script_dir()
        relative_dir = f'latex/project{project_nr}/'
        self.compile_latex(relative_dir,latex_filename)
        self.clean_up_after_compilation(latex_filename)
        self.move_pdf_into_latex_dir(relative_dir,latex_filename)

    # runs jupyter notebook
    def compile_latex(self,relative_dir,latex_filename):
        os.system(f'pdflatex {relative_dir}{latex_filename}')

    def clean_up_after_compilation(self,latex_filename):
        latex_filename_without_extention = latex_filename[:-4]
        print(f'latex_filename_without_extention={
           ↪ latex_filename_without_extention}')
        self.delete_file_if_exists(f'{
           ↪ latex_filename_without_extention}.aux')
        self.delete_file_if_exists(f'{
           ↪ latex_filename_without_extention}.log')
        self.delete_file_if_exists(f'texput.log')

    def move_pdf_into_latex_dir(self,relative_dir,latex_filename):
        pdf_filename = f'{latex_filename[:-4]}.pdf'
        destination= f'{self.get_script_dir()}/../../../{relative_dir
           ↪ }{pdf_filename}'

        try:
            shutil.move(pdf_filename, destination)
        except:
            print("Error while moving file ", pdf_filename)

    def delete_file_if_exists(self,filename):
        try:
            os.remove(filename)
        except:
            print(f'Error while deleting file: {filename} but that is
               ↪ not too bad because the intention is for it to not
               ↪ be there.')

    def get_script_dir(self):
        ''' returns the directory of this script regardles of from
           ↪ which level the code is executed '''
        return os.path.dirname(__file__)

if __name__ == '__main__':
    main = Compile_latex()
```

D Appendix Export_code_to_latex.py

```
# runs a jupyter notebook and converts it to pdf

import os
import shutil
import nbformat
from nbconvert.preprocessors import ExecutePreprocessor


def export_code_to_latex(project_nr, main_latex_filename):
        script_dir = get_script_dir()
        relative_dir = f'latex/project{project_nr}/'
        appendix_dir = script_dir+'/../../../'+relative_dir+'
           ↪ Appendices/'
        path_to_main_latex_file = f'{script_dir}/../../../{
           ↪ relative_dir}/{main_latex_filename}'
        root_dir = script_dir[0:script_dir.rfind(f'code/project{
           ↪ project_nr}')]

        python_filepaths = get_filenames_in_dir('py',script_dir, ['
           ↪ __init__.py'])
        compiled_notebook_pdf_filepaths = get_compiled_notebook_paths
           ↪ (script_dir)

        python_files_already_included_in_appendices =
           ↪ get_code_files_already_included_in_appendices('.py',
           ↪ python_filepaths, appendix_dir, project_nr, root_dir)
        notebook_pdf_files_already_included_in_appendices =
           ↪ get_code_files_already_included_in_appendices('.ipynb',
           ↪  compiled_notebook_pdf_filepaths, appendix_dir,
           ↪ project_nr, root_dir)

        missing_python_files_in_appendices =
           ↪ get_code_files_not_yet_included_in_appendices('.py',
           ↪ python_files_already_included_in_appendices,
           ↪ python_filepaths)
        missing_notebook_files_in_appendices =
           ↪ get_code_files_not_yet_included_in_appendices('.pdf',
           ↪ notebook_pdf_files_already_included_in_appendices,
           ↪ compiled_notebook_pdf_filepaths)

        created_python_appendix_filenames =
           ↪ create_appendices_with_code('.py',
           ↪ missing_python_files_in_appendices, appendix_dir,
           ↪ project_nr, root_dir)
        created_notebook_appendix_filenames =
           ↪ create_appendices_with_code('.ipynb',
           ↪ missing_notebook_files_in_appendices, appendix_dir,
           ↪ project_nr, root_dir)

        appendices = get_list_of_appendix_files(appendix_dir,
           ↪ python_filepaths, compiled_notebook_pdf_filepaths)

        main_tex_code, start_index, end_index, appendix_tex_code =
           ↪ get_appendix_tex_code(path_to_main_latex_file)
        non_code_appendices, non_code_appendix_lines =
           ↪ get_order_of_non_code_appendices_in_main(
           ↪ appendix_tex_code,appendices) # assumes non-included
           ↪ non-code appendices should not be included.

        python_appendix_filenames = list(map(lambda x: x.
          ↪ appendix_filename, filter_appendices_by_type(appendices
          ↪ , 'python')))
        sorted_created_python_appendices = sort_python_appendices(
          ↪ filter_appendices_by_type(appendices, 'python'))
        sorted_python_appendix_filenames = list(map(lambda x: x.
          ↪ appendix_filename, sorted_created_python_appendices))

        notebook_appendix_filenames = list(map(lambda x: x.
          ↪ appendix_filename, filter_appendices_by_type(appendices
          ↪ , 'notebook')))
        sorted_created_notebook_appendices = sort_notebook_appendices
          ↪ (filter_appendices_by_type(appendices, 'notebook'))
        sorted_notebook_appendix_filenames = list(map(lambda x: x.
          ↪ appendix_filename, sorted_created_notebook_appendices))

        appendix_latex_code = create_appendices_latex_code(
          ↪ non_code_appendix_lines,
          ↪ sorted_created_python_appendices,
          ↪ sorted_created_notebook_appendices, project_nr)

        updated_main_tex_code = substitute_appendix_code(
          ↪ main_tex_code, start_index, end_index,
          ↪ appendix_latex_code)

        overwrite_content_to_file(path_to_main_latex_file,
          ↪ updated_main_tex_code)


def create_appendices_latex_code(
  ↪ main_non_code_appendix_inclusion_lines, python_appendices,
  ↪ notebook_appendices, project_nr):
    ''' creates the appendix text for main.'''
    main_appendix_inclusion_lines =
      ↪ main_non_code_appendix_inclusion_lines
    for appendix in python_appendices:
        line = update_appendix_tex_code(appendix.appendix_filename,
          ↪ project_nr)
        main_appendix_inclusion_lines.append(line)

    for appendix in notebook_appendices:
        line = update_appendix_tex_code(appendix.appendix_filename,
          ↪ project_nr)
        main_appendix_inclusion_lines.append(line)
    print(f'main_appendix_inclusion_lines={
      ↪ main_appendix_inclusion_lines}')
    return main_appendix_inclusion_lines


def filter_appendices_by_type(appendices, appendix_type):
    ''' Returns the list of appendices of certain type from a list of
      ↪  appendix objects.'''
    return_appendices = []
    for appendix in appendices:
        if appendix.appendix_type == appendix_type:
            return_appendices.append(appendix)
    return return_appendices


def sort_python_appendices(appendices):
    ''' First puts __main__.py, followed by main.py followed by a-z
      ↪ code files.'''
```

```python
    return_appendices = []
    for appendix in appendices: # first get appendix containing __main__.py
        if (appendix.code_filename=="__main__.py") or (appendix.code_filename=="__Main__.py"):
            return_appendices.append(appendix)
            appendices.remove(appendix)
    for appendix in appendices: # second get appendix containing main.py
        if (appendix.code_filename=="main.py") or (appendix.code_filename=="Main.py"):
            return_appendices.append(appendix)
            appendices.remove(appendix)
    return_appendices

    # Filter remaining appendices in order of a-z
    filtered_remaining_appendices = [i for i in appendices if i.code_filename is not None]
    appendices_sorted_a_z = filter_list_on_property(filtered_remaining_appendices)
    return return_appendices+appendices_sorted_a_z


def sort_notebook_appendices(appendices):
    ''' Sorts notebooks on a-z pdf filenames.'''
    return_appendices = []
    filtered_remaining_appendices = [i for i in appendices if i.code_filename is not None]
    appendices_sorted_a_z = filter_list_on_property(filtered_remaining_appendices)
    return return_appendices+appendices_sorted_a_z


def filter_list_on_property(appendices):
    ''' Returns a list based on the property: code_filename'''
    attributes = list(map(lambda x: x.code_filename, appendices))
    sorted_indices = sorted(range(len(attributes)), key=lambda k: attributes[k])
    sorted_list = []
    for i in sorted_indices:
        sorted_list.append(appendices[i])
    return sorted_list


def get_order_of_non_code_appendices_in_main(appendix_tex_code, appendices):
    ''' Scans the lines of appendices in the main code, and returns the lines that
    of appendices that do not contain code, in specified order.'''
    non_code_appendices = []
    non_code_appendix_lines = []
    appendix_tex_code = list(dict.fromkeys(appendix_tex_code))
    for line in appendix_tex_code:
        appendix_filename = get_filename_from_latex_appendix_line(line, appendices)

        # Check if line is not commented
        if not appendix_filename is None:
            if not line_is_commented(line,appendix_filename):
                appendix = get_appendix_from_filename(appendix_filename, appendices)
                if appendix.appendix_type == "no_code":
                    non_code_appendices.append(appendix)
                    non_code_appendix_lines.append(line)
    return non_code_appendices, non_code_appendix_lines


def get_filename_from_latex_appendix_line(appendix_line, appendices):
    for filename in list(map(lambda appendix: appendix.appendix_filename, appendices)):
        if filename in appendix_line:
            return filename


def get_appendix_from_filename(appendix_filename, appendices):
    for appendix in appendices:
        if appendix_filename == appendix.appendix_filename:
            return appendix


def get_compiled_notebook_paths(script_dir):
    ''' Returns the list of jupiter notebook filepaths that were compiled successfully'''
    notebook_filepaths= get_filenames_in_dir('.ipynb', script_dir)
    compiled_notebook_filepaths = []

    # check if the jupyter notebooks were compiled
    for notebook_filepath in notebook_filepaths:

        # swap file extension
        notebook_filepath = notebook_filepath.replace('.ipynb','.pdf')

        # check if file exists
        if os.path.isfile(notebook_filepath):
            compiled_notebook_filepaths.append(notebook_filepath)
    return compiled_notebook_filepaths


def get_list_of_appendix_files(appendix_dir, absolute_python_filepaths, absolute_notebook_filepaths):
    ''' Returns a list with all the appendix files with .tex extension.'''
    appendices = []
    appendices_paths = get_filenames_in_dir('.tex', appendix_dir)

    for appendix_filepath in appendices_paths:
        appendix_type = "no_code"
        appendix_filecontent = read_file(appendix_filepath)
        line_nr_python_file_inclusion = get_line_of_latex_command(appendix_filecontent, "\pythonexternal{")
        line_nr_notebook_file_inclusion = get_line_of_latex_command(appendix_filecontent, "\includepdf[pages=")
        if  line_nr_python_file_inclusion > -1:
            appendix_type = "python"
            # get python filename
            line = appendix_filecontent[line_nr_python_file_inclusion]
            filename = get_filename_from_latex_inclusion_command('.py', line, "\pythonexternal{")
            appendices.append(Appendix(appendix_filepath, appendix_filecontent, appendix_type, filename, line))
        if line_nr_notebook_file_inclusion > -1:
            appendix_type = "notebook"
            line = appendix_filecontent[line_nr_notebook_file_inclusion]
            filename = get_filename_from_latex_inclusion_command('.pdf', line, "\includepdf[pages=")
            appendices.append(Appendix(appendix_filepath, appendix_filecontent, appendix_type, filename, line))
        else:
            appendices.append(Appendix(appendix_filepath, appendix_filecontent, appendix_type))
    return appendices


def get_filename_from_latex_inclusion_command(extension, appendix_line, start_substring):
    ''' returns the filename in a latex inclusion command that is located in an appendix.
    The inclusion command includes a python code or jupiter notebook pdf.'''
    start_index = appendix_line.index(start_substring)
    end_index = appendix_line.index(extension)
    return get_filename_from_dir(appendix_line[start_index:end_index+len(extension)])


def get_filenames_in_dir(extension, path, excluded_files=None):
    '''Returns a list of the relative paths to all files within the code/projectX/src/ folder that match
    the given file extension.'''
    filepaths=[]
    for r, d, f in os.walk(path):
        for file in f:
            if file.endswith(extension):
                if (excluded_files is None) or ((not excluded_files is None) and (not file in excluded_files)):
                    filepaths.append(r+'/'+file)
    return filepaths


def get_code_files_already_included_in_appendices(extension, absolute_filepaths, appendix_dir, project_nr, root_dir):
    ''' Returns a list of filepaths that are already properly included in some appendix of this projectX,'''
    appendix_files = get_filenames_in_dir('.tex', appendix_dir)
    contained_codes = []
    for code_filepath in absolute_filepaths:
        for appendix_filepath in appendix_files:
            appendix_filecontent = read_file(appendix_filepath)
            line_nr = check_if_appendix_contains_file(extension, code_filepath, appendix_filecontent, project_nr, root_dir)
            if line_nr>-1:
                # add filepath to list of files that are already in the appendices
                contained_codes.append(Appendix_with_code(code_filepath,
                appendix_filepath,
                appendix_filecontent,
                line_nr,
                '.py'))
    return contained_codes
```

```


def check_if_appendix_contains_file(extension, code_filepath,
  ↪ appendix_content, project_nr, root_dir):
    ''' scans an appendix content to determine whether it contains a
      ↪ substring that
    includes the python code file.'''
    # convert code_filepath to the inclusion format in latex format
    latex_relative_filepath = f'latex/project{project_nr}/../../{
      ↪ code_filepath[len(root_dir):]}'
    latex_command = get_latex_inclusion_command(extension,
      ↪ latex_relative_filepath)
    return get_line_of_latex_command(appendix_content, latex_command)


def get_line_of_latex_command(appendix_content, latex_command):
    ''' Returns the line number of a latex command if it is found.
      ↪ Returns -1 otherwise.'''
    # check if the file is in the latex code
    line_nr = 0
    for line in appendix_content:
        if latex_command in line:
            if line_is_commented(line,latex_command):
                commented=True
            else:
                return line_nr
        line_nr=line_nr+1
    return -1


def line_is_commented(line, target_substring):
    ''' Returns true if a line is commented, returns false otherwise
      ↪ '''
    left_of_command = line[:line.rfind(target_substring)]
    if '%' in left_of_command:
        return True
    return False


def get_latex_inclusion_command(extension,
  ↪ latex_relative_filepath_to_codefile):
    if extension==".py":
        left = "\pythonexternal{"
        right = "}"
        latex_command = f'{left}{latex_relative_filepath_to_codefile
          ↪ }{right}'
    elif extension==".ipynb":

        left = "\includepdf[pages=-]{"
        right = "}"
        latex_command = f'{left}{latex_relative_filepath_to_codefile
          ↪ }{right}'
    return latex_command


def read_file(filepath):
    ''' Reads content of a file and returns it as a list of strings
      ↪ '''
    with open(filepath) as f:
        content = f.readlines()
    return content

```

```python

def get_code_files_not_yet_included_in_appendices(extension, contained_codes, code_filepaths):
    ''' Returns a list of filepaths that are not yet properly included in some appendix of this projectX,'''
    contained_filepaths = list(map(lambda contained_file: contained_file.code_filepath, contained_codes))
    not_contained = []
    for filepath in code_filepaths:
        if not filepath in contained_filepaths:
            not_contained.append(filepath)
    return not_contained


def create_appendices_with_code(extension, code_filepaths, appendix_dir, project_nr, root_dir):
    ''' Creates the latex appendix files in with relevant codes included.'''
    appendix_filenames = []
    appendix_reference_index = 0

    for code_filepath in code_filepaths:
        latex_relative_filepath = f'latex/project{project_nr}/../../{code_filepath[len(root_dir):]}'
        content = []
        filename = get_filename_from_dir(code_filepath)
        content = create_section(content,filename, appendix_reference_index)
        inclusion_command = get_latex_inclusion_command(extension, latex_relative_filepath)
        content.append(inclusion_command)
        overwrite_content_to_file(f'{appendix_dir}Auto_generated_{extension[1:]}_App{appendix_reference_index}.tex', content, False)
        appendix_filenames.append(f'Auto_generated_{extension[1:]}_App{appendix_reference_index}.tex')
        appendix_reference_index = appendix_reference_index+1
    return appendix_filenames


def create_section(content, code_filename, appendix_reference_index):
    # write section
    left ="\section{Appendix "
    middle = code_filename.replace("_","\_")
    right = "}\label{app:"
    end = "}" # TODO: update appendix reference index
    content.append(f'{left}{middle}{right}{appendix_reference_index}{end}')
    return content


def overwrite_content_to_file(filepath, content, content_has_newlines=True):
    ''' Writes the content of an appendix to a new appendix'''
    with open(filepath,'w') as f:
        for line in content:
            if content_has_newlines:
                f.write(line)
            else:
                f.write(line+'\n')


```

```python
def get_appendix_tex_code(main_latex_filename):
    ''' gets the latex appendix code from the main tex file.'''
    main_tex_code = read_file(main_latex_filename)
    start =  "\\begin{appendices}"
    end = "\end{appendices}"
    start_index = get_index_of_substring_in_list(start, main_tex_code)+1
    end_index = get_index_of_substring_in_list(end, main_tex_code)
    return main_tex_code, start_index, end_index, main_tex_code[start_index:end_index]


def get_index_of_substring_in_list(target_substring, lines):
    for i in range(0, len(lines)):
        if target_substring in lines[i]:
            if not line_is_commented(lines[i], target_substring):
                return i


def update_appendix_tex_code(appendix_filename, project_nr):
    ''' Includes the appendices as latex commands in the tex code string'''
    left = "\input{latex/project"
    middle = "/Appendices/"
    right = "} \\newpage\n"
    return f'{left}{project_nr}{middle}{appendix_filename}{right}'


def substitute_appendix_code(main_tex_code, start_index, end_index, updated_appendices_tex_code):
    ''' Replaces the old latex code that include the appendices with the new latex
    commands that include the appendices in the latex report.'''
    updated_main_tex_code = main_tex_code[0:start_index]+updated_appendices_tex_code+main_tex_code[end_index:]
    return updated_main_tex_code


def get_filename_from_dir(path):
    return path[path.rfind("/")+1:]


def get_script_dir():
    ''' returns the directory of this script regardles of from which level the code is executed '''
    return os.path.dirname(__file__)


class Appendix_with_code:
    ''' stores in which appendix file and accompanying line number in the appendix in which a code file is
    already included. Does not take into account whether this appendix is in the main tex file or not'''
    def __init__(self, code_filepath, appendix_filepath, appendix_content, file_line_nr, extension):
        self.code_filepath = code_filepath
        self.appendix_filepath = appendix_filepath
        self.appendix_content = appendix_content
        self.file_line_nr = file_line_nr
        self.extension = extension

class Appendix:
    ''' stores in appendix files and type of appendix.'''
    # TODO: refactor remove the appendix_ cause that's what the object already implies
    def __init__(self, appendix_filepath, appendix_content, appendix_type, code_filename=None, appendix_inclusion_line=None):
        self.appendix_filepath = appendix_filepath
        self.appendix_filename = get_filename_from_dir(self.appendix_filepath)
        self.appendix_content = appendix_content
        self.appendix_type = appendix_type # TODO: perform validation of input values
        self.code_filename = code_filename
        self.appendix_inclusion_line = appendix_inclusion_line
```

E Appendix Plot_to_tex.py

```
### Call this from another file, for project 11, question 3b:
### from Plot_to_tex import Plot_to_tex as plt_tex
### multiple_y_series = np.zeros((nrOfDataSeries,nrOfDataPoints), dtype=int); # actually fill with data
### lineLabels = [] # add a label for each dataseries
### plt_tex.plotMultipleLines(plt_tex,single_x_series,multiple_y_series,"x-axis label [units]","y-axis label [units]",lineLabels,"3b",4,11)
### 4b=filename
### 4 = position of legend, e.g. top right.
###
### For a single line, use:
### plt_tex.plotSingleLine(plt_tex,range(0, len(dataseries)), dataseries,"x-axis label [units]","y-axis label [units]",lineLabel,"3b",4,11)

### You can also plot a table directly into latex, see example_create_a_table(..)
###
### Then put it in latex with for example:
###\begin{table}[H]
###    \centering
###    \caption{Results some computation.}\label{tab:some_computation}
###    \begin{tabular}{|c|c|} % remember to update this to show all columns of table
###        \hline
###        \input{latex/project3/tables/q2.txt}
###    \end{tabular}
###\end{table}
import random
from matplotlib import lines
import matplotlib.pyplot as plt
import numpy as np
import os
class Plot_to_tex:

    def __init__(self):
        self.script_dir = self.get_script_dir()
        print("Created main")

    # plot graph (legendPosition = integer 1 to 4)
    def plotSingleLine(self,x_path,y_series,x_axis_label,y_axis_label,label,filename,legendPosition,project_nr):
        fig=plt.figure();
        ax=fig.add_subplot(111);
        ax.plot(x_path,y_series,c='b',ls='-',label=label,fillstyle='none');
        plt.legend(loc=legendPosition);
        plt.xlabel(x_axis_label);
        plt.ylabel(y_axis_label);
        plt.savefig(os.path.dirname(__file__)+'/../../../latex/project'+str(project_nr)+'/Images/'+filename+'.png');
#         plt.show();

    # plot graphs
    def plotMultipleLines(self,x,y_series,x_label,y_label,label,filename,legendPosition,project_nr):
        fig=plt.figure();
        ax=fig.add_subplot(111);
```

```python

        # generate colours
        cmap = self.get_cmap(len(y_series[:,0]))

        # generate line types
        lineTypes = self.generateLineTypes(y_series)

        for i in range(0,len(y_series)):
            # overwrite linetypes to single type
            lineTypes[i] = "-"
            ax.plot(x,y_series[i,:],ls=lineTypes[i],label=label[i], fillstyle='none',c=cmap(i)); # color

        # configure plot layout
        plt.legend(loc=legendPosition);
        plt.xlabel(x_label);
        plt.ylabel(y_label);
        plt.savefig(os.path.dirname(__file__)+'/../../../latex/project'+str(project_nr)+'/Images/'+filename+'.png');

        print(f'plotted lines')

    # Generate random line colours
    # Source: https://stackoverflow.com/questions/14720331/how-to-generate-random-colors-in-matplotlib
    def get_cmap(n, name='hsv'):
        '''Returns a function that maps each index in 0, 1, ..., n-1 to a distinct
        RGB color; the keyword argument name must be a standard mpl colormap name.'''
        return plt.cm.get_cmap(name, n)

    def generateLineTypes(y_series):
        # generate varying linetypes
        typeOfLines = list(lines.lineStyles.keys())

        while(len(y_series)>len(typeOfLines)):
            typeOfLines.append("-.");

        # remove void lines
        for i in range(0, len(y_series)):
            if (typeOfLines[i]=='None'):
                typeOfLines[i]='-'
            if (typeOfLines[i]==''):
                typeOfLines[i]=':'
            if (typeOfLines[i]==' '):
                typeOfLines[i]='--'
        return typeOfLines

    # Create a table with: table_matrix = np.zeros((4,4),dtype=object) and pass it to this object
    def put_table_in_tex(self, table_matrix,filename,project_nr):
        cols = np.shape(table_matrix)[1]
        format = "%s"
        for col in range(1,cols):
            format = format+" & %s"
        format = format+""
        plt.savetxt(os.path.dirname(__file__)+"/../../../latex/project"+str(project_nr)+"/tables/"+filename+".txt", table_matrix, delimiter=' & ', fmt=format, newline=' \\\\ \hline \n')

    # replace this with your own table creation and then pass it to put_table_in_tex(..)
    def example_create_a_table(self):
        project_nr = "1"
        table_name = "example_table_name"
        rows = 2;
        columns = 4;
        table_matrix = np.zeros((rows,columns),dtype=object)
        table_matrix[:,:]="" # replace the standard zeros with emtpy cell
        print(table_matrix)
        for column in range(0,columns):
            for row in range(0,rows):
                table_matrix[row,column]=row+column
        table_matrix[1,0]="example"
        table_matrix[0,1]="grid sizes"

        self.put_table_in_tex(table_matrix,table_name,project_nr)


    def get_script_dir(self):
        ''' returns the directory of this script regardles of from which level the code is executed '''
        return os.path.dirname(__file__)

if __name__ == '__main__':
    main = Plot_to_tex()
    main.example_create_a_table()
```

F Appendix Run_jupyter_notebooks.py

```python
# runs a jupyter notebook and converts it to pdf

import os
import nbformat
from nbconvert.preprocessors import ExecutePreprocessor

class Run_jupyter_notebook:

    def __init__(self):
        self.script_dir = self.get_script_dir()
        print("Created main")

    # runs jupyter notebook
    def run_notebook(self,notebook_filename):


        # Load your notebook
        with open(notebook_filename) as f:
            nb = nbformat.read(f, as_version=4)

        # Configure
        ep = ExecutePreprocessor(timeout=600, kernel_name='python3')

        # Execute
        ep.preprocess(nb, {'metadata': {'path': f'{self.
            ↪ get_script_dir()}/../../../'}})

        # Save output notebook
        with open(notebook_filename, 'w', encoding='utf-8') as f:
            nbformat.write(nb, f)

    # converts jupyter notebook to pdf
    def convert_notebook_to_pdf(self,notebook_filename):
        os.system(f'jupyter nbconvert --to pdf {notebook_filename}')

    def get_script_dir(self):
        ''' returns the directory of this script regardles of from
            ↪ which level the code is executed '''
        return os.path.dirname(__file__)

if __name__ == '__main__':
    main = Run_jupyter_notebook()
```

Appendix Example Jupyter Notebook

AE4868_example_notebook_update20201025

December 26, 2020

[1]:

```python
def addThree(input_nr):
    '''returns the input integer plus 3, used to verify unit test'''
    return input_nr + 3
```

[2]:

```python
################################################################################
# IMPORT STATEMENTS ############################################################
################################################################################
import os
import numpy as np
from tudatpy.kernel import constants
from tudatpy.kernel.interface import spice_interface
from tudatpy.kernel.simulation import environment_setup
from tudatpy.kernel.simulation import propagation_setup
from tudatpy.kernel.astro import conversion

# Set path to latex image folders for project 1
latex_image_path = 'latex/project1/Images/'

# Load spice kernels.
spice_interface.load_standard_kernels()

# Set simulation start and end epochs.
simulation_start_epoch = 0.0
simulation_end_epoch = constants.JULIAN_DAY

############################################################################
# CREATE ENVIRONMENT #######################################################
############################################################################

# Create default body settings for selected celestial bodies
bodies_to_create = ["Sun", "Earth", "Moon", "Mars", "Venus"]

# Create default body settings for bodies_to_create, with "Earth"/"J2000" as
# global frame origin and orientation. This environment will only be valid
# in the indicated time range
# [simulation_start_epoch --- simulation_end_epoch]
body_settings = environment_setup.get_default_body_settings(
    bodies_to_create,
    simulation_start_epoch,
    simulation_end_epoch,
    "Earth","J2000")

# Create system of selected celestial bodies
bodies = environment_setup.create_system_of_bodies(body_settings)

###########################################################################
# CREATE VEHICLE ##########################################################
###########################################################################

# Create vehicle objects.
bodies.create_empty_body( "Delfi-C3" )
bodies.get_body( "Delfi-C3").set_constant_mass(400.0)

# Create aerodynamic coefficient interface settings, and add to vehicle
reference_area = 4.0
drag_coefficient = 1.2
aero_coefficient_settings = environment_setup.aerodynamic_coefficients.constant(
    reference_area,[drag_coefficient,0,0]
)
environment_setup.add_aerodynamic_coefficient_interface(
            bodies, "Delfi-C3", aero_coefficient_settings )

# Create radiation pressure settings, and add to vehicle
reference_area_radiation = 4.0
radiation_pressure_coefficient = 1.2
occulting_bodies = ["Earth"]
radiation_pressure_settings = environment_setup.radiation_pressure.cannonball(
    "Sun", reference_area_radiation, radiation_pressure_coefficient,␣
 ↪occulting_bodies
)
environment_setup.add_radiation_pressure_interface(
            bodies, "Delfi-C3", radiation_pressure_settings )

###########################################################################
# CREATE ACCELERATIONS ####################################################
###########################################################################

# Define bodies that are propagated.
bodies_to_propagate = ["Delfi-C3"]

# Define central bodies.
central_bodies = ["Earth"]

# Define accelerations acting on Delfi-C3 by Sun and Earth.
```

```
accelerations_settings_delfi_c3 = dict(
    Sun=
    [
        propagation_setup.acceleration.cannonball_radiation_pressure(),
        propagation_setup.acceleration.point_mass_gravity()
    ],
    Earth=
    [
        propagation_setup.acceleration.spherical_harmonic_gravity(5, 5),
        propagation_setup.acceleration.aerodynamic()
    ])

# Define point mass accelerations acting on Delfi-C3 by all other bodies.
for other in set(bodies_to_create).difference({"Sun", "Earth"}):
    accelerations_settings_delfi_c3[other] = [
        propagation_setup.acceleration.point_mass_gravity()]

# Create global accelerations settings dictionary.
acceleration_settings = {"Delfi-C3": accelerations_settings_delfi_c3}

# Create acceleration models.
acceleration_models = propagation_setup.create_acceleration_models(
    bodies,
    acceleration_settings,
    bodies_to_propagate,
    central_bodies)

############################################################################
# CREATE PROPAGATION SETTINGS ##############################################
############################################################################

# Set initial conditions for the Asterix satellite that will be
# propagated in this simulation. The initial conditions are given in
# Keplerian elements and later on converted to Cartesian elements.
earth_gravitational_parameter = bodies.get_body( "Earth" ).
 ↪gravitational_parameter
initial_state = conversion.keplerian_to_cartesian(
    gravitational_parameter=earth_gravitational_parameter,
    semi_major_axis=7500.0E3,
    eccentricity=0.1,
    inclination=np.deg2rad(85.3),
    argument_of_periapsis=np.deg2rad(235.7),
    longitude_of_ascending_node=np.deg2rad(23.4),
    true_anomaly=np.deg2rad(139.87)
)

# Define list of dependent variables to save.
```

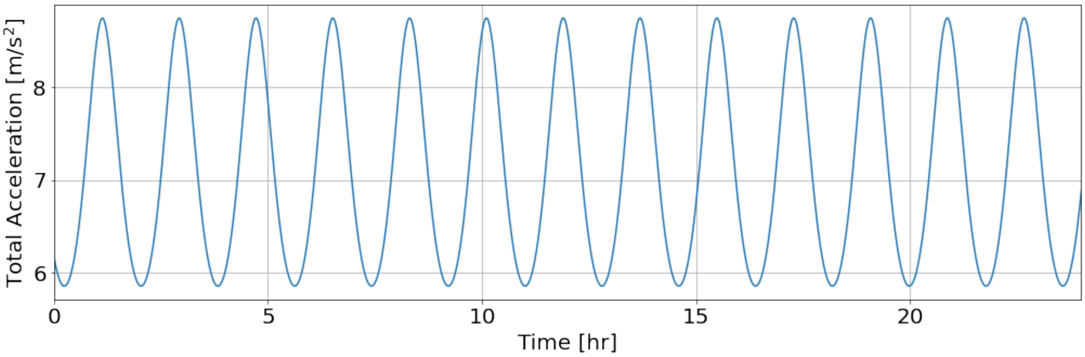
```
dependent_variables_to_save = [
    propagation_setup.dependent_variable.total_acceleration( "Delfi-C3" ),
    propagation_setup.dependent_variable.keplerian_state( "Delfi-C3", "Earth" ),
    propagation_setup.dependent_variable.latitude( "Delfi-C3", "Earth" ),
    propagation_setup.dependent_variable.longitude( "Delfi-C3", "Earth"),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.point_mass_gravity_type, "Delfi-C3",␣
 ↪"Sun"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.point_mass_gravity_type, "Delfi-C3",␣
 ↪"Moon"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.point_mass_gravity_type, "Delfi-C3",␣
 ↪"Mars"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.point_mass_gravity_type, "Delfi-C3",␣
 ↪"Venus"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.spherical_harmonic_gravity_type,␣
 ↪"Delfi-C3", "Earth"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.aerodynamic_type, "Delfi-C3", "Earth"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.cannonball_radiation_pressure_type,␣
 ↪"Delfi-C3", "Sun"
    )
    ]


# Create propagation settings.
propagator_settings = propagation_setup.propagator.translational(
    central_bodies,
    acceleration_models,
    bodies_to_propagate,
    initial_state,
    simulation_end_epoch,
    output_variables = dependent_variables_to_save
)
# Create numerical integrator settings.
fixed_step_size = 10.0
```

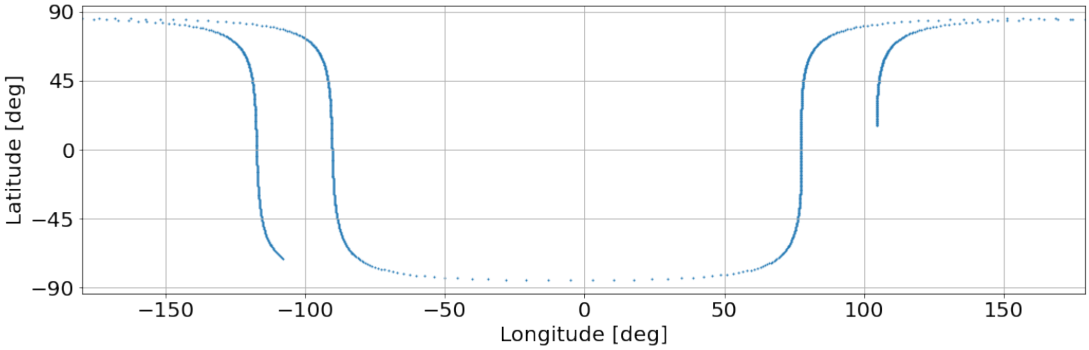
```
integrator_settings = propagation_setup.integrator.runge_kutta_4(
    simulation_start_epoch,
    fixed_step_size
)

###########################################################################
# PROPAGATE ORBIT #########################################################
###########################################################################

# Create simulation object and propagate dynamics.
dynamics_simulator = propagation_setup.SingleArcDynamicsSimulator(
    bodies, integrator_settings, propagator_settings)
states = dynamics_simulator.state_history
dependent_variables = dynamics_simulator.dependent_variable_history

###########################################################################
# PRINT INITIAL AND FINAL STATES ##########################################
###########################################################################

print(
    f"""
Single Earth-Orbiting Satellite Example.
The initial position vector of Delfi-C3 is [km]: \n{
    states[simulation_start_epoch][:3] / 1E3}
The initial velocity vector of Delfi-C3 is [km/s]: \n{
    states[simulation_start_epoch][3:] / 1E3}
After {simulation_end_epoch} seconds the position vector of Delfi-C3 is [km]:␣
 ↪\n{
    states[simulation_end_epoch][:3] / 1E3}
And the velocity vector of Delfi-C3 is [km/s]: \n{
    states[simulation_end_epoch][3:] / 1E3}
    """
)
```

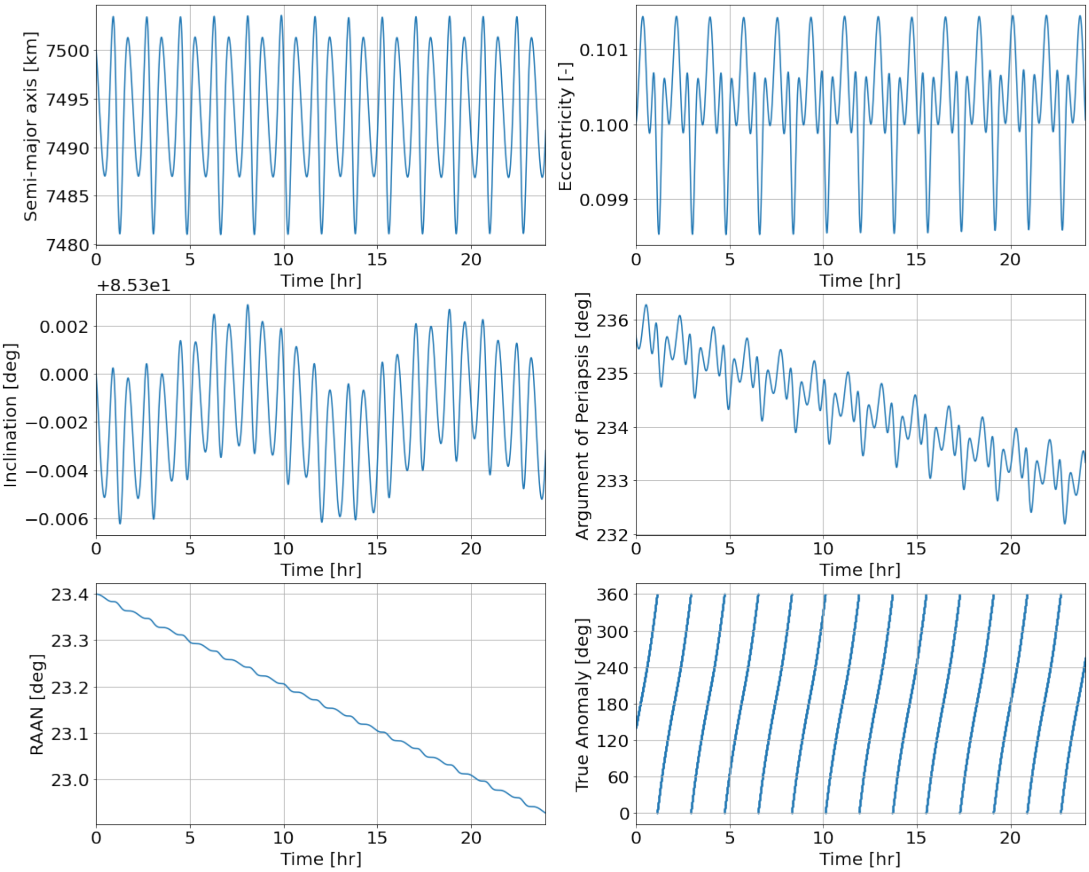
```
Single Earth-Orbiting Satellite Example.
The initial position vector of Delfi-C3 is [km]:
[7037.48400133 3238.05901792 2150.7241875 ]
The initial velocity vector of Delfi-C3 is [km/s]:
[-1.46565763 -0.04095839  6.62279761]
After 86400.0 seconds the position vector of Delfi-C3 is [km]:
[-4602.79426676 -1421.16740978  5883.69740624]
And the velocity vector of Delfi-C3 is [km/s]:
[-4.53846052 -2.36988263 -5.04163195]
```

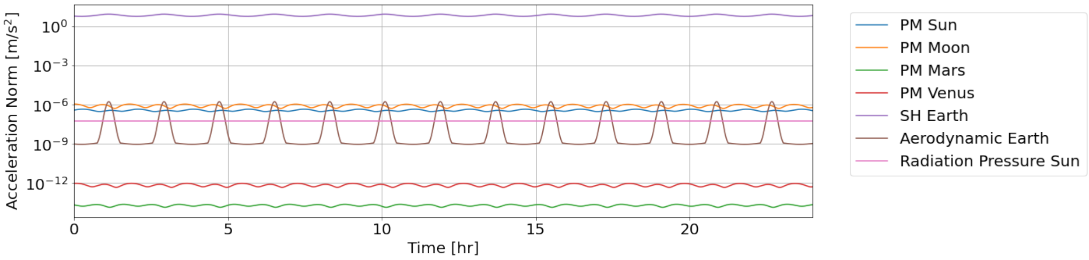
[3]:
```python
import os
from matplotlib import pyplot as plt

time = dependent_variables.keys()
dependent_variable_list = np.vstack(list(dependent_variables.values()))
font_size = 20

plt.rcParams.update({'font.size': font_size})

# dependent variables
# 0-2: total acceleration
# 3-8: Keplerian state
# 9: latitude
# 10: longitude
# 11: Acceleration Norm PM Sun
# 12: Acceleration Norm PM Moon
# 13: Acceleration Norm PM Mars
# 14: Acceleration Norm PM Venus
# 15: Acceleration Norm SH Earth

total_acceleration = np.sqrt( dependent_variable_list[:,0] ** 2 +␣
 ↪dependent_variable_list[:,1] ** 2 + dependent_variable_list[:,2] ** 2 )

time_hours = [ t / 3600 for t in time]
# Total Acceleration
plt.figure( figsize=(17,5))
plt.grid()
plt.plot( time_hours , total_acceleration )
plt.xlabel('Time [hr]')
plt.ylabel( 'Total Acceleration [m/s$^2$]')
plt.xlim( [min(time_hours), max(time_hours)] )
plt.savefig( fname = f'{latex_image_path}total_acceleration.png',␣
 ↪bbox_inches='tight')



# Ground Track
latitude = dependent_variable_list[:,9]
longitude = dependent_variable_list[:,10]

part = int(len(time)/24*3)
latitude = np.rad2deg( latitude[0:part] )
longitude = np.rad2deg( longitude[0:part] )
plt.figure( figsize=(17,5))
plt.grid()
plt.yticks(np.arange(-90, 91, step=45))
plt.scatter( longitude, latitude, s=1 )
plt.xlabel('Longitude [deg]')
plt.ylabel( 'Latitude [deg]')
plt.xlim( [min(longitude), max(longitude)] )
plt.savefig( fname = f'{latex_image_path}ground_track.png', bbox_inches='tight')

# Kepler Elements
kepler_elements = dependent_variable_list[:,3:9]

fig, ((ax1, ax2), (ax3, ax4), (ax5, ax6)) = plt.subplots( 3, 2, figsize = (20,17) )

# Semi-major Axis
semi_major_axis = [ element/1000 for element in kepler_elements[:,0] ]
ax1.plot( time_hours, semi_major_axis )
ax1.set_ylabel( 'Semi-major axis [km]' )

# Eccentricity
eccentricity = kepler_elements[:,1]
ax2.plot( time_hours, eccentricity )
ax2.set_ylabel( 'Eccentricity [-]' )

# Inclination
inclination = [ np.rad2deg( element ) for element in kepler_elements[:,2] ]
ax3.plot( time_hours, inclination )
ax3.set_ylabel( 'Inclination [deg]')

# Argument of Periapsis
argument_of_periapsis = [ np.rad2deg( element ) for element in kepler_elements[:,3] ]
ax4.plot( time_hours, argument_of_periapsis )
ax4.set_ylabel( 'Argument of Periapsis [deg]' )

# Right Ascension of the Ascending Node
raan = [ np.rad2deg( element ) for element in kepler_elements[:,4] ]
ax5.plot( time_hours, raan )
ax5.set_ylabel( 'RAAN [deg]' )

# True Anomaly
true_anomaly = [ np.rad2deg( element ) for element in kepler_elements[:,5] ]
ax6.scatter( time_hours, true_anomaly, s=1 )
ax6.set_ylabel( 'True Anomaly [deg]' )
ax6.set_yticks(np.arange(0, 361, step=60))

for ax in fig.get_axes():
    ax.set_xlabel('Time [hr]')
    ax.set_xlim( [min(time_hours), max(time_hours)] )
    ax.grid()
```

```
plt.savefig( fname = f'{latex_image_path}kepler_elements.png',␣
 ↪bbox_inches='tight')

plt.figure( figsize=(17,5))

# Point Mass Gravity Acceleration Sun
acceleration_norm_pm_sun = dependent_variable_list[:, 11]
plt.plot( time_hours, acceleration_norm_pm_sun, label='PM Sun')

# Point Mass Gravity Acceleration Moon
acceleration_norm_pm_moon = dependent_variable_list[:, 12]
plt.plot( time_hours, acceleration_norm_pm_moon, label='PM Moon')

# Point Mass Gravity Acceleration Mars
acceleration_norm_pm_mars = dependent_variable_list[:, 13]
plt.plot( time_hours, acceleration_norm_pm_mars, label='PM Mars')

# Point Mass Gravity Acceleration Venus
acceleration_norm_pm_venus = dependent_variable_list[:, 14]
plt.plot( time_hours, acceleration_norm_pm_venus, label='PM Venus')

# Spherical Harmonic Gravity Acceleration Earth
acceleration_norm_sh_earth = dependent_variable_list[:, 15]
plt.plot( time_hours, acceleration_norm_sh_earth, label='SH Earth')

# Aerodynamic Acceleration Earth
acceleration_norm_aero_earth = dependent_variable_list[:, 16]
plt.plot( time_hours, acceleration_norm_aero_earth, label='Aerodynamic Earth')

# Cannonball Radiation Pressure Acceleration Sun
acceleration_norm_rp_sun = dependent_variable_list[:, 17]
plt.plot( time_hours, acceleration_norm_rp_sun, label='Radiation Pressure Sun')

plt.grid()
plt.legend( bbox_to_anchor=(1.04,1) )
plt.xlim( [min(time_hours), max(time_hours)])
plt.yscale('log')
plt.xlabel( 'Time [hr]' )
plt.ylabel( 'Acceleration Norm [m/s$^2$]' )

plt.savefig( fname = f'{latex_image_path}acceleration_norms.png',␣
 ↪bbox_inches='tight')
#plt.savefig('acceleration_norms.png', bbox_inches='tight')
```


Total Acceleration [m/s^2]
8
7
6
0
5
10
15
20
Time [hr]


90
45
0
−45
−90
Latitude [deg]
−150
−100
−50
0
50
100
150
Longitude [deg]


Semi-major axis [km]
7500
7495
7490
7485
7480
Eccentricity [-]
0.101
0.100
0.099
+8.53e1
Inclination [deg]
0.002
0.000
−0.002
−0.004
−0.006
Argument of Periapsis [deg]
236
235
234
233
232
RAAN [deg]
23.4
23.3
23.2
23.1
23.0
True Anomaly [deg]
360
300
240
180
120
60
0
0
5
10
15
20
Time [hr]


Acceleration Norm [m/s^2]
10^{0}
10^{-3}
10^{-6}
10^{-9}
10^{-12}
0
5
10
15
20
Time [hr]
PM Sun
PM Moon
PM Mars
PM Venus
SH Earth
Aerodynamic Earth
Radiation Pressure Sun

[ ]:

G Appendix test_add.pdf

AE4868_example_notebook_update20201025

December 26, 2020

[1]:

```
def addThree(input_nr):
    '''returns the input integer plus 3, used to verify unit test'''
    return input_nr + 3
```

[2]:

```
###############################################################################
# IMPORT STATEMENTS ###########################################################
###############################################################################
import os
import numpy as np
from tudatpy.kernel import constants
from tudatpy.kernel.interface import spice_interface
from tudatpy.kernel.simulation import environment_setup
from tudatpy.kernel.simulation import propagation_setup
from tudatpy.kernel.astro import conversion

# Set path to latex image folders for project 1
latex_image_path = 'latex/project1/Images/'

# Load spice kernels.
spice_interface.load_standard_kernels()

# Set simulation start and end epochs.
simulation_start_epoch = 0.0
simulation_end_epoch = constants.JULIAN_DAY

###########################################################################
# CREATE ENVIRONMENT ######################################################
###########################################################################

# Create default body settings for selected celestial bodies
bodies_to_create = ["Sun", "Earth", "Moon", "Mars", "Venus"]

# Create default body settings for bodies_to_create, with "Earth"/"J2000" as
# global frame origin and orientation. This environment will only be valid
# in the indicated time range
# [simulation_start_epoch --- simulation_end_epoch]
body_settings = environment_setup.get_default_body_settings(
    bodies_to_create,
    simulation_start_epoch,
    simulation_end_epoch,
    "Earth","J2000")

# Create system of selected celestial bodies
bodies = environment_setup.create_system_of_bodies(body_settings)

###########################################################################
# CREATE VEHICLE ##########################################################
###########################################################################

# Create vehicle objects.
bodies.create_empty_body( "Delfi-C3" )
bodies.get_body( "Delfi-C3").set_constant_mass(400.0)

# Create aerodynamic coefficient interface settings, and add to vehicle
reference_area = 4.0
drag_coefficient = 1.2
aero_coefficient_settings = environment_setup.aerodynamic_coefficients.constant(
    reference_area,[drag_coefficient,0,0]
)
environment_setup.add_aerodynamic_coefficient_interface(
            bodies, "Delfi-C3", aero_coefficient_settings )

# Create radiation pressure settings, and add to vehicle
reference_area_radiation = 4.0
radiation_pressure_coefficient = 1.2
occulting_bodies = ["Earth"]
radiation_pressure_settings = environment_setup.radiation_pressure.cannonball(
    "Sun", reference_area_radiation, radiation_pressure_coefficient,␣
 ↪occulting_bodies
)
environment_setup.add_radiation_pressure_interface(
            bodies, "Delfi-C3", radiation_pressure_settings )

###########################################################################
# CREATE ACCELERATIONS ####################################################
###########################################################################

# Define bodies that are propagated.
bodies_to_propagate = ["Delfi-C3"]

# Define central bodies.
central_bodies = ["Earth"]

# Define accelerations acting on Delfi-C3 by Sun and Earth.
```

```
accelerations_settings_delfi_c3 = dict(
    Sun=
    [
        propagation_setup.acceleration.cannonball_radiation_pressure(),
        propagation_setup.acceleration.point_mass_gravity()
    ],
    Earth=
    [
        propagation_setup.acceleration.spherical_harmonic_gravity(5, 5),
        propagation_setup.acceleration.aerodynamic()
    ])

# Define point mass accelerations acting on Delfi-C3 by all other bodies.
for other in set(bodies_to_create).difference({"Sun", "Earth"}):
    accelerations_settings_delfi_c3[other] = [
        propagation_setup.acceleration.point_mass_gravity()]

# Create global accelerations settings dictionary.
acceleration_settings = {"Delfi-C3": accelerations_settings_delfi_c3}

# Create acceleration models.
acceleration_models = propagation_setup.create_acceleration_models(
    bodies,
    acceleration_settings,
    bodies_to_propagate,
    central_bodies)

###########################################################################
# CREATE PROPAGATION SETTINGS #############################################
###########################################################################

# Set initial conditions for the Asterix satellite that will be
# propagated in this simulation. The initial conditions are given in
# Keplerian elements and later on converted to Cartesian elements.
earth_gravitational_parameter = bodies.get_body( "Earth" ).
 ↪gravitational_parameter
initial_state = conversion.keplerian_to_cartesian(
    gravitational_parameter=earth_gravitational_parameter,
    semi_major_axis=7500.0E3,
    eccentricity=0.1,
    inclination=np.deg2rad(85.3),
    argument_of_periapsis=np.deg2rad(235.7),
    longitude_of_ascending_node=np.deg2rad(23.4),
    true_anomaly=np.deg2rad(139.87)
)

# Define list of dependent variables to save.
```

```
dependent_variables_to_save = [
    propagation_setup.dependent_variable.total_acceleration( "Delfi-C3" ),
    propagation_setup.dependent_variable.keplerian_state( "Delfi-C3", "Earth" ),
    propagation_setup.dependent_variable.latitude( "Delfi-C3", "Earth" ),
    propagation_setup.dependent_variable.longitude( "Delfi-C3", "Earth"),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.point_mass_gravity_type, "Delfi-C3",␣
 ↪"Sun"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.point_mass_gravity_type, "Delfi-C3",␣
 ↪"Moon"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.point_mass_gravity_type, "Delfi-C3",␣
 ↪"Mars"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.point_mass_gravity_type, "Delfi-C3",␣
 ↪"Venus"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.spherical_harmonic_gravity_type,␣
 ↪"Delfi-C3", "Earth"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.aerodynamic_type, "Delfi-C3", "Earth"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.cannonball_radiation_pressure_type,␣
 ↪"Delfi-C3", "Sun"
    )
    ]


# Create propagation settings.
propagator_settings = propagation_setup.propagator.translational(
    central_bodies,
    acceleration_models,
    bodies_to_propagate,
    initial_state,
    simulation_end_epoch,
    output_variables = dependent_variables_to_save
)
# Create numerical integrator settings.
fixed_step_size = 10.0
```

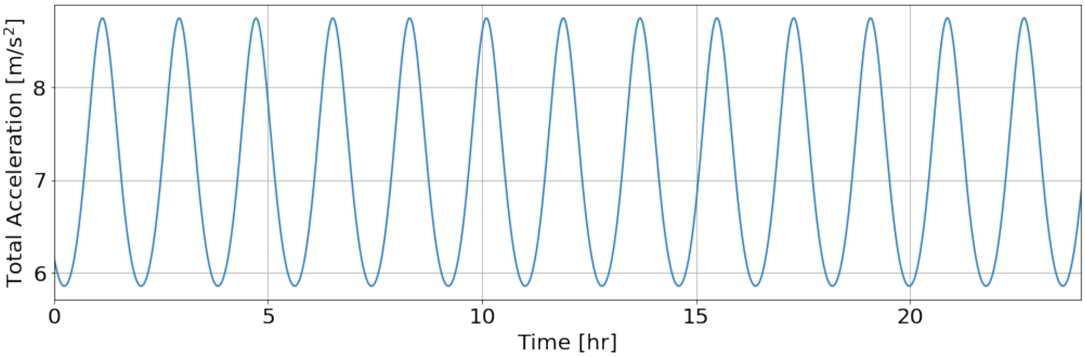
```python
integrator_settings = propagation_setup.integrator.runge_kutta_4(
    simulation_start_epoch,
    fixed_step_size
)

###########################################################################
# PROPAGATE ORBIT #########################################################
###########################################################################

# Create simulation object and propagate dynamics.
dynamics_simulator = propagation_setup.SingleArcDynamicsSimulator(
    bodies, integrator_settings, propagator_settings)
states = dynamics_simulator.state_history
dependent_variables = dynamics_simulator.dependent_variable_history

###########################################################################
# PRINT INITIAL AND FINAL STATES ##########################################
###########################################################################

print(
    f"""
Single Earth-Orbiting Satellite Example.
The initial position vector of Delfi-C3 is [km]: \n{
    states[simulation_start_epoch][:3] / 1E3}
The initial velocity vector of Delfi-C3 is [km/s]: \n{
    states[simulation_start_epoch][3:] / 1E3}
After {simulation_end_epoch} seconds the position vector of Delfi-C3 is [km]: \n{
    states[simulation_end_epoch][:3] / 1E3}
And the velocity vector of Delfi-C3 is [km/s]: \n{
    states[simulation_end_epoch][3:] / 1E3}
    """
)
```

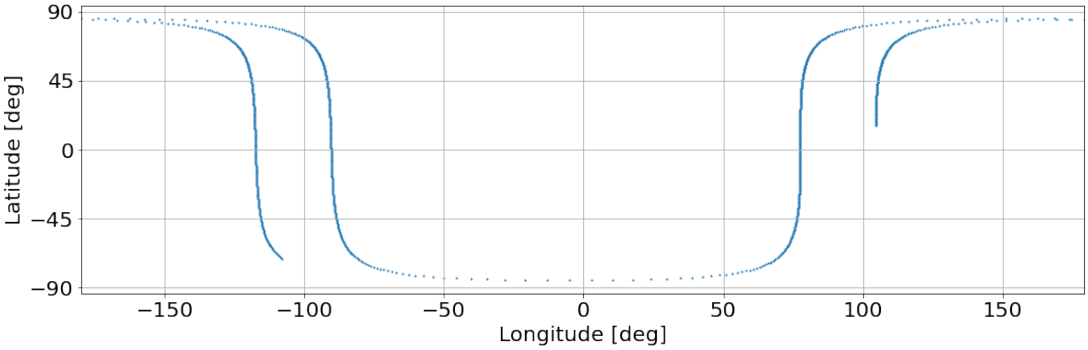
```
Single Earth-Orbiting Satellite Example.
The initial position vector of Delfi-C3 is [km]:
[7037.48400133 3238.05901792 2150.7241875 ]
The initial velocity vector of Delfi-C3 is [km/s]:
[-1.46565763 -0.04095839  6.62279761]
After 86400.0 seconds the position vector of Delfi-C3 is [km]:
[-4602.79426676 -1421.16740978  5883.69740624]
And the velocity vector of Delfi-C3 is [km/s]:
[-4.53846052 -2.36988263 -5.04163195]
```

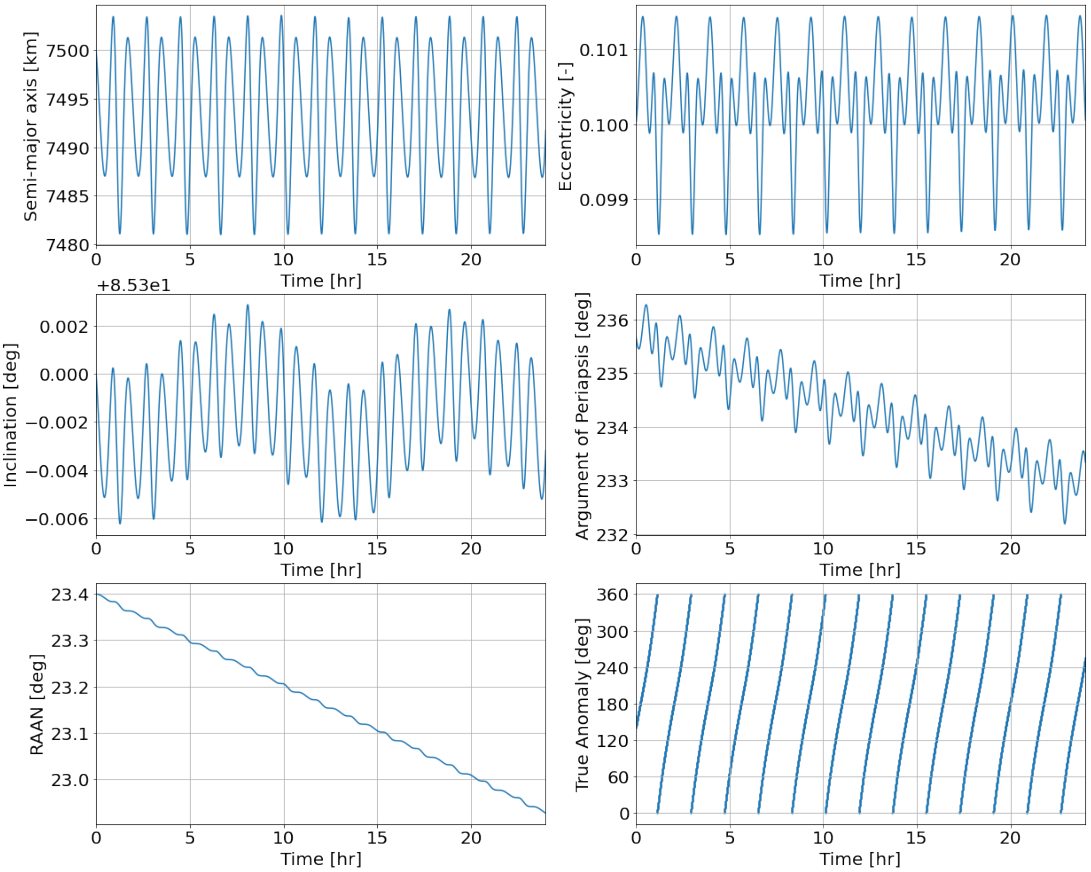
[3]:

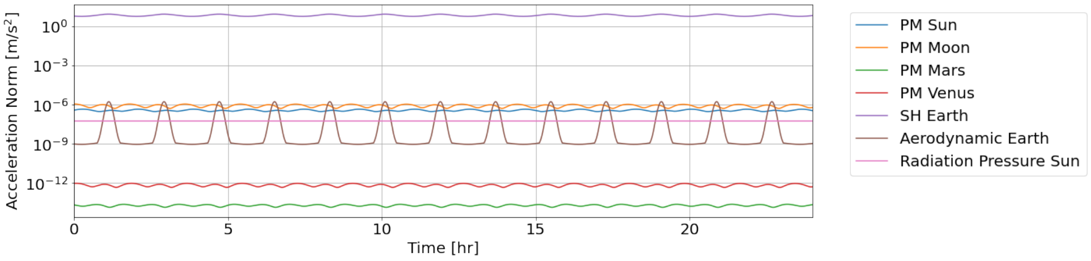
```
import os
from matplotlib import pyplot as plt

time = dependent_variables.keys()
dependent_variable_list = np.vstack(list(dependent_variables.values()))
font_size = 20

plt.rcParams.update({'font.size': font_size})

# dependent variables
# 0-2: total acceleration
# 3-8: Keplerian state
# 9: latitude
# 10: longitude
# 11: Acceleration Norm PM Sun
# 12: Acceleration Norm PM Moon
# 13: Acceleration Norm PM Mars
# 14: Acceleration Norm PM Venus
# 15: Acceleration Norm SH Earth

total_acceleration = np.sqrt( dependent_variable_list[:,0] ** 2 +␣
 ↪dependent_variable_list[:,1] ** 2 + dependent_variable_list[:,2] ** 2 )

time_hours = [ t / 3600 for t in time]
# Total Acceleration
plt.figure( figsize=(17,5))
plt.grid()
plt.plot( time_hours , total_acceleration )
plt.xlabel('Time [hr]')
plt.ylabel( 'Total Acceleration [m/s$^2$]')
plt.xlim( [min(time_hours), max(time_hours)] )
plt.savefig( fname = f'{latex_image_path}total_acceleration.png',␣
 ↪bbox_inches='tight')



# Ground Track
latitude = dependent_variable_list[:,9]
longitude = dependent_variable_list[:,10]

part = int(len(time)/24*3)
latitude = np.rad2deg( latitude[0:part] )
longitude = np.rad2deg( longitude[0:part] )
plt.figure( figsize=(17,5))
plt.grid()
plt.yticks(np.arange(-90, 91, step=45))
plt.scatter( longitude, latitude, s=1 )
plt.xlabel('Longitude [deg]')
plt.ylabel( 'Latitude [deg]')
plt.xlim( [min(longitude), max(longitude)] )
plt.savefig( fname = f'{latex_image_path}ground_track.png', bbox_inches='tight')

# Kepler Elements
kepler_elements = dependent_variable_list[:,3:9]

fig, ((ax1, ax2), (ax3, ax4), (ax5, ax6)) = plt.subplots( 3, 2, figsize =␣
 ↪(20,17) )

# Semi-major Axis
semi_major_axis = [ element/1000 for element in kepler_elements[:,0] ]
ax1.plot( time_hours, semi_major_axis )
ax1.set_ylabel( 'Semi-major axis [km]' )

# Eccentricity
eccentricity = kepler_elements[:,1]
ax2.plot( time_hours, eccentricity )
ax2.set_ylabel( 'Eccentricity [-]' )

# Inclination
inclination = [ np.rad2deg( element ) for element in kepler_elements[:,2] ]
ax3.plot( time_hours, inclination )
ax3.set_ylabel( 'Inclination [deg]')

# Argument of Periapsis
argument_of_periapsis = [ np.rad2deg( element ) for element in kepler_elements[:
 ↪,3] ]
ax4.plot( time_hours, argument_of_periapsis )
ax4.set_ylabel( 'Argument of Periapsis [deg]' )

# Right Ascension of the Ascending Node
raan = [ np.rad2deg( element ) for element in kepler_elements[:,4] ]
ax5.plot( time_hours, raan )
ax5.set_ylabel( 'RAAN [deg]' )

# True Anomaly
true_anomaly = [ np.rad2deg( element ) for element in kepler_elements[:,5] ]
ax6.scatter( time_hours, true_anomaly, s=1 )
ax6.set_ylabel( 'True Anomaly [deg]' )
ax6.set_yticks(np.arange(0, 361, step=60))

for ax in fig.get_axes():
    ax.set_xlabel('Time [hr]')
    ax.set_xlim( [min(time_hours), max(time_hours)] )
    ax.grid()
```

```
plt.savefig( fname = f'{latex_image_path}kepler_elements.png',␣
 ↪bbox_inches='tight')

plt.figure( figsize=(17,5))

# Point Mass Gravity Acceleration Sun
acceleration_norm_pm_sun = dependent_variable_list[:, 11]
plt.plot( time_hours, acceleration_norm_pm_sun, label='PM Sun')

# Point Mass Gravity Acceleration Moon
acceleration_norm_pm_moon = dependent_variable_list[:, 12]
plt.plot( time_hours, acceleration_norm_pm_moon, label='PM Moon')

# Point Mass Gravity Acceleration Mars
acceleration_norm_pm_mars = dependent_variable_list[:, 13]
plt.plot( time_hours, acceleration_norm_pm_mars, label='PM Mars')

# Point Mass Gravity Acceleration Venus
acceleration_norm_pm_venus = dependent_variable_list[:, 14]
plt.plot( time_hours, acceleration_norm_pm_venus, label='PM Venus')

# Spherical Harmonic Gravity Acceleration Earth
acceleration_norm_sh_earth = dependent_variable_list[:, 15]
plt.plot( time_hours, acceleration_norm_sh_earth, label='SH Earth')

# Aerodynamic Acceleration Earth
acceleration_norm_aero_earth = dependent_variable_list[:, 16]
plt.plot( time_hours, acceleration_norm_aero_earth, label='Aerodynamic Earth')

# Cannonball Radiation Pressure Acceleration Sun
acceleration_norm_rp_sun = dependent_variable_list[:, 17]
plt.plot( time_hours, acceleration_norm_rp_sun, label='Radiation Pressure Sun')

plt.grid()
plt.legend( bbox_to_anchor=(1.04,1) )
plt.xlim( [min(time_hours), max(time_hours)])
plt.yscale('log')
plt.xlabel( 'Time [hr]' )
plt.ylabel( 'Acceleration Norm [m/s$^2$]' )

plt.savefig( fname = f'{latex_image_path}acceleration_norms.png',␣
 ↪bbox_inches='tight')
#plt.savefig('acceleration_norms.png', bbox_inches='tight')
```


Total Acceleration [m/s^2]
6
7
8
0
5
10
15
20
Time [hr]


Latitude [deg]
90
45
0
−45
−90
−150
−100
−50
0
50
100
150
Longitude [deg]


Semi-major axis [km]
7480
7485
7490
7495
7500
Eccentricity [-]
0.099
0.100
0.101
+8.53e1
Inclination [deg]
−0.006
−0.004
−0.002
0.000
0.002
Argument of Periapsis [deg]
232
233
234
235
236
RAAN [deg]
23.0
23.1
23.2
23.3
23.4
True Anomaly [deg]
0
60
120
180
240
300
360
0
5
10
15
20
Time [hr]


Acceleration Norm [m/s^2]
10^0
10^{-3}
10^{-6}
10^{-9}
10^{-12}
0
5
10
15
20
Time [hr]
PM Sun
PM Moon
PM Mars
PM Venus
SH Earth
Aerodynamic Earth
Radiation Pressure Sun

```
[ ]:
```