# ME 449 Asst 3

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## Introduction

This pdf contains the simulation parameters and the answers for all four parts of the assignment. The csv files corresponding to each simluation run are also mentioned in this file. The commented code is included in the `code` directory and can be run easily using the `run_sim` helper function.

## Part 1: Simulating a falling robot

(a) Energy appears nearly constant (part1a.csv)

```
t = 5.0, dt = 0.005
```

(b) Energy does not appear constant (part1b.csv)

```
t = 5.0, dt = 0.05
```

To calculate the total energy of the robot at each time step we would have to calculate the kinetic and potential energies at each time step and then add them up.
The kinetic energy is given by $K(\theta, \dot{\theta}) = 0.5 \sum_{i=1}^{n} \sum_{j=1}^{n} m_{ij}(\theta)\dot{\theta}_i\dot{\theta}_j = 0.5\dot{\theta}^T M(\theta)\dot{\theta}$, where $m_{ij}(\theta)$ is the $(i,j)th$ element of the mass matrix $M(\theta)$
The potential energy is given by $P(\theta, \dot{\theta}) = \sum_{i=1}^{n} m_i g r_i$ where $m_i$ is the mass of each link, $g$ is gravity and $r_i$ is the coordinate of the link's centre of mass.
So based on the current configuration of the robot, we can calculate these values at each time step and then add them to get the total energy given by $TE = K(\theta, \dot{\theta}) + P(\theta, \dot{\theta})$

## Part 2: Adding damping

(a) Positive damping (part2a.csv)

```
damping = 2.0, t = 5.0, dt = 0.01
```

(b) Negative damping (part2b.csv)

```
damping = -0.005, t = 5.0, dt = 0.01
```

If the damping value is too large like `damping = 8.0` at `dt = 0.01` we get

```
RuntimeWarning: overflow encountered in multiply
+ np.dot(ad(Vi[:, i + 1]), Ai[:, i]) * dthetalist[i]
```

which happens because the joint velocities start growing larger as the time step is too coarse for the Euler Integration method to correctly calculate the values for the next time step.
If we reduce the time step to `dt = 0.001`, we can avoid this error as the Euler Integration has a small enough time step to calculate the next step values correctly.

## Part 3: Adding a spring

(a) No damping (part3a.csv)

```
stiffness = 4.0 ,damping = 0.0, t = 10.0, dt = 0.01
```

The total energy of the system over time should be constant, but we see the energy of the system increasing because of the absence of any damping and dissipative forces in the environment (also the accumulated error in Euler Integration)

If the spring constant is large, the system behaves chaotically where it seems the total energy of the system increases because the value of spring potential energy is given by $0.5 K x^2$ where $K$ is the spring stiffness and $x$ is the extension in the spring.

(b) Positive damping (part3b.csv)

```
stiffness = 4.0 ,damping = 2.0, t = 10.0, dt = 0.01
```

## Part 4: A moving spring

(part4.csv)

```
damping = 2.0, stiffness = 4.0, t = 10.0, dt = 0.01
```