FDS 2024: Field and service robotics
Homework 1

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Question 1: Consider the ATLAS robot from Boston Dynamics. If ATLAS actuators can produce unbounded torques, establish whether each of the following statements is true or not, and briefly justify your answer.

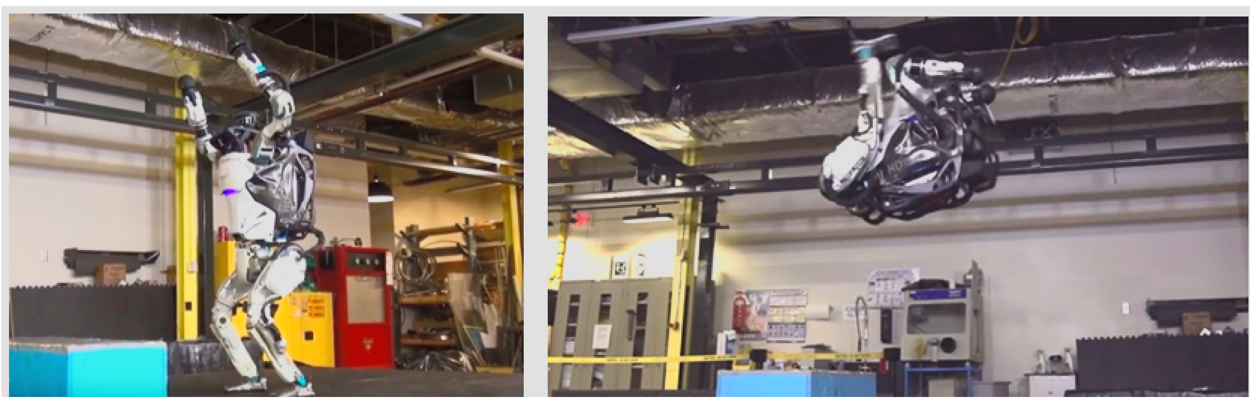

Figure 1: Atlas Robot

Part (a): While standing, ATLAS is fully actuated.

The Atlas robot is a bipedal robot; it takes the human body as its inspiration. As stated on the course slides[2]: "The human body has an incredible number of actuators (muscles), and in many cases has multiple muscles per joint;..." it is therefore possible to assume that similar to the human body, Atlas has a large number of actuators, which make it capable, in the condition of contact with the ground, of performing an instantaneous acceleration in an arbitrary direction in q, where q are the variables of the model (in this case position and orientation of the robot itself). Indeed, we recall that[2]: "... we will refer to underactuation as a property of the mathematical model used to model our robotic system." The ground contact condition is crucial for full actuation.
Therefore, Atlas is fully actuated while standing.

Part (b): While doing backflip, ATLAS is fully actuated.

As stated on the slides[2]: "[The human body] despite having more actuators than position variables, when we jump into the air there is no combination of muscle inputs that can change the ballistic trajectory of the centre of mass (apart from aerodynamic effects)." The same can be said for the Atlas robot. Underactuation and full actuation are closely related to the current state, time and constraints. In this case, the absence of the ground contact constraint makes the robot underactuated in this condition. Recall, however, that to define an underactuated system (course slide[2]): "a system is underactuated if it is underactuated in all states and times". So Atlas is not an underactuated system, but it is underactuated while doing a backflip.
Therefore, Atlas is not fully actuated while doing backflip.

Question 2: Consider the planar mechanism on the left and the spatial mechanism on the right. Determine the number of the degrees of freedom for each mechanism, comparing the result with your intuition about the possible motions of these mechanisms. For each mechanism, write its configuration space topology.

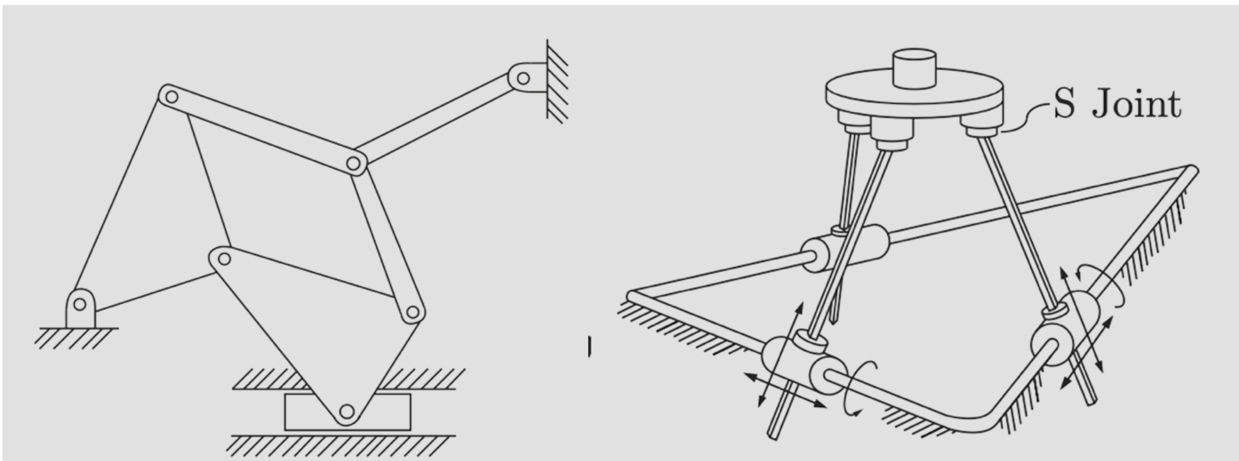

Figure 2: Mechanisms

To calculate the number of Dofs of the two mechanisms, Grübler's formula can be used

$$DoFs = m(N - 1 - J) + \sum(f_i)$$

For the the planar mechanism applies:

$m = 3$
$N = 7$
$J = 9$

8 Revolute joints ($f_i = 1$), 1 prismatic($f_i = 1$).
So the Grübler's formula:

$$DoFs = 3(7 - 1 - 9) + 9 * (1) = 0$$

Since this formula holds only if all joint constraints are independent in this case the formula provides a lower bound on the number of DoFs. in fact, according to intuition, the mechanism does not appear to be a structure, rather it appears to have one degree of freedom.

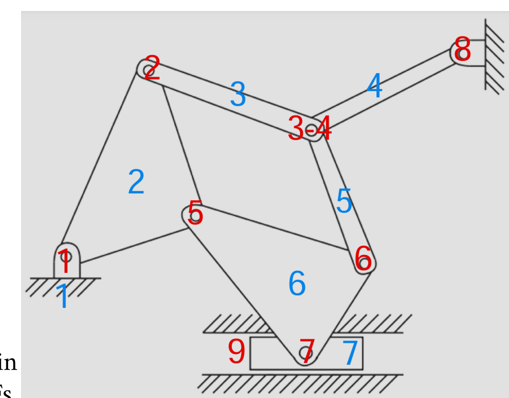

Figure 3: Planar mechanism

The configuration space topology

$$R^1 * I^8$$

where R^1 is the space of the Prismatic joint (unlimited traslation supposed) and I^8 are the space of the 8 Revolute joints (limited rotation) (if they were unlimited they would have been T^8)

For the the spatial mechanism applies:

$m = 6$
$N = 8$
$J = 9$

3 prismatic joints ($f_i = 1$), 3 Cylindrical($f_i = 2$) 3 Spherical ($f_i = 3$).
So the Grübler's formula:

$$DoFs = 6(8 - 1 - 9) + 3 * (1) + 3 * (2) + 3 * (3) = 6$$

According to intuition, the mechanism would appear to have 6 degrees of freedom (complete freedom of the end-effector in space), as confirmed by the formula.

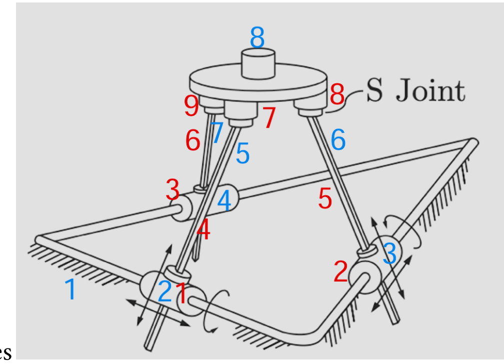

Figure 4: Spatial mechanism

The configuration space topology

$$I^3 * R^3 * T^3 * S^2 * S^2 * S^2$$

where I^3 are the space of the 3 orizontal Prismatic joints (limited traslation)(if they were unlimited they would have been R^8), $R^3 * T^3$ are the space of the 3 Cylindrical joints, $S^2 * S^2 * S^2$ are the space of the 3 Spherical joints (limited rotation).

Question 3: State whether the following sentences regarding underactuation or fully actuation are true or false. Briefly justify your answers.

Part (a): A car with inputs the steering angle and the throttle is underactuated.

Yes. The car cannot generate any acceleration in the space (cannot generate a lateral acceleration). From the slides[2]: "A car is underactuated because it has two control inputs (steering and forward/backward speed) but at least three DoFs given by the planar rigid body chassis".

Part (b): The KUKA youBot system on the slides is fully actuated.

Yes. The KUKA youBot is the combination of a wheeled robot with four independent actuators for each of the wheels and a 5Dofs Robotic arm. It can generate any acceleration in an arbitrary direction in q, by combination of the actuation given by the wheels and the actuation given by the arm joints, it can express any possible acceleration(between the joints max actuation torque) in an arbitrary direction in q(in this case it can be the end_effector variable).

Part (c): The hexarotor system with co-planar propellers is fully actuated.

No. The hexarotor system with co-planar propellers cannot generate any acceleration in the space (cannot generate a lateral acceleration).

Part (d): The 7-DoF KUKA iiwa robot is redundant.

Yes. The 7-DoF KUKA iiwa robot is intyrinsically redundant, it has 7 DoFs in a 6 dimensional space, so intrinsically it has 1 Dof exceeding (according to the task it can have more than 1 Dof exceeding, functional redaundancy).

Question 4: RRT method

The matlab script contains the solution with a brief explanation of the code. The file is on the github repository:
https://github.com/Andremorgh/FSR2024.git [1]
The file is in the folder HW1 and it is named **HW1_es4.mlx.**

Question 5: Numerical navigation method

The matlab script contains the solution with a brief explanation of the code. The file is on the github repository:
https://github.com/Andremorgh/FSR2024.git [1]
The file is in the folder HW1 and it is named **HW1_es5.mlx.**

References

[1] Andrea Morghen. FSR2024. 2024. URL: `https://github.com/Andremorgh/FSR2024.git`.

[2] PRISMA UNINA. FSR_Slides_2024. 2024.