Robot Motion Planning

Algorithms and Data Structures 2 – Motion Planning and its applications

University of Applied Sciences Stuttgart

Dr. Daniel Schneider

What is a robot?

"A reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of task.“

Robot Institute of America, 1979

Some history

The earliest robots as we know them were created in the early 1950s by George C. Devol, an inventor from Louisville, Kentucky. He invented and patented a reprogrammable manipulator called "Unimate," from "Universal Automation." For the next decade, he attempted to sell his product in the industry, but did not succeed. In the late 1960s, businessman/engineer Joseph Engleberger acquired Devol's robot patent and was able to modify it into an industrial robot and form a company called Unimation to produce and market the robots. For his efforts and successes, Engleberger is known in the industry as "the Father of Robotics.“

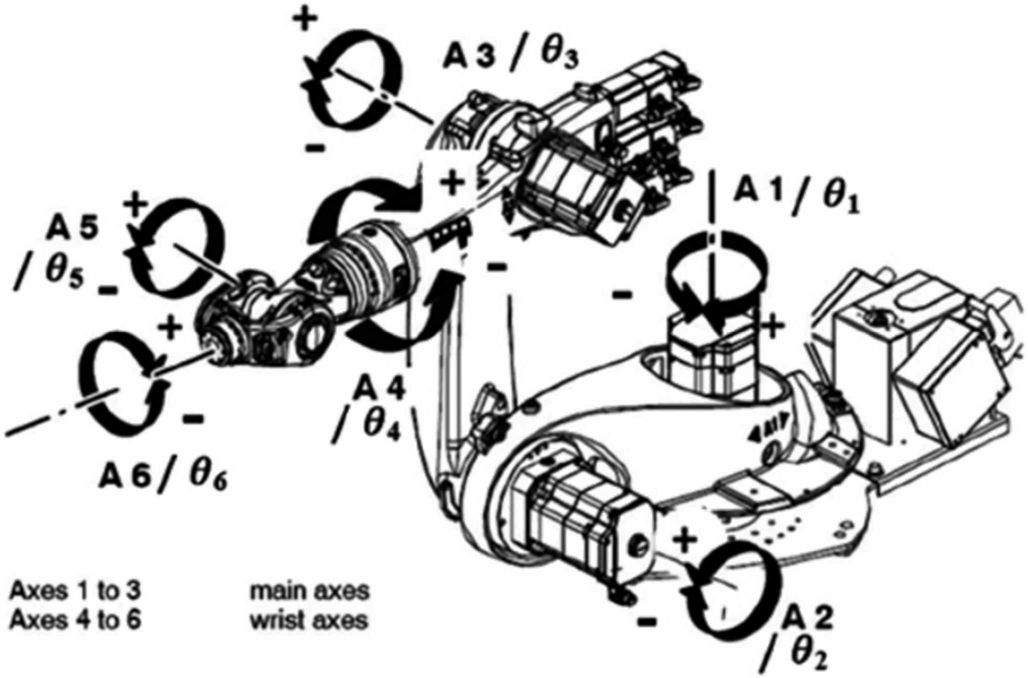
Source: Stanford, https://cs.stanford.edu/people/eroberts/courses/soco/projects/1998-99/robotics/history.html

“Classic” Robot

www.kuka.com

- Robots are mainly used in industrial applications.
- They are the corner stone of automation.
- They are large and able to apply huge forces.
- These robots are always inside an fence (Security)

“Classic” Robot



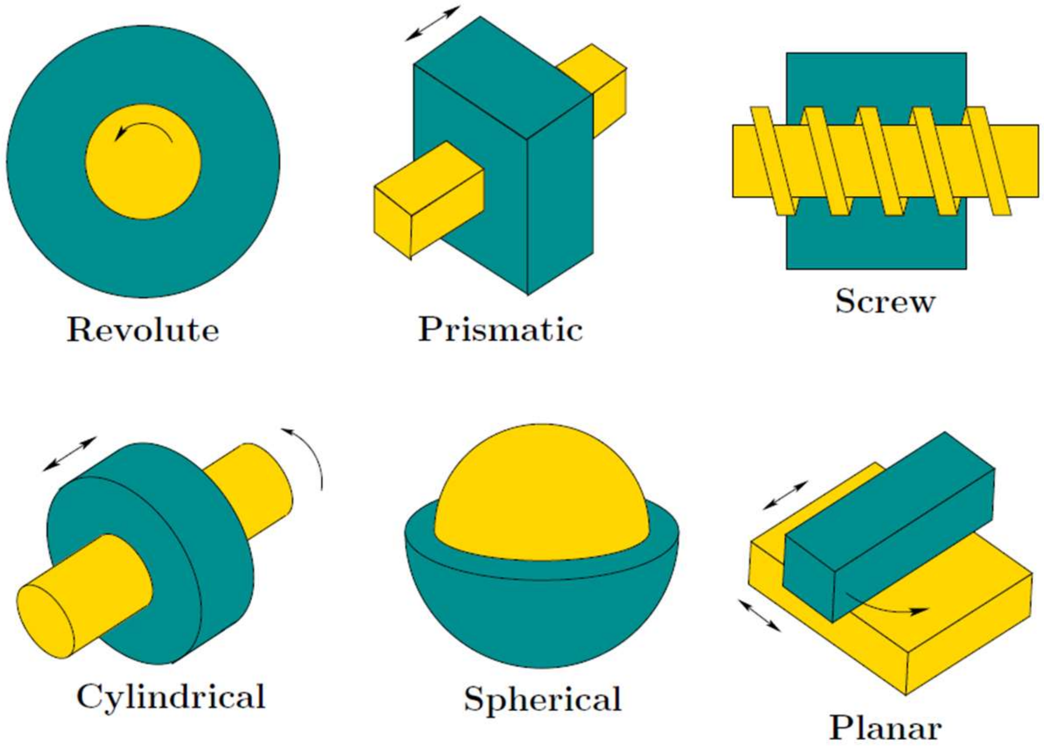
- Robots are often defined by their amount of DOFs
- Some of them are rotational some of them are translational.
- The amount of DOFs defines the complexity of the robot movements.

Sources:
Yun Suen Pai, Hwa Jen Yap and Ramesh Singh – Augmented reality–based programming, planning and simulation of a robotic work cell(2014) - https://www.researchgate.net/publication/267668970_Augmented_reality-based_programming_planning_and_simulation_of_a_robotic_work_cell/download

Type of: Degree of Freedom in RMP

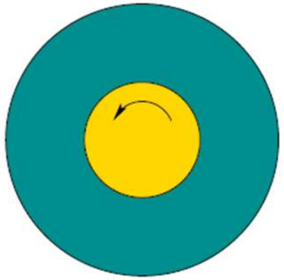
There are 6 common movements in Robot Motion Planning. Those are shown on the left-hand side.

Exercise:
Note down the amount (#) and type (translational vs rotational) of DOFs



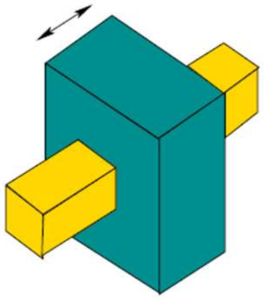
Sources:
Motion Planning: The Essentials – LaValle - http://msl.cs.illinois.edu/~lavalle/papers/Lav11b.pdf

Type of: Degree of Freedom in RMP



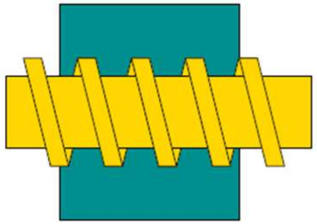
Revolute

1 rotational DOF



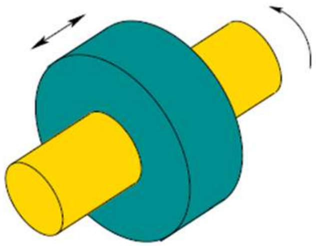
Prismatic

1 translational DOF



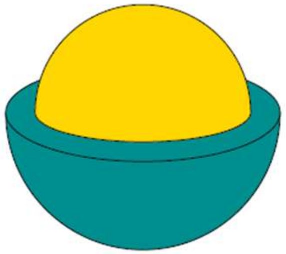
Screw

1 rotational DOF



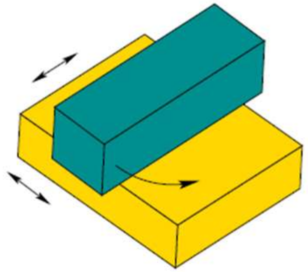
Cylindrical

1 rotational DOF
1 translational DOF



Spherical

3 rotational DOF



Planar

1 rotational DOF
2 translational DOF

Modern industrial Robots – What is special?

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- These robots are called lightweight robots.
- These robots can „feel".
- They have sensors in the axis that can „tell" the robots when it is colliding with obstacels.
- They have security programes that avoid any harm to people.
- These robots are designed to jointly work with humans.
- They can handle sensible tasks that need an instinct and finese (*german: Fingerspitzengefühl*)

Modern industrial Robots – Some history

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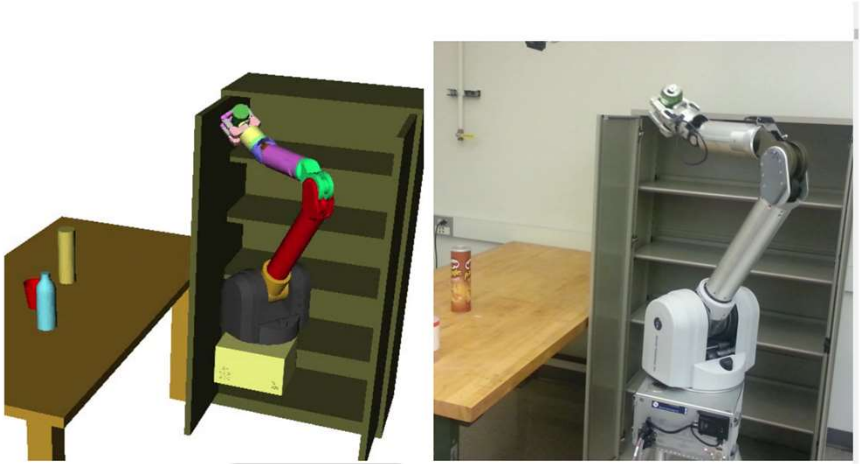
- They where first introduced in the 2000s for aerospace applications buy the german *“Deutschen Zentrum für Luft- und Raumfahrt“*
- The company KUKA started to prompt these robots for industrial applications.
- In 2005-2007 the first applications took place at larger german OEMs with the LBR 3. (*e.g Daimler AG*)
- In 2008 Kuka released the LBR 4 which is the basis for modern robots.
- Nowadays every larger robotic company offers these kind of robots.

Problems in Robot Motion Planning

Roundtrip



- The robot has to grasp multiple objects.
- Each object has a defined goal position.
- The roboat has to place the object one after the other.
- After having placed all object it has to return to its initial state.

Sources:
Continuous-time Gaussian process motion planning via probabilistic inference –
Mustafa Mukadam* , Jing Dong* , Xinyan Yan, Frank Dellaert and Byron Boots - https://arxiv.org/pdf/1707.07383.pdf

Problems in Robot Motion Planning

Minimum Energy Planning

- The shortest path for a robot is not necessarily the one with the least energy consumption.
- How can you plan path that minimize the energy consumption of a robot?
- In recent times, researches focused more on energy efficient motion planning.

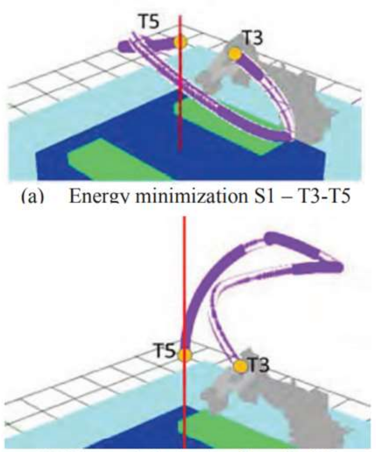
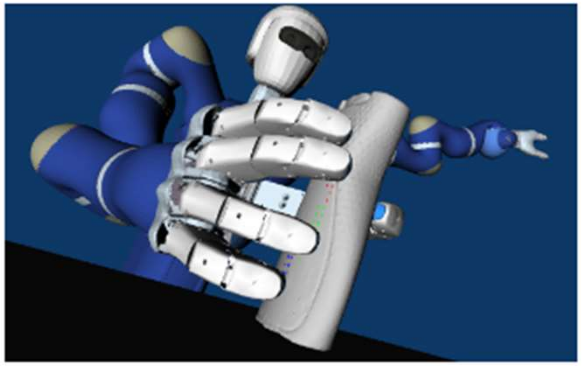


Figure 5: Example of the same trajectory (at the end effector) generated in S1 and S2

Sources:
Minimization of the energy consumption in motion planning for single-robot tasks –
Stefania Pellegrinellia, Stefano Borgiaa , Nicola Pedrocchia , Enrico Villagrossia , Giacomo Bianchia , Lorenzo Molinari Tosattia-
https://www.sciencedirect.com/science/article/pii/S2212827115004886

Problems in Robot Motion Planning

Grasping Problem

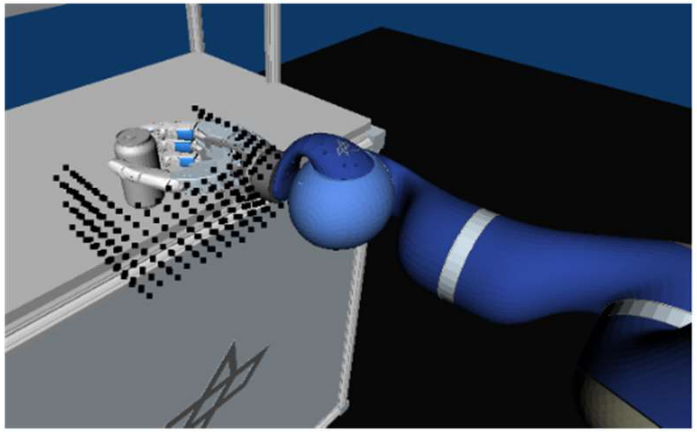


- Grasping object is quite a challenging task.
- Many physical constraints like friction, gravity, acceleration.. Have to be taken into account.
- The hand/gripper of the robot are additional DOFs (sometimes a lot) have to be taken into account in motion planning as well.

Sources:
Integrated Grasp and Motion Planning usingIndependent Contact Regions
Joan Fontanals, Bao-Anh Dang-Vu, Oliver Porges, Jan Rosell, and Maximo A. Roa-
https://core.ac.uk/reader/41776685

Problems in Robot Motion Planning

Constraint Motion Planning



- In some robotic task there are constraints involved.
- For example in grasping an object, the object is not allowed to be “turned”, as the coke can should not be spilled.
- Those constraints are often additionally added to the general constraint of “being free of collision”.
- These constraints limit the freespace and often create narrow passages in the configurations space, that makes planning very challenging.

Sources:
Integrated Grasp and Motion Planning usingIndependent Contact Regions
Joan Fontanals, Bao-Anh Dang-Vu, Oliver Porges, Jan Rosell, and Maximo A. Roa-
https://core.ac.uk/reader/41776685

Problems in Robot Motion Planning

Dynamic Balancing Motion Planning

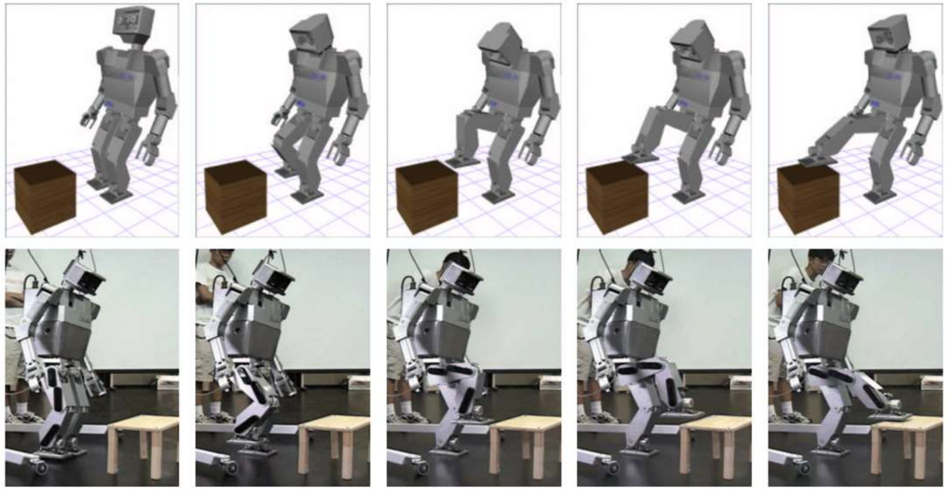


Figure 4: Positioning the right foot above an obstacle while balancing on the left leg. (*top*: simulation, *bottom*: actual hardware).

- Humanoid robots are a still a great challenge in robotic motion planning.
- The motion of humanoid robots needs to be same as for humans.
- To achieve this, it is necessary to plan motions that enable robots to balance them while moving.
- In these scenarios physical simulations of the robot have to considered while planning the motion.

Sources:
Motion Planning for Humanoid Robots Under Obstacle and Dynamic Balance Constraints
James Kuffner, Koichi Nishiwaki, Satoshi Kagami, Masayuki Inaba, Hirochika Inoue -
https://www.researchgate.net/publication/3902280_Motion_Planning_for_Humanoid_Robots_Under_Obstacle_and_Dynamic_Balance_Constraints

Summary

- Robot Motion planning is manifold.
- Often the amount of DOF is higher as with other motion planning problems.
- Also there are often constraints applied to the motion.
- In former times the motion planning was done offline and then transferred to the robot.
- Nowadays, the increasing hardware power (especially mobile SOCs) is enabling online motion planning. This makes robots more autonomous.