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MOTION PLANNING

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Preface

Why am I writing this book?

- Robot motion planning has been studied for many decades. Nonetheless, those techniques do not provide enough accuracy and performance for real-world robots. I believe that robots will start to be parts of our daily lives around 20's and 30's. We need to identify issues and technical challenges when the future comes to reality.

- Robot motion planning and collision detection have been developed in a long time. It is very hard to catch up all the major concepts. Also, new concepts and techniques have been constantly proposed. To develop new ideas, it is very important to understand them in an efficient manner

- Since there are a few books that cover the fundamental topics of collision detection and motion planning, I'll focus on recent topics.

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Introduction to Motion Planning

Robots have been around us early on. A robot can be an electro-mechanical or a virtual agent. One of early examples includes a water-powered clock tower developed in 1088 at China (Fig. 1.1). Since the industrial revolution, modern concepts on robots have been introduced thanks to various mechanical components powered by steams, fossil fuels, and electricity. Recent robots come in a variety of different types including industrial robots, humanoids, medical robots, vacuum cleaner, self-driving cars, etc.

Path planning is not merely a technical concept; it is the heartbeat of modern robotics and automation. It is the intelligence behind the motion, the algorithmic brain that guides machines through complex mazes, avoiding obstacles, optimizing routes, and achieving their objectives. It is the technology that brings us closer to fully autonomous systems capable of making informed decisions in a multitude of domains.

Early robots are commonly controlled by humans or designed to follow a series of predetermined steps. Recent robots, however, have complex mechanical structures and are designed to conduct various types of jobs. As a result, maneuvering them manually is getting harder and harder. This cries for automatic ways of controlling them, and various motion planning with different levels of automation levels have been designed.

Demands for robots are clearly getting bigger and bigger for higher productivity and human convenience. On top of that, various technology advances turn previously impossible jobs for robots to doable tasks that can be done automatically by robots. An example is driving. Many people and researchers have been considered driving to be a difficult task for robots, but thanks to developments of artificial intelligence, it becomes possible ones for robots nowadays.

Path planning is not just theory; it is a powerful tool in practical applications. We will showcase how path planning is used in autonomous vehicles, industrial automation, search and rescue mis-

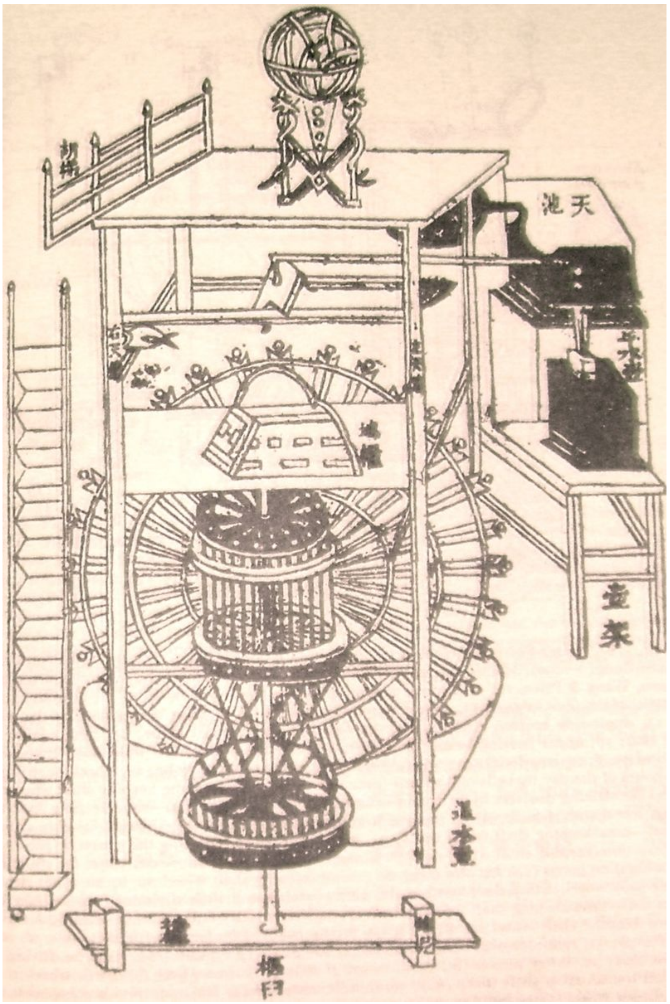

Figure 1.1: A water-powered tower clock developed in 1088 at China. Excerpted from the history of robots at Wikipedia.

sions, healthcare, space exploration, and beyond. Real-world case studies and examples will illustrate its impact on various industries.

In this book, we will consider classic motion planning methods developed early on for controlling robots and discuss recent trends that are useful for future robots.

The following tools and libraries are related to and useful for understanding our topic:

1. **Robot Operating System (ROS)**. This is rather a middleware consisting of various tools and library, e.g., collision detection and message passing between different modules, that are useful for robot development, instead of operating system.

2. **Open Motion Planning (OMPL) library.** It supports various sampling based planners in simple environments. We can test different methods and see their different behaviors.

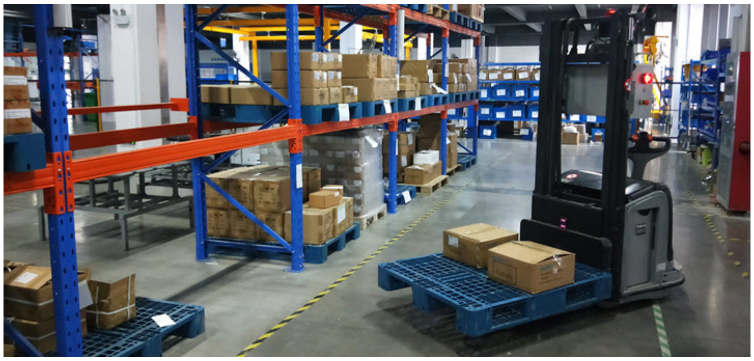

Figure 1.2: This shows an AGV (automatic guided vehicles) that is used for delivering packages in a controlled environment such as factory. Image credit: conveyco.com

1.1 *Applications*

Here are some key applications you can highlight:

- **Autonomous Vehicles.** Path planning plays a crucial role in self-driving cars and drones. It helps these vehicles navigate complex urban environments, avoid collisions, and reach their destinations safely.
- **Industrial Automation.** Manufacturing robots, such as robotic arms and AGVs (Automated Guided Vehicles), rely on path planning to perform tasks like picking and placing objects on assembly lines (Fig. 1.2).
- **Search and Rescue Operations.** In disaster scenarios or search missions, robots equipped with path planning capabilities can navigate hazardous environments, locate survivors, and plan efficient routes for first responders.
- **Surveillance and Security.** Unmanned aerial vehicles (UAVs) and ground-based robots are used for surveillance and security purposes. Path planning helps them patrol areas, monitor critical infrastructure, and respond to security threats effectively.
- **Healthcare and Medical Robotics.** Surgical robots and assistive devices in healthcare rely on path planning to perform precise procedures and assist patients with mobility challenges. Fig. 1.3 shows an da Vinci medical robot.
- **Agriculture and Precision Farming.** Autonomous agricultural machinery uses path planning to perform tasks like planting, harvesting, and weed control with minimal human intervention.
- **Space Exploration.** Autonomous rovers and spacecraft rely on path planning to navigate extraterrestrial environments such as Mars. Discuss how path planning is essential for exploring unknown terrains and collecting scientific data in space missions.

Figure 1.3: This shows a da Vinci medical robot. A single surgeon alone can control four arms of the robot. Image credit: IEEE Spectrum

- **Underwater Robotics.** Submersibles and underwater drones employ path planning for underwater exploration, marine research, and pipeline inspection. In these applications, path planning can aid in mapping and studying the ocean depths.
- **Delivery and Logistics.** Delivery drones and autonomous delivery vehicles use path planning to optimize routes, reduce delivery times, and minimize fuel consumption for improving the efficiency of e-commerce and logistics industries.
- **Game Development and Simulations.** Path planning algorithms are used in video games and simulations to create realistic character movements and behaviors. Game developers and virtual environment creators are commonly applying path planning for immersive experiences.

1.2 *Key Milestones*

Motion and path planning have a rich history with several key milestones that have shaped the field. Understanding these milestones can provide valuable context for readers. Here are some of the most significant milestones in the development of motion and path planning:

- **Early Robotics Concepts (1940s-1950s).** The field of robotics and motion planning traces its roots to early concepts and experiments. Inventor George Devol with his business partner Engelberger developed the first industrial robot, the Unimate, in the late 1950s, which was used in General Motors assembly lines and marked the beginning of automation and the need for motion planning.

- **The A* Algorithm (1968).** In 1968, computer scientist Peter Hart and his co-authors introduced the A* algorithm, a fundamental contribution to pathfinding and motion planning. A* is widely used in robotics and video games to find the shortest path in graphs.
- **The Configuration Space (1970s).** Lozano-Perez introduced the concept of configuration space, which represents all possible positions and orientations of a robot. This concept greatly simplified motion planning problems.
- **Probabilistic Roadmaps (PRM) and Rapidly Exploring Random Trees (RRT) (1990s).** PRM uses random sampling and graph theory to efficiently plan paths in complex environments. RRT is a breakthrough algorithm for solving high-dimensional motion planning problems. It is particularly valuable for robots with many degrees of freedom.
- **Machine learning and deep learning (2010s to present).** Machine learning and deep learning techniques have been applied to motion planning, enabling robots to learn from data and improve their planning capabilities through experience.

These milestones represent just a fraction of the significant developments in motion and path planning. The field continues to evolve, driven by advances in technology, robotics applications, and the ever-increasing demand for intelligent and autonomous systems.