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Beijing University of Posts and Telecommunications

Beijing University of Posts and Telecommunications: Design & Build

46 Groups of Technical Reports

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- Time: October 2025

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Contents

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01

Academic Background

Academic Background

With the rapid development of technologies such as artificial intelligence and autonomous driving, intelligent cars have shown great application potential in many fields including industry, logistics, and security. As an important sensor for intelligent cars, radar can assist them in environmental perception and obstacle detection, and is one of the key technologies for realizing autonomous navigation and driving of intelligent cars.

Autonomous tracking capability

The smart car is equipped with advanced sensors, and after data fusion, it performs autonomous navigation and tracking.

Widely applicable scenarios

The technology focuses on the "perception-decision" closed loop, embodying the combination of intelligence and practicality.

Study background

工业和信息化部等十七部门关于印发“机器人+”应用行动实施方案的通知

工信部联通装〔2022〕187号

各省、自治区、直辖市及计划单列市、新疆生产建设兵团工业和信息化、教育、公安、民政、财政、人力资源社会保障、住房城乡建设、交通运输、农业农村、卫生健康、应急管理、市场监管、能源、邮政、药监、矿山安全监管、煤炭行业主管部门，国家矿山安全监察局

现

十五部门关于印发《“十四五”机器人产业发展规划》的通知

工信部联规〔2021〕206号

各省、自治区、直辖市、计划单列市及新疆生产建设兵团工业和信息化、发展改革、科技、公安、民政、住房和城乡建设、农业农村、卫生健康、应急管理、市场监管、银保监、证监、国防科工、矿山安监主管部门，各人民银行分行，各有关单位：

国务院关于深化“互联网+先进制造业”
发展工业互联网的指导意见

各省、自治区、直辖市人民政府，国务院各部委、各直属机构：

当前，全球范围内新一轮科技革命和产业变革蓬勃兴起。工业互联网作为新一代信息技术与制造业深度融合的产物，日益成为新工业革命的关键支撑和深化“互联网+先进制造业”的重要基石，对未来工业发展产生全方位、深层次、革命性影响。工业互联网通过系统构建网络、平台、安全三大功能体系，打造人、机、物全面互联的新型网络基础设施，形成智能化发展的新兴业态和应用模式，是推进制造强国和网络强国建设的重要基础，是全面建成小康社会和建设社会主义现代化强国的有力支撑。为深化供给侧结构性改革，深入推进“互联网+先进制造业”，规范和指导我国工业互联网发展，现提出以下意见。

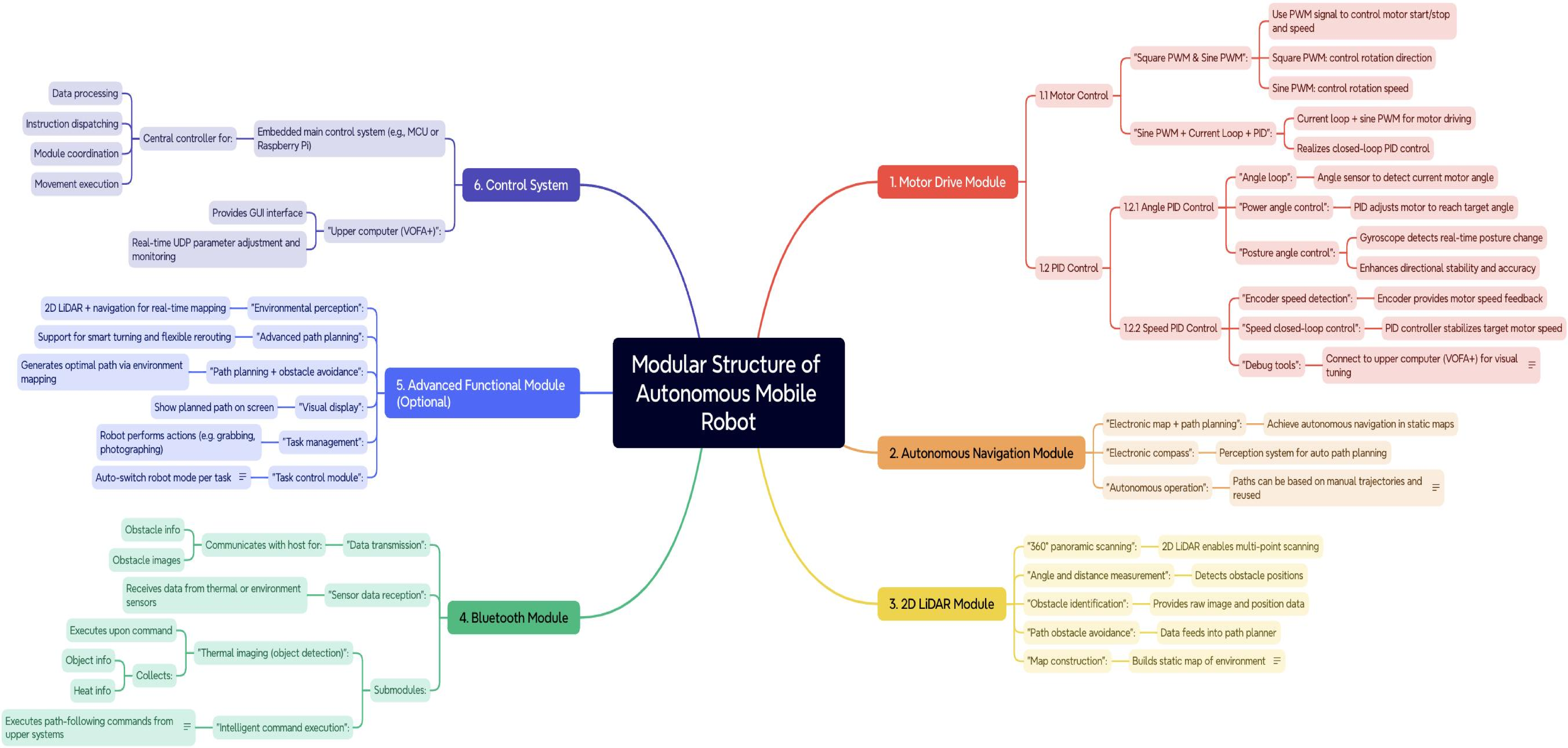
The national policies strongly support the development of the intelligent robot industry.

In China's strategic planning, the concepts of "intelligent manufacturing and robotics" were first introduced in the "Tenth Five-Year Plan" (2001-2005), which emphasized making breakthroughs in robotics technology. The "Fourteenth Five-Year Plan" (2021-2025) has formulated clearer plans for industrial robots: it proposes to establish a number of advanced manufacturing clusters, including industrial parks and industrial clusters, and focus on achieving breakthroughs in the core technologies of robotics.

2019-2025年中国智能机器人市场规模及预测

02

Hardware Section



Modular Structure of Autonomous Mobile Robot
1. Motor Drive Module
1.1 Motor Control
"Square PWM & Sine PWM":
Use PWM signal to control motor start/stop and speed
Square PWM: control rotation direction
Sine PWM: control rotation speed
"Sine PWM + Current Loop + PID":
Current loop + sine PWM for motor driving
Realizes closed-loop PID control
1.2 PID Control
1.2.1 Angle PID Control
"Angle loop":
Angle sensor to detect current motor angle
"Power angle control":
PID adjusts motor to reach target angle
"Posture angle control":
Gyroscope detects real-time posture change
Enhances directional stability and accuracy
1.2.2 Speed PID Control
"Encoder speed detection":
Encoder provides motor speed feedback
"Speed closed-loop control":
PID controller stabilizes target motor speed
"Debug tools":
Connect to upper computer (VOFA+) for visual tuning
2. Autonomous Navigation Module
"Electronic map + path planning":
Achieve autonomous navigation in static maps
"Electronic compass":
Perception system for auto path planning
"Autonomous operation":
Paths can be based on manual trajectories and reused
3. 2D LiDAR Module
"360° panoramic scanning":
2D LiDAR enables multi-point scanning
"Angle and distance measurement":
Detects obstacle positions
"Obstacle identification":
Provides raw image and position data
"Path obstacle avoidance":
Data feeds into path planner
"Map construction":
Builds static map of environment
4. Bluetooth Module
"Data transmission":
Communicates with host for:
Obstacle info
Obstacle images
"Sensor data reception":
Receives data from thermal or environment sensors
Submodules:
"Thermal imaging (object detection)":
Executes upon command
Collects:
Object info
Heat info
"Intelligent command execution":
Executes path-following commands from upper systems
5. Advanced Functional Module (Optional)
"Environmental perception":
2D LiDAR + navigation for real-time mapping
"Advanced path planning":
Support for smart turning and flexible rerouting
"Path planning + obstacle avoidance":
Generates optimal path via environment mapping
"Visual display":
Show planned path on screen
"Task management":
Robot performs actions (e.g. grabbing, photographing)
"Task control module":
Auto-switch robot mode per task
6. Control System
Embedded main control system (e.g., MCU or Raspberry Pi)
Central controller for:
Data processing
Instruction dispatching
Module coordination
Movement execution
"Upper computer (VOFA+)":
Provides GUI interface
Real-time UDP parameter adjustment and monitoring

Main Technologies and Hardware

- Autonomous Cruising
- PID algorithm
- State Machine Settings
- Plug-in Software Architecture
- Multiple communication protocols

Final Positioning

An autonomous tracking smart car with autonomous decision-making and intelligent recognition functions provides users with multiple functions to cope with different road conditions.

Technical Explanation and Application

Motor drive module

The motor drive module adopts the cooperative control of direction PWM and conventional PWM to construct a **two-layerPID PID PID closed-loop system**:

Speed loop PID: Real-time data from the encoder is used to fit the waveform, and parameters are adjusted via VOFA and the host computer to achieve precise speed regulation of the motor.

Angle loop PID: Calculations are performed based on the attitude information of the gyroscope to dynamically correct the steering attitude and suppress jitter deviations.

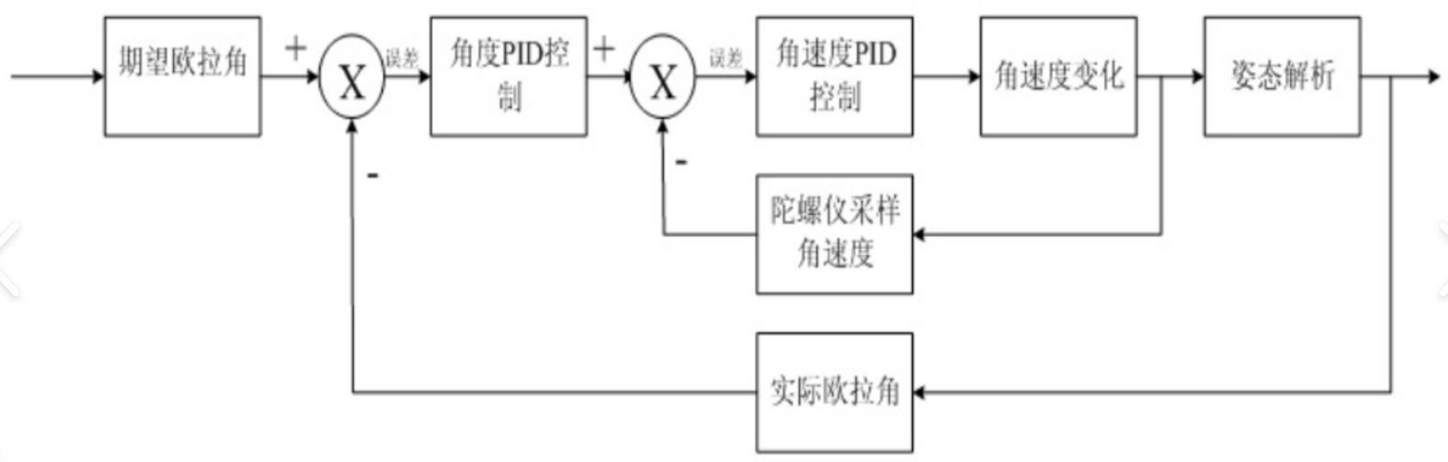
Dual-loop cooperative work: The speed loop ensures speed accuracy, and the angle loop ensures steering stability, jointly improving the system's control performance.

计算原理

$$u(t) = K_p \cdot e(t) + K_i \cdot \int e(t)dt + K_d \cdot de(t)/dt$$

e(t)= 目标转速 - 实际转速

u(t)= 速度环输出（通常为PWM占空比控制量）



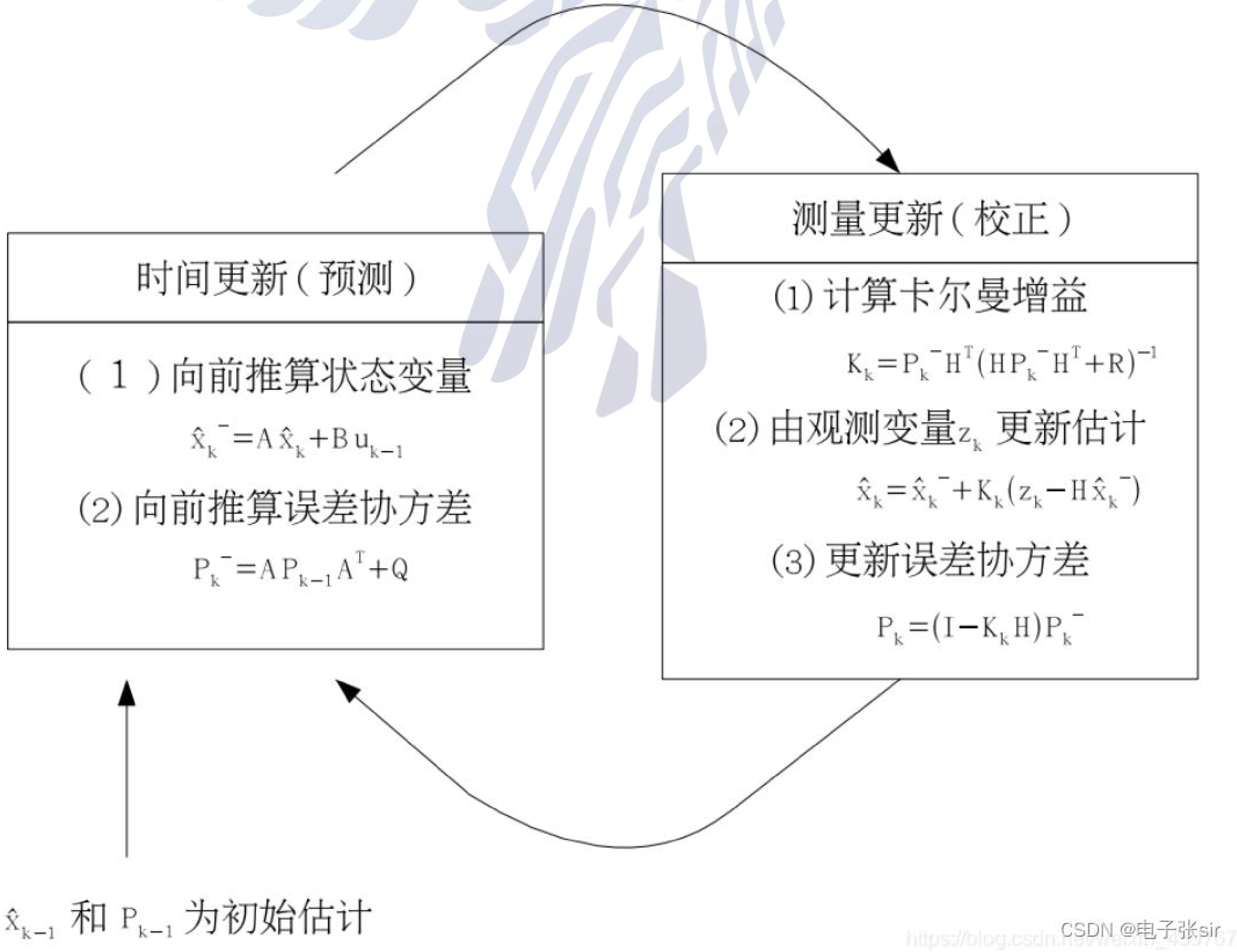
Technical Explanation and Application

Gyroscope solves the angle PID

In the angle PID control, the Kalman filter algorithm is adopted to optimize the gyroscope data, thereby solving the problem of zero bias drift in the original gyroscope data.

Specific Plan

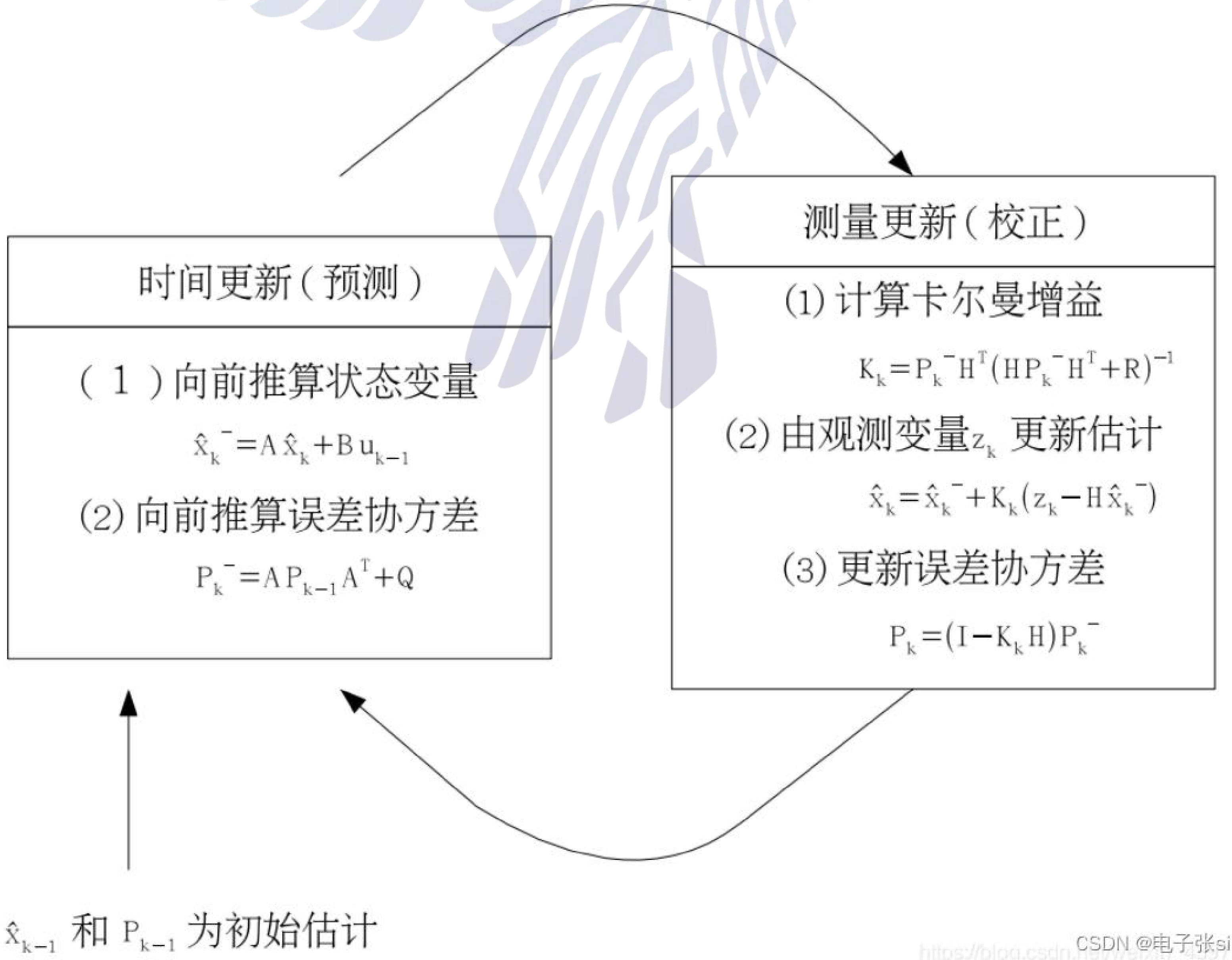
- Establish a state-space model (state transition matrix + observation matrix)
- Quantization noise (process noise + observation noise covariance)
- Real-time fusion of gyroscope angular velocity integration



Technical Explanation and Application

Achievement Effect

1.Suppress cumulative errors such as temperature drift and vibration
2.Improve angle feedback accuracy by 30%-50%
3.Enhance the dynamic response of motor steering



The algorithm adopts an optimal estimation strategy that minimizes the mean square error, improving the angle feedback accuracy by approximately 30%-50%. It provides a more stable attitude reference signal for angle PID control and significantly enhances the dynamic response characteristics of motor steering.

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Technical Explanation and Application

Automatic Pathfinding Settings

●Laser scanning ranging radar

We use the RPLIDAR C1, a low-cost 360° laser radar, which can provide intelligent environment scanning, real-time mapping (SLAM) and autonomous obstacle avoidance functions for smart cars.

It generates point cloud data through TOF ranging technology, supports PWM speed regulation to control scanning density, and is compatible with RoboStudio visualization tools and cross-platform SDK development.

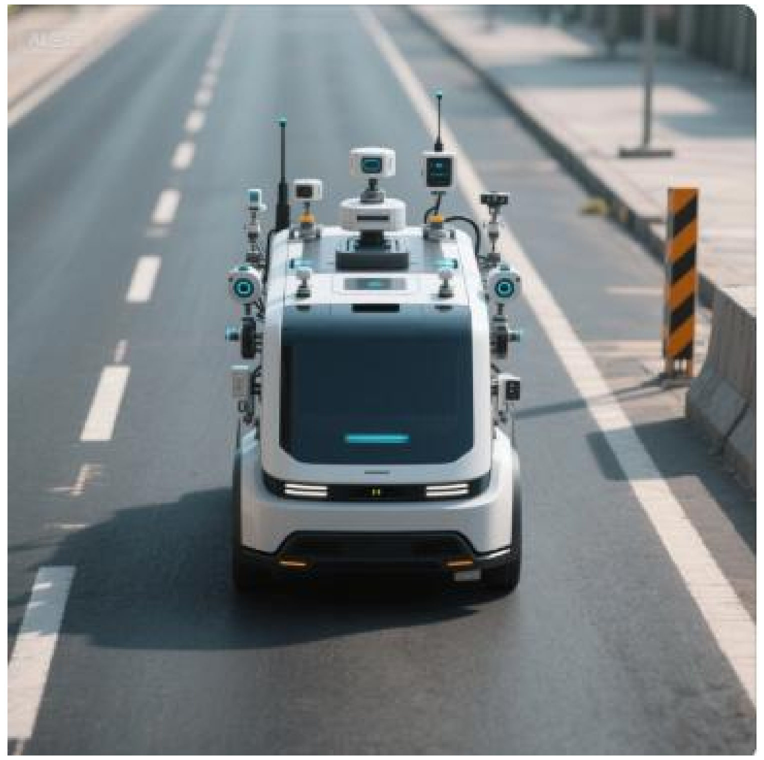
We used this radar to measure and transmit back the angles and distances of obstacles around the car.

Technical Explanation and Application

Automatic pathfinding settings

●right-hand rule

The robot uses sensors to perceive the distance to obstacles on its right side in real time. When no obstacles are detected on the right, it turns right to expand the path; when an obstacle is encountered, it continues moving along the right boundary.



Perceive obstacles on the right side

If there are no obstacles on the right, turn right.

If there is an obstacle on the right, drive along the right boundary

Technical Explanation and Application

Bluetooth Two-Way Communication

The Bluetooth module enables a bidirectional communication link. It wirelessly transmits processed LiDAR data and odometry uplink, while receiving and parsing navigation commands downlink. Integrated with IMU data, it facilitates 20ms-response motion control, completing a perception-decision-action loop for autonomous navigation.

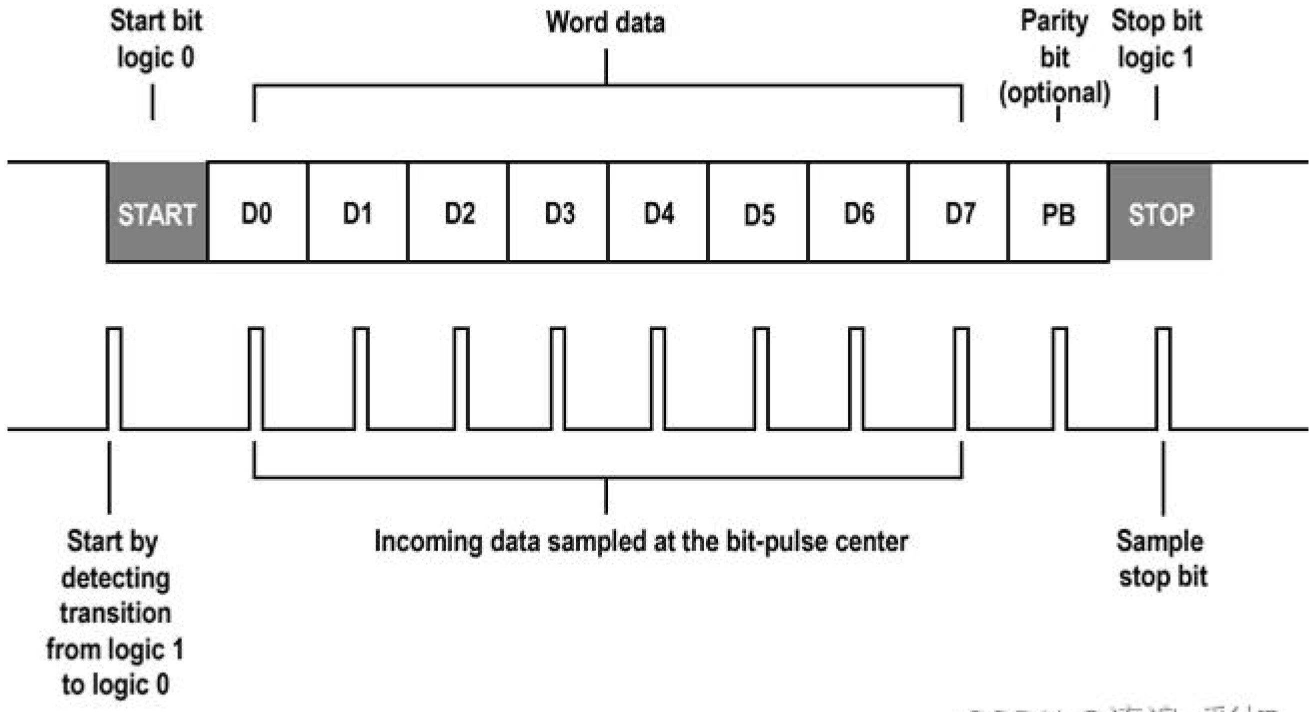
Technical Explanation and Application

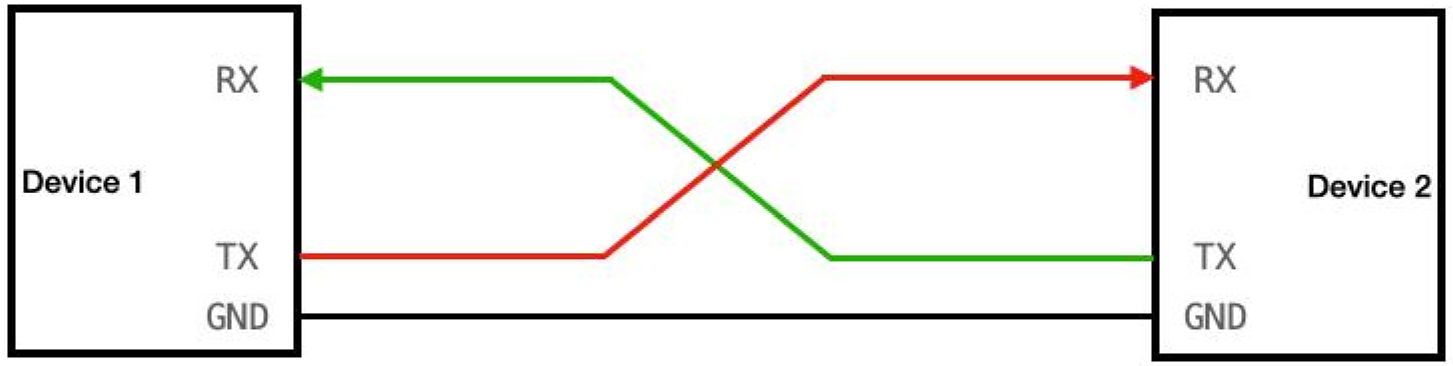
Communication Protocol

The **UART communication protocol** of the smart car enables key data interaction between the main control chip, laser radar, and Bluetooth module:

- The **laser radar** outputs 360° environmental data via UART.
- The **Bluetooth module** converts it into wireless signals for transmission to the upper computer, supporting remote monitoring.

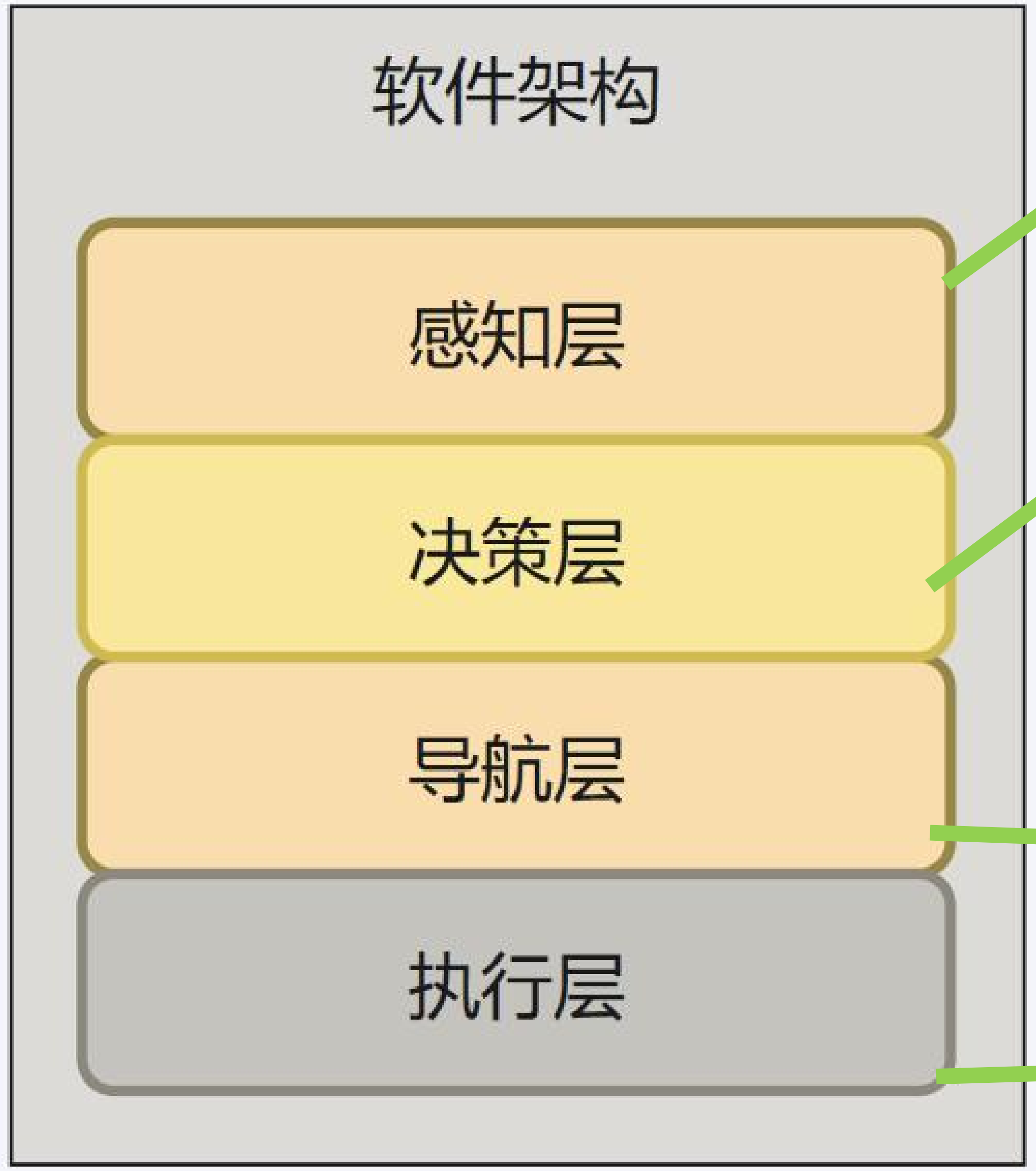
The asynchronous nature and full-duplex mode of UART simplify hardware design, ensure bidirectional real-time transmission of environmental data and control commands, and provide a reliable communication foundation for autonomous cruising and remote debugging.





Technical Explanation and Application

Plugin-based Software Architecture



Collect environmental and status information, and conduct preliminary processing and analysis

Based on the current environment, the status of the smart car, and the predetermined target, calculate and determine the next action of the smart car.

Localization, path planning, obstacle avoidance

Parse instructions and implement control

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03

Software section

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Tech Stack Overview

SLAM: BreezySLAM/TinySLAM (wrapped in slam/slam_wrapper.py)
Sensor & Odometry Simulation: Lidar in simulator/lidar_sim.py, odometry in simulator/odometry_sim.py

Map & Scenes: JSON maze maps (maze*.json) via simulator/map_loader.py

Path Planning: Global A* (planner/a_star.py), local obstacle avoidance DWA (planner/dwa.py)

Navigation & Control: Coordinator in control/navigator.py (pose fusion, path tracking, velocity commands)

Visualization: Map/trajectory rendering in visualization/map_viewer.py

```python
def create_scan_message(self):  1 个用法
    """create LaserScan message from scan values"""
    scan_msg = LaserScan()
    scan_msg.header = Header()
    scan_msg.header.stamp = self.get_clock().now().to_msg()
    scan_msg.header.frame_id = self.scan_frame
    scan_msg.angle_min = 0.0
    scan_msg.angle_max = 2 * math.pi
    scan_msg.angle_increment = math.radians(1.0)
    scan_msg.time_increment = 0.0
    scan_msg.scan_time = 1.0 / self.pub_rate
    scan_msg.range_min = 0.05
    scan_msg.range_max = 20.0
    scan_msg.ranges = self.scan_values
    return scan_msg

# ============ 速度指令处理 =============
def handle_velocity_command(self, velocity_msg):  1 个用法
    """处理速度指令"""
    linear_velocity = velocity_msg.linear.x
    angular_velocity = velocity_msg.angular.z
    direction = self.determine_direction(linear_velocity, angular_velocity)

    # 仅当方向变化时发送指令
    if direction != self.last_direction:
        self.send_movement_command(direction)
        self.last_direction = direction
```

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Implementation & Data Flow

Core Algorithms:Tiny SLAM, A* ,DWA

Scene Loading & Initialization

Sensor Simulation for SLAM

Navigation & Path Planning

Simulation & Visualization

Motion Control Disbatch

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ROS2-Based Maze Exploration Control System

Core Control Architecture

1.Control System Components

Exploration Controller:

- Task Planning & Scheduling
- Motion Control Generation
- Entry/Exit Position Management

2.Communication Framework

Data Processing Node:

- Upper/Lower Computer

Communication:

- Control Command Distribution
- Sensor Data Reception

Coordinate Transform:

- TF Tree Maintenance
- Lidar-Chassis Relationship

3.Simulation Environment

- Gazebo Virtual Environment
- Sensor Simulation
- Physics Engine Support

```python
def determine_direction(self, linear, angular):  1个用法
    """根据速度确定移动方向，返回按键编码"""
    if abs(linear) < 0.01 and abs(angular) < 0.01:
        return 5  # 停止（松开）
    elif linear > 0.01:
        return 2  # 前进（按下）
    elif linear < -0.01:
        return 8  # 后退（按下）
    elif angular > 0.01:
        return 4  # 左转（按下）
    elif angular < -0.01:
        return 6  # 右转（按下）
    return self.last_direction  # 默认保持上次方向
```

ROS2-Based Maze Exploration Control System

Navigation and Perception Architecture

SLAM System
Cartographer Framework:
- Real-time Mapping
- Pose Estimation
- Loop Closure Detection

Navigation System
Nav2 Framework:
- Global Path Planning
- Local Obstacle Avoidance
- Trajectory Generation

Task Execution System
Exploration Strategy:
- Unknown Area Exploration
- Path Optimization
- Status Monitoring

Sensor Fusion:
- Lidar Processing
- Odometry Integration

Summary of software part

The software architecture mainly has two parts: **navigation perception and core control.**

Navigation perception uses Cartographer for SLAM (mapping, pose estimation, loop closure detection) and Nav2 for path planning, obstacle avoidance, and trajectory generation; its task execution system manages unknown area exploration, path optimization, status monitoring, and lidar-odometry sensor fusion.

Core control features an exploration controller for task scheduling, motion control, and entry/exit management; a communication framework with data processing nodes (upper/lower computer communication, command distribution, data reception) and a coordinate transformation module (TF tree, lidar-chassis relationship maintenance); and a Gazebo simulation environment supporting sensor simulation and physics engine functions.

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04

Project Achievements

Project Achievements

- Basic Movement and Control

```
flowchart LR
    A[Robot<br/>机器人] -->|1. Uplink Data 上行数据| B[Uplink<br/>上行链路]
    B -->|Real-time: Pose (x,y,yaw) + LiDAR Point Cloud| C[Navigation Algorithm<br/>导航算法]

    C -->|2. Downlink Command 下行指令| D[Downlink<br/>下行链路]
    D -->|Target Waypoint Control Commands| A
```

High-Precision Motion Control

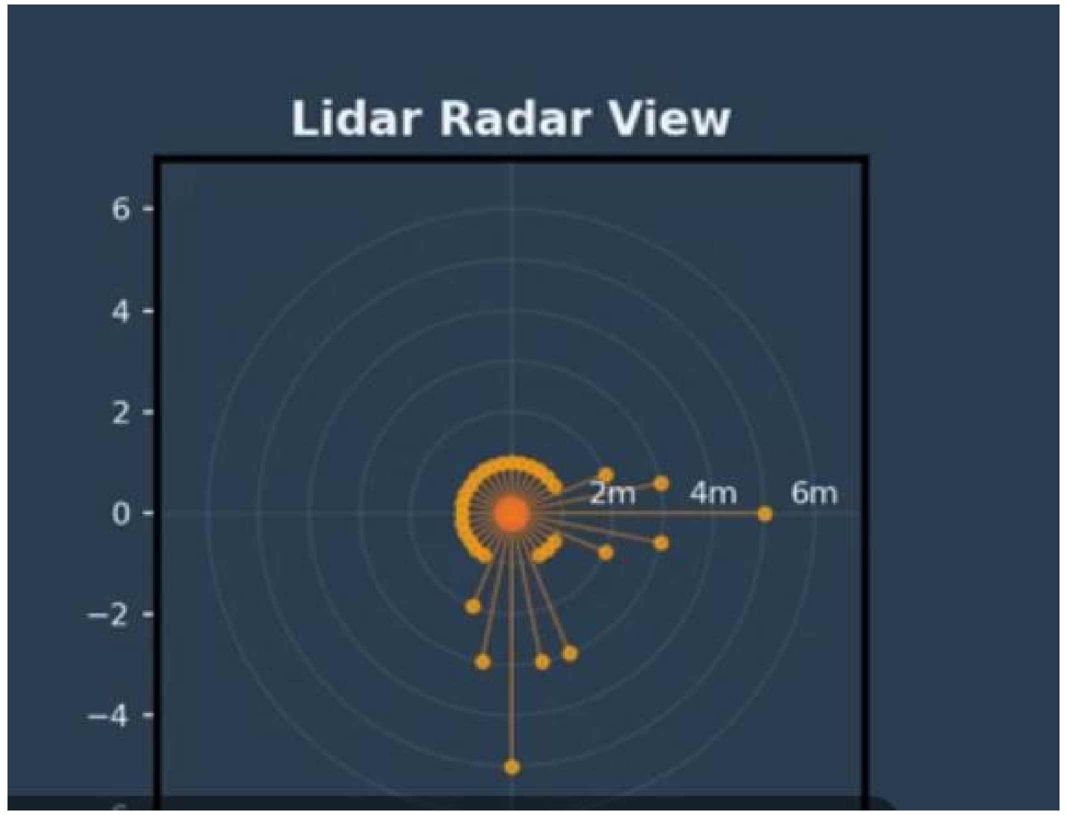
Utilizing a dual-loop PID controller (speed loop + angle loop) and Kalman filtering to achieve **accurate motor speed regulation** and **stable vehicle attitude control.**

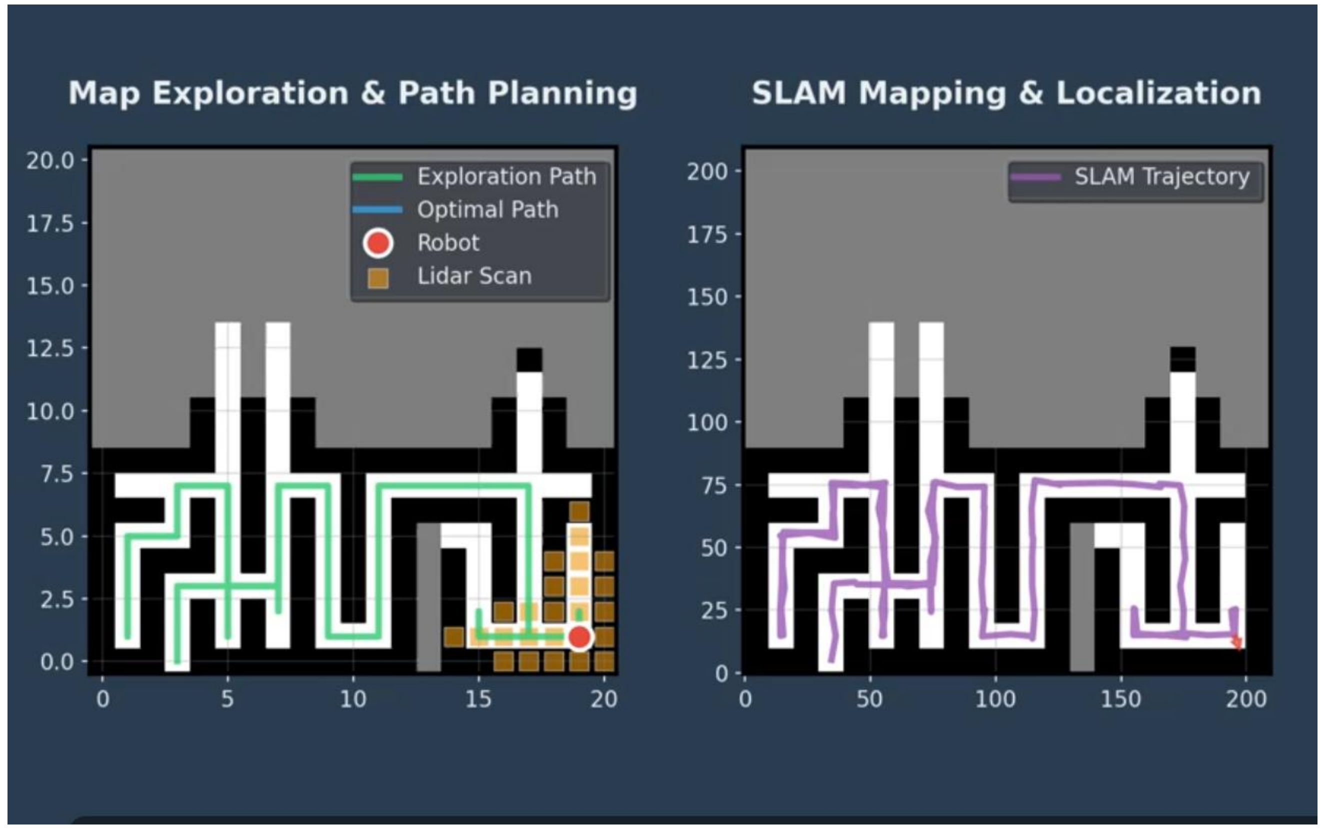
Stable Bidirectional Communication

Established a reliable wireless data link with the host computer (PC) via a Bluetooth 5.0 module.

Project Achievements

● Environmental Perception & Modeling





Real-Time Environmental Perception

Integrates a 2D LiDAR (RPLIDAR C1) and an IMU to achieve 360° environmental scanning, obstacle detection, and self-pose awareness.

Real-Time Map Construction

Runs a "SLAM-lite" algorithm in the software, capable of creating a real-time Occupancy Grid Map of the environment based on sensor data.

Project Achievements

● System Integration & Autonomous Navigation

Successfully bridged the simulation-to-reality gap by implementing the three core I/O functions as per guidance

get_robot_pose(): Fused onboard IMU & odometry for 20Hz pose streaming.

get_lidar_scan(): Integrated RPLIDAR C1, delivering 5Hz+ 360° point cloud data.

send_setpoint(): Executed navigation commands with 20ms control latency.

Built a complete autonomy stack based on the provided pipeline:
SENSE → (ICP) → MAP (OGM) → DECIDE → ACT → LOG.

Went beyond basic navigation by extending the system with a frontier detection algorithm.

The robot can autonomously explore, map, and identify exits in an unknown maze without a pre-defined map, fulfilling the core objective of the guidance.

1.All data packets feature CRC verification, ensuring communication reliability.
2.Motion control is stabilized by a Dual-loop PID controller (Speed & Angle).
3.Safety interlocks (v_max, ω_max) are implemented to ensure operational safety.

Project Achievements

● Core Implementation & Components

These core implementation breakthroughs transformed the foundational guidance into a robust, real-world system. By mastering the critical seams between hardware, software, and communication, we ensured reliable and high-performance autonomous operation.

Core Implementation Highlights

Modified Execution Model

Adapted the blocking tick model for real-robot use with non-blocking I/O and timeouts, preventing UI freeze.

Protocol & Validation

Designed custom serial protocols with headers and CRC checksums, meeting the guidance's requirements for robust data handling.

Sensor Fusion

Designed custom serial protocols with headers and CRC checksums, meeting the guidance's requirements for robust data handling.

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05

Team Division of Labor

Hardware Section

Name	Role and contribution	Basic information	Main work
Zhuang Hou	Leader,15%	Tel,sophomore, algorithm	Responsible for the overall electronic control part of the smart car and the engineering coordination with team members.
Haoyang Li	Member,9%	Tel,sophomore,radar	Responsible for writing gyroscope code and integrating radar code.
Zihan Li	Member,9%	Tel,sophomore, assemble	Responsible for the assembly of intelligent vehicles and auxiliary research.
Mu Du	Member,9%	Tel,sophomore, bluetooth	Responsible for learning radar code and implementing radar functions.
Fei Meng	Member,9%	Tel,sophomore, bluetooth	Responsible for radar integration learning and 3D modeling of the vehicle shell.
Huilan Sun	Member,9%	Tel,sophomore,radar	Responsible for writing gyroscope code and integrating radar code.

Software Section

Name	Role and contribution	Basic information	Main work
Jiarui Xu	Leader,13%	IoT, sophomore	Environmental perception and data reception, and arranging coordination among team members
Kaichen Yang	Member,9%	IoT, sophomore	Map construction and algorithm optimization debugging
Yiben Liu	Member,9%	IST, sophomore	Autonomous exploration and path planning
Taoran Li	Member,9%	IoT, sophomore	System integration and simulation testing

Thanks For Your Watching

Thank you

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