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RC Car Project

Lane Keeping Control in Autonomous Driving by Computer Vision Approach

SEP 742 – Group 1

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Content

Project Background

Why Lane-Keeping?

- Core task in autonomous driving
- Improves safety, comfort, and traffic flow
- Critical in highway scenarios

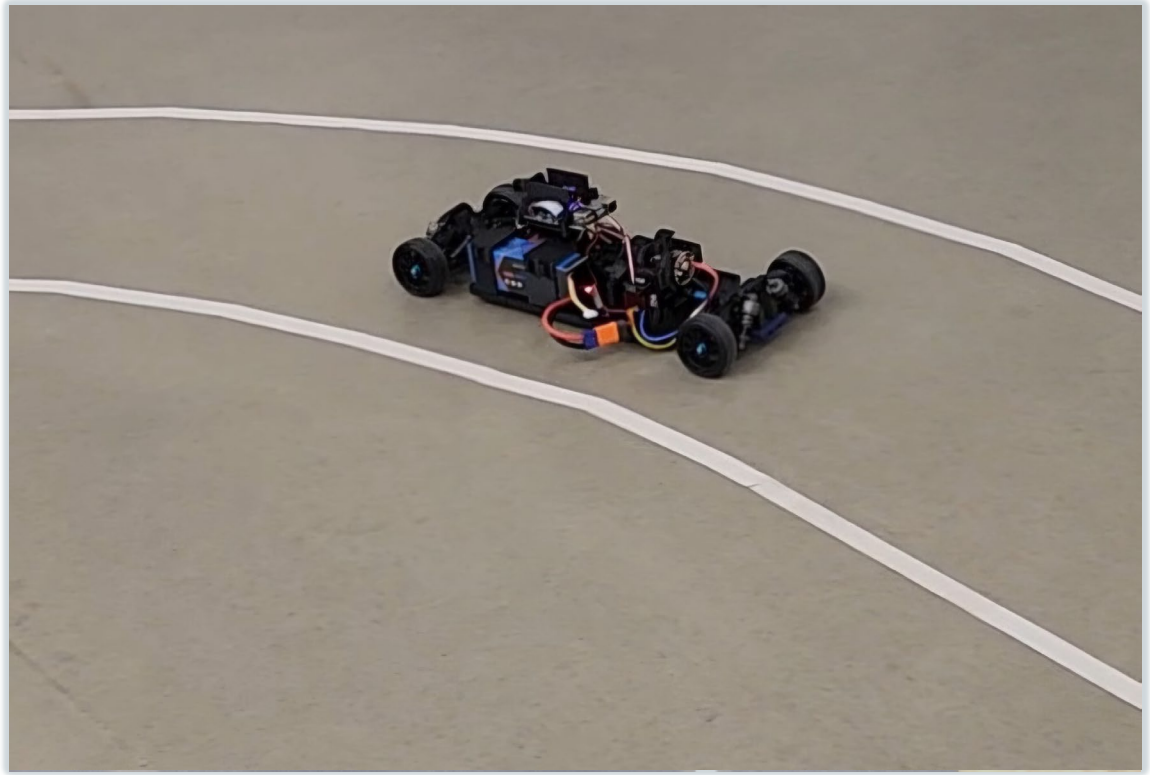
Our Approach

- Use a vision-based system on an RC car
- Focus on detecting lanes and adjusting steering

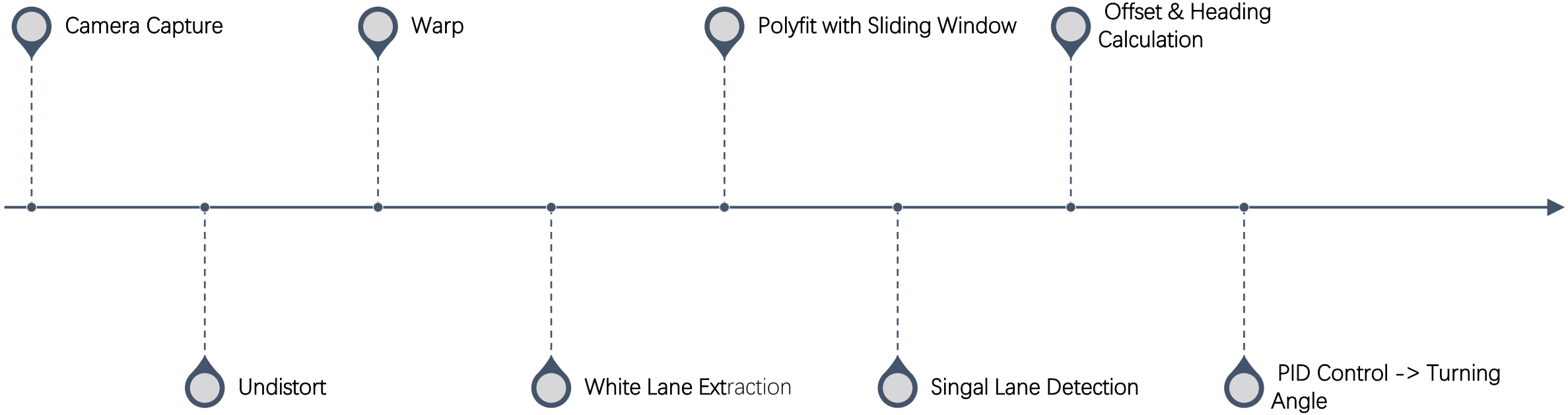
Problem Definition

- **Main Tasks**
  - Detect lane boundaries
  - Estimate curvature & position
  - Control steering in real-time

- **In our setup**
  - Maintain constant forward speed
  - Adapt to different curve geometries
  - Focus on lateral control (not lane change or obstacle avoidance)



System Flowchart



01 Demo (video)

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CONTENT

02 Computer Vision

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Scene Preparation

Computer vision-based lane detection systems require precise scene preparation to create a standardized view of the road environment.

Camera Calibration

Aerial View Transform

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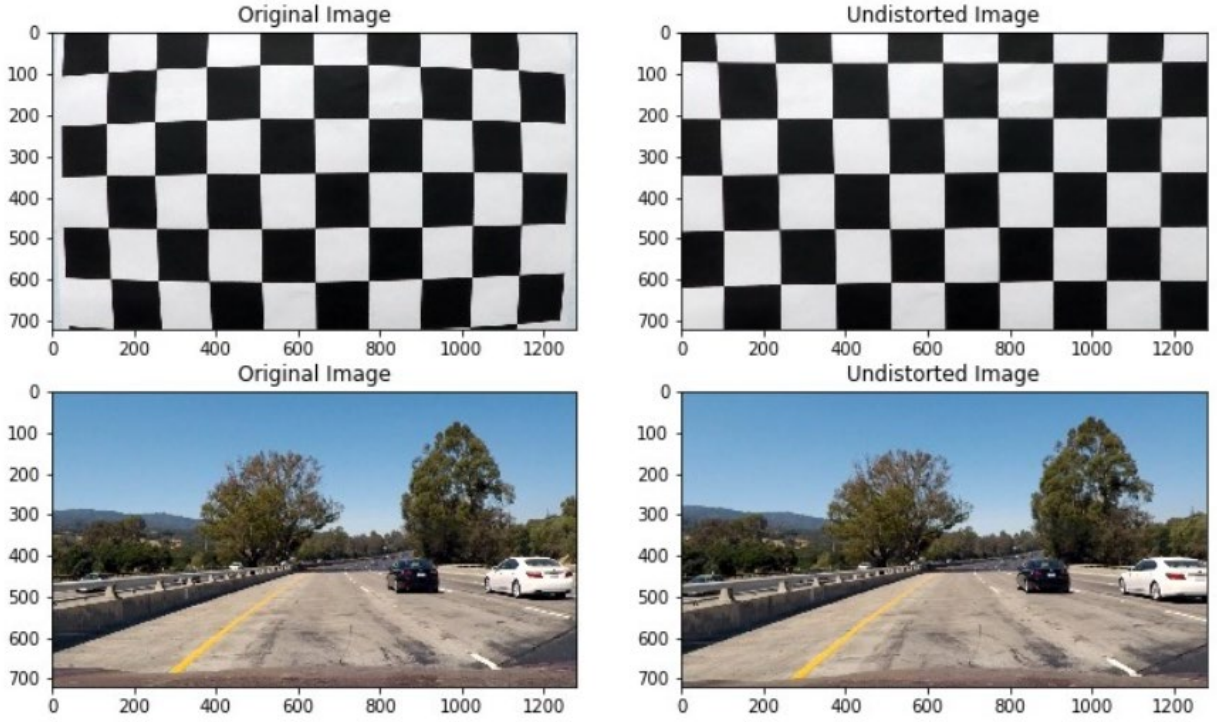
Scene Preparation

Correct lens distortion by establishing the relationship between 3D world coordinates and 2D image coordinates through parameters such as length, point, and distortion coefficients.

Camera Calibration



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Scene Preparation

Correct lens distortion by establishing the relationship between 3D world coordinates and 2D image coordinates through parameters such as length, point, and distortion coefficients.

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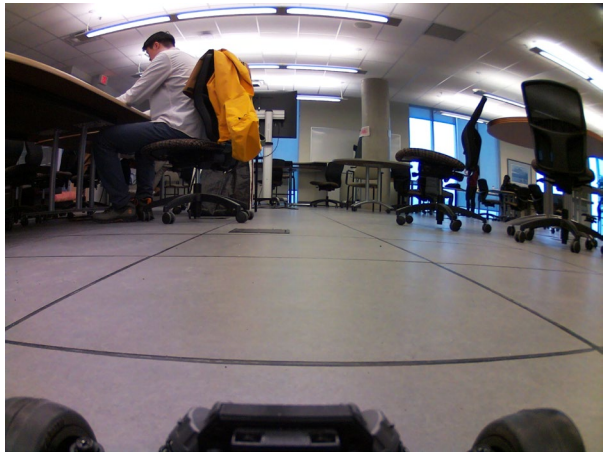

Original Image

Undistorted

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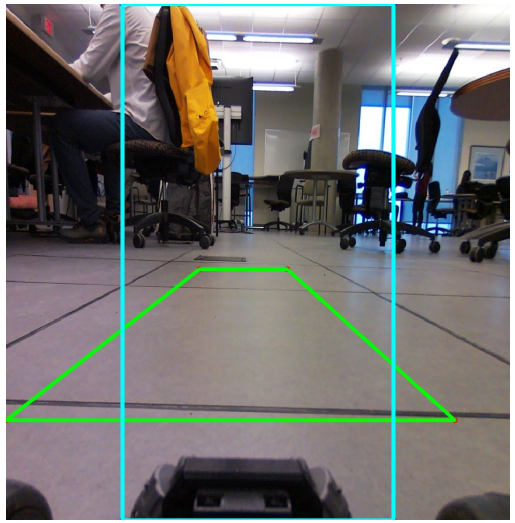
Scene Preparation

A perspective transformation is applied to obtain a bird's-eye view of the road, converting the frontal camera perspective into a top-down view where lane lines appear parallel rather than converging at the horizon.

Aerial View Transformed



a) Original Image

b) Aerial View Transformed

02 Computer Vision

Image Transformation - HSV

HSV converts the input BGR image to HSV space and applies specific thresholds to identify lane markings.

- Color Information (Hue)
- Color Saturation (Saturation)
- Brightness (Value)

(Abbas & Kadhim, 2024;Hillel et al., 2012)

With carefully tuned thresholds, we can detect both white and yellow lane markings on roads and have higher resistance on interferences compared with RGB image.

a) Original Image

b) Image Extracted White-Yellow in RGB

c) Image Applied White-Yellow HSV

02 Computer Vision

Edge Detection- Canny

Lane lines possess a distinct characteristic: they typically form long, continuous borders!

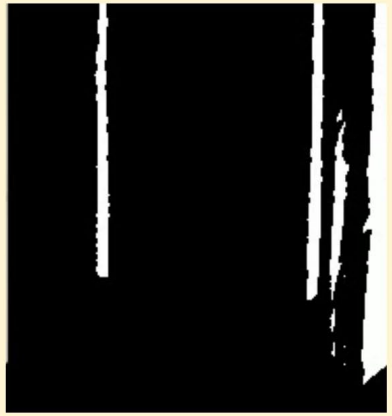
- **Noise Reduction**
  Apply Gaussian filter to smooth image and reduce noise
- **Gradient Calculation**
  Use Sobel operator to find intensity gradients
- **Double Thresholding on Classified Pixels**
  - Strong: above high threshold
  - Weak: between low & high
  - Non-edge: below low threshold

  Link weak edges to strong ones if connected.

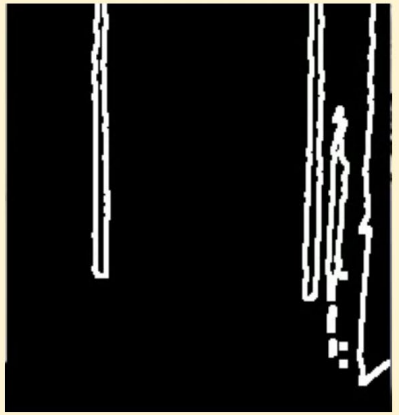
(Malche, 2024; Educative, 2025; Scikit, 2013)

Original Video

Scene Preparation



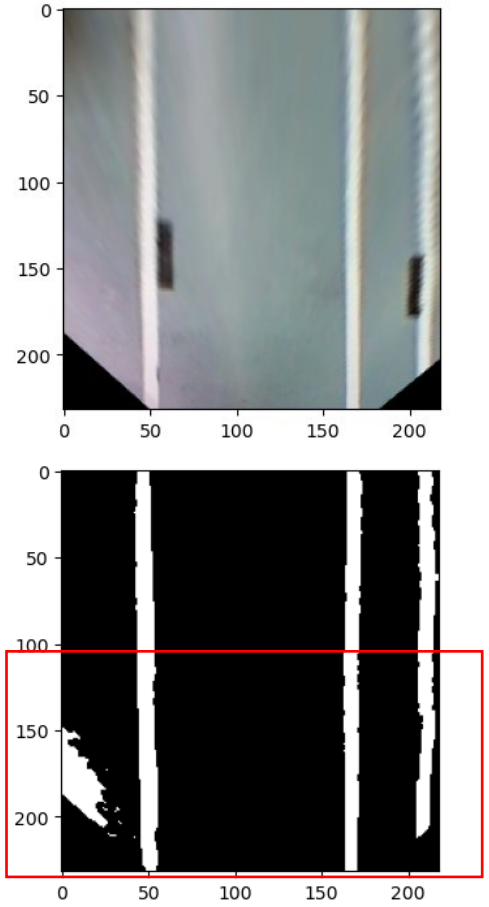
Transformed



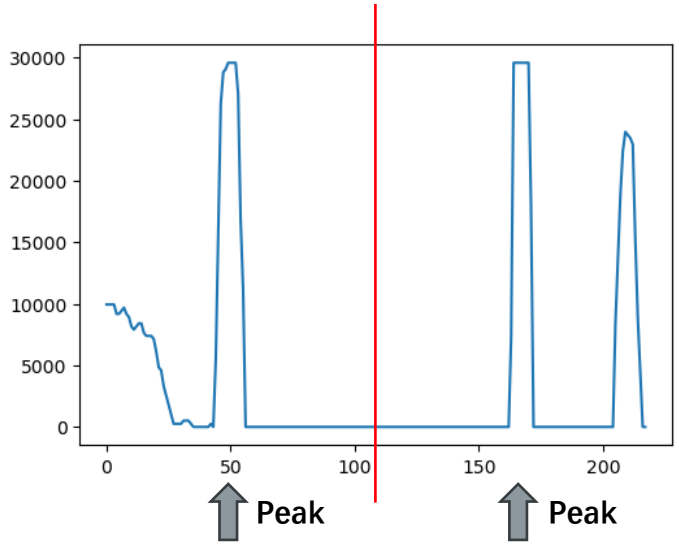
Edge Detected

02 Computer Vision

Lane Detection using Sliding Window

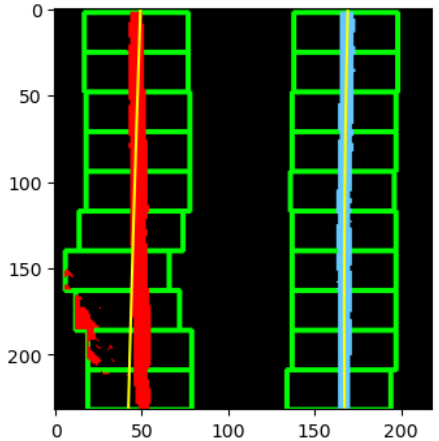


HSV Threshold Filtered



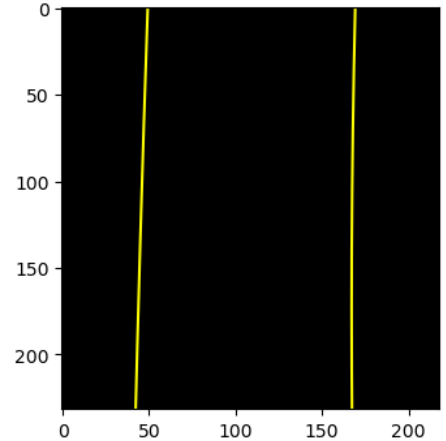
Initial Position Determination

- Build histogram from bottom-half of the image
- Split left and right by mid point
- Select peak points as initial left lane and right lane starting location



Sliding Windows

- Building blocks vertically
- Whole image split into *n* windows
- **Filtering** points – **calculate** average x – **reposition** next window



Polynomial Fitting

- 2-degree polynomial
- y=ax^2+bx+c
- Next sliding window location base on fitting

02 Computer Vision

Lane Geometry – Offset, Heading

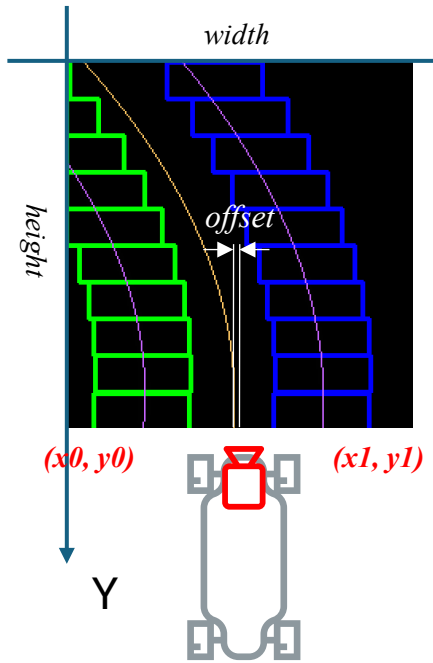
Offset

When y=*height*, solve y_{left} ➡️ *(x0, y0)*

When y=*height*, solve y_{right} ➡️ *(x1, y1)*

y0=y1=*height*

offset = $\frac{width}{2} - \frac{x_0+x_1}{2}$ The camera always point at the mid point of the image!



$$y_{left} = a_1x^2 + b_1x + c_1$$

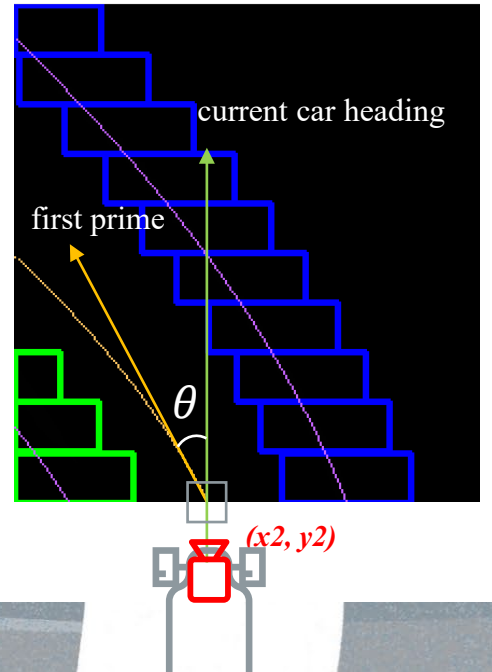
$$y_{right} = a_2x^2 + b_2x + c_2$$

Heading

$y'(x_n) = (a_1 + a_2)x_n + \frac{b_1+b_2}{2}$, at given point x_n

$\theta = \arctan(a_1 + a_2)$

$$y_{middle} = \frac{a_1 + a_2}{2}x^2 + \frac{b_1 + b_2}{2}x + \frac{c_1 + c_2}{2}$$



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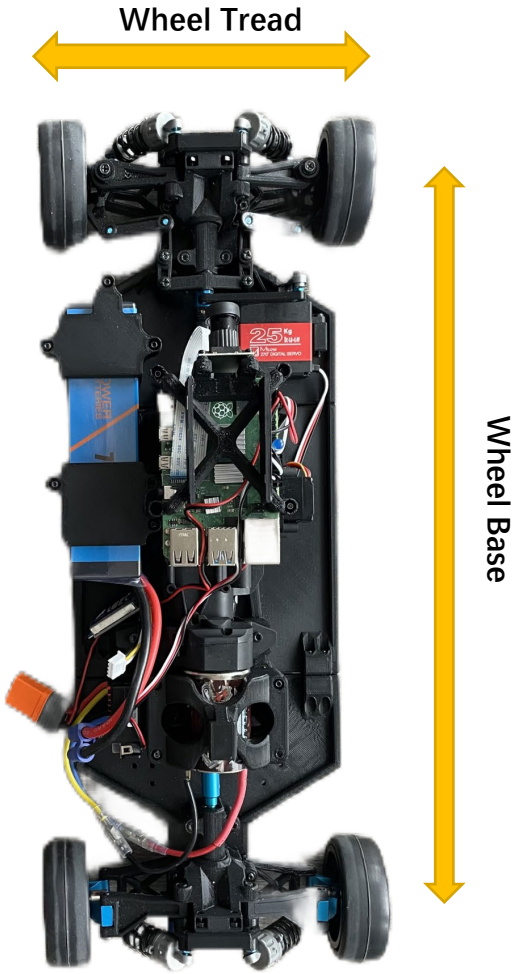
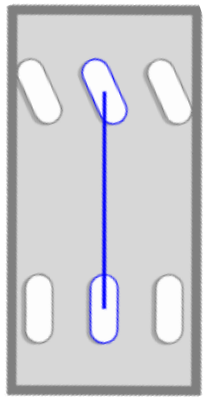
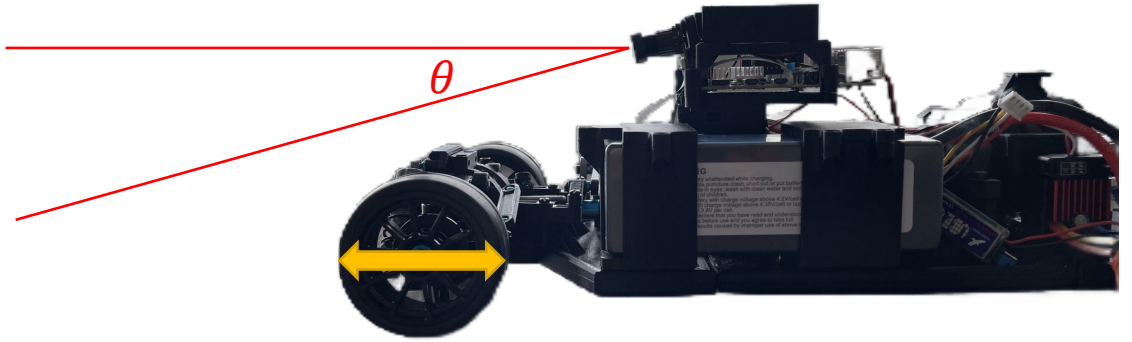
03 Hardware and Control

RC Car Hardware





Two-Wheel Bicycle Model



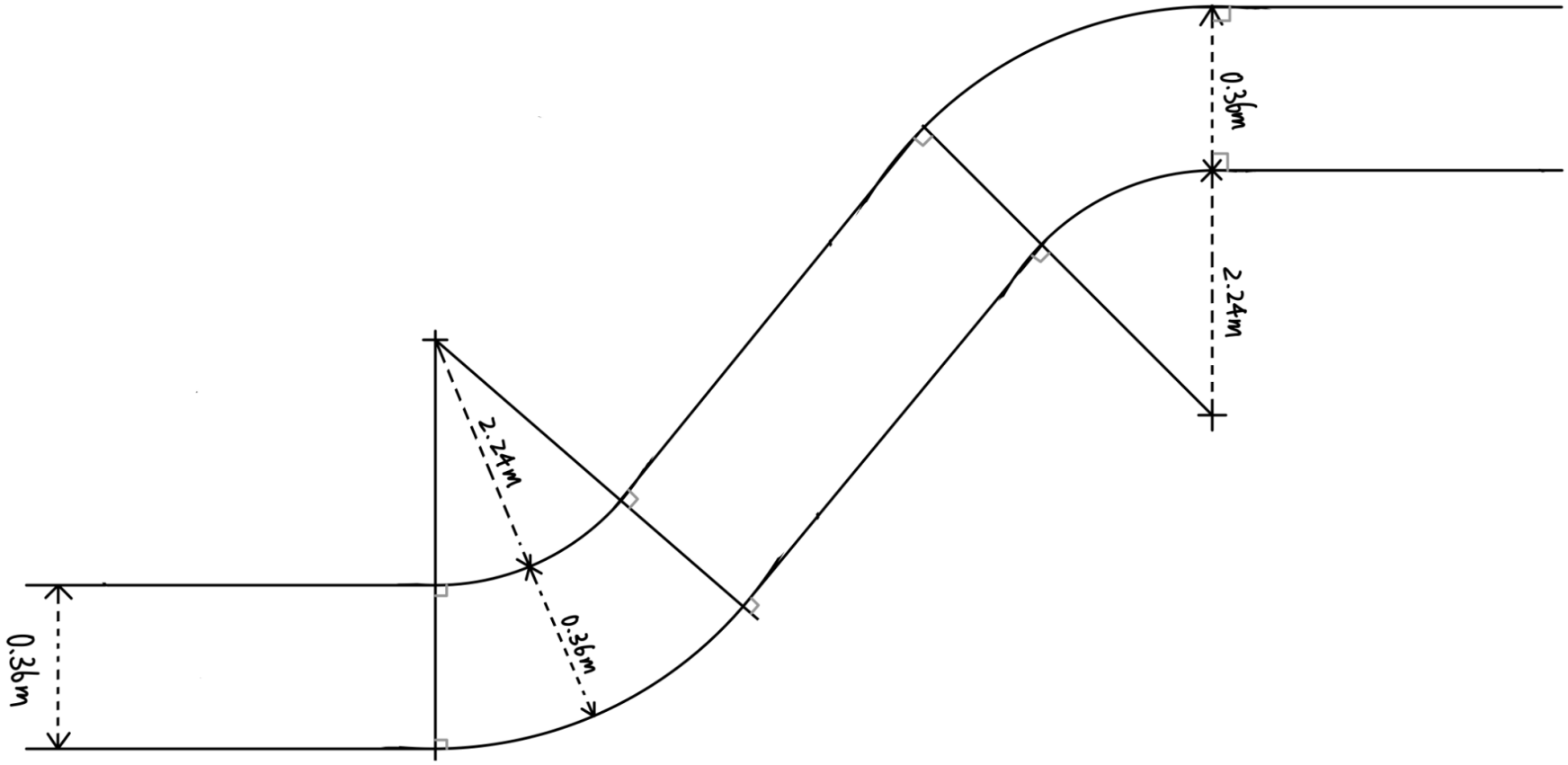
Wheel Diameter

Specification	Value
Wheel Base	0.4 m
Minimum Turning Radius	~2.8 m
Maximum Steering Angle	~8°
Camera Incline Angle	10°
Camera Resolution	Up to 2592x1944

03 Hardware and Control

Track Design

1. Straight Line
2. Left Turn
3. Straight Line
4. Right Turn
5. Straight Line



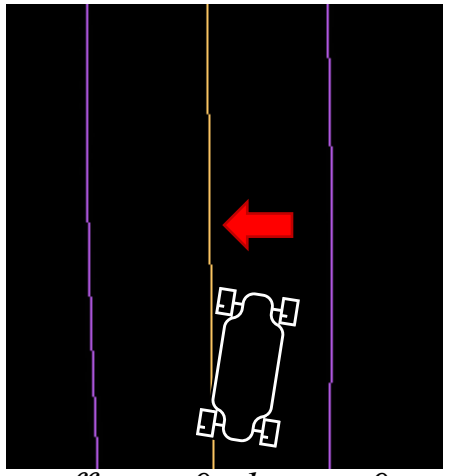
03 Hardware and Control

$\text{offset} \rightarrow 0, theta \rightarrow 0$

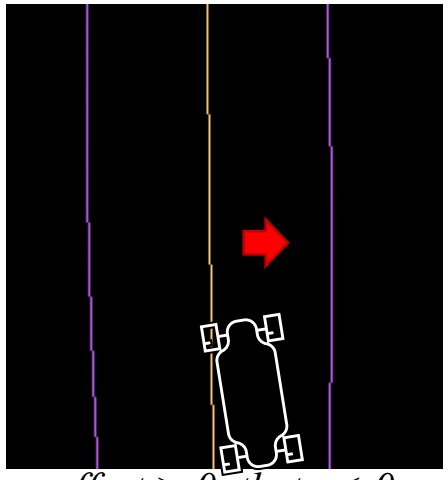
$Observation = k * Offset\ (1 - k) * Heading$ $\theta = tanh(\lambda * Gain) * \omega_{max}$

$PID\ Gain = PID(SetPoint, Observation)$

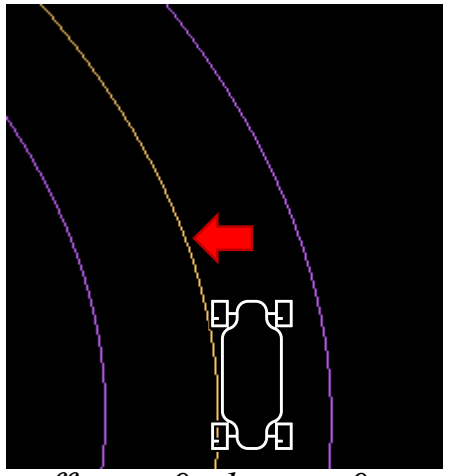
PID Control



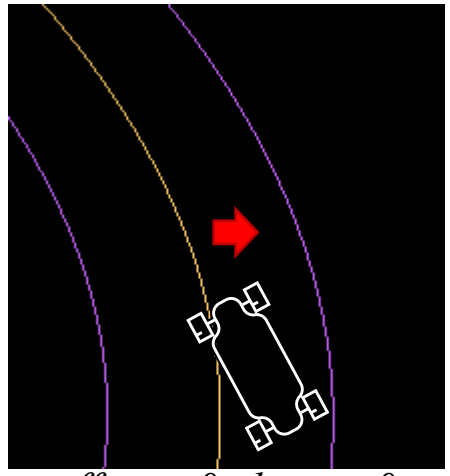
offset > 0, theta > 0



offset > 0, theta < 0



offset > 0, theta > 0



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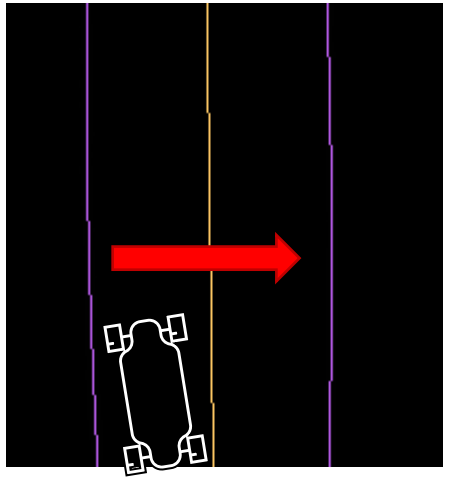

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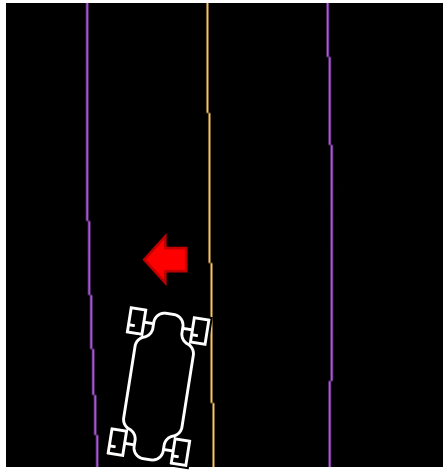
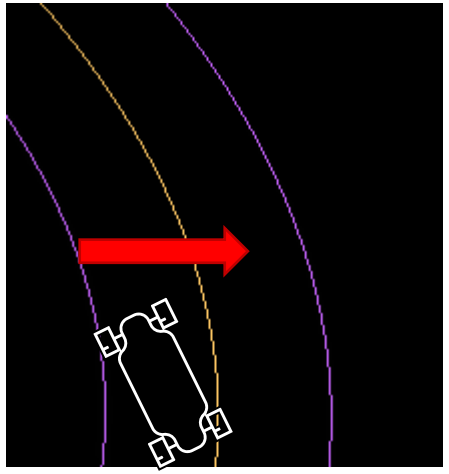
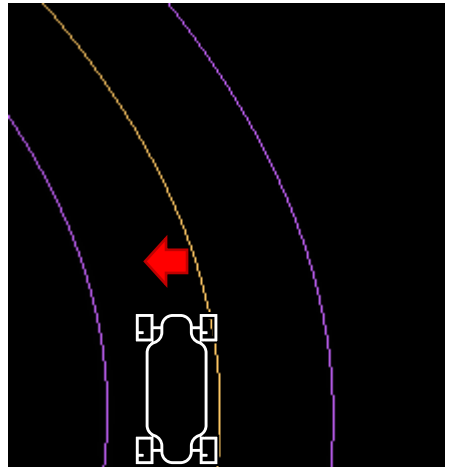


offset < 0, theta > 0



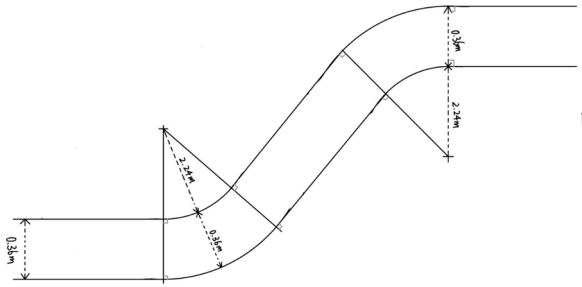
offset < 0, theta < 0

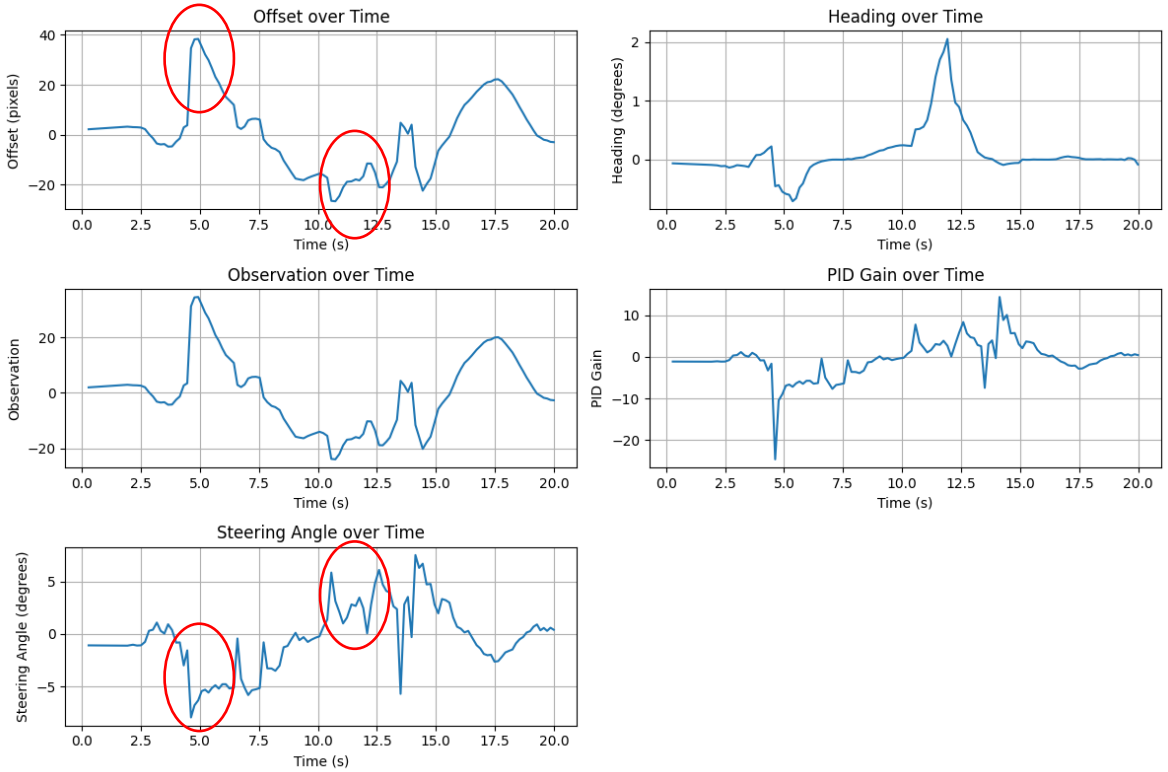


offset < 0, theta > 0

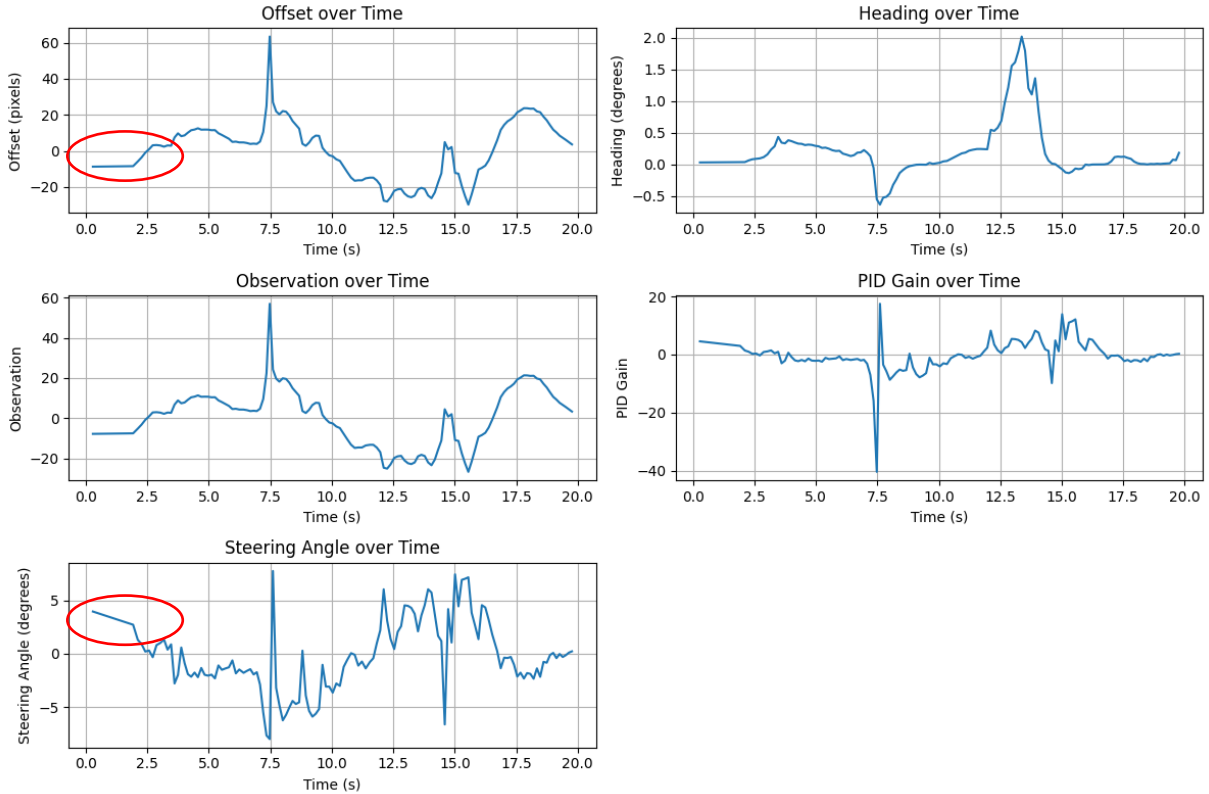
03 Hardware and Control

System Control Analysis





Forward Pass



Backward Pass

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CONTENT

04 Summary

- **Overview**
  - Successfully ran the entire pipeline
  - Very fast, achieving 10 fps, allowing steering adjustments 10 times per second
  - Strong results from PID parameter tuning
  - Accelerated parameter tuning driven by data plots
- **Hardware Limitations**
  - Camera: Narrow FOV (Field of View) causes loss of one lane during turns
  - Vehicle does not go perfectly straight forward, though PID control compensates
- **Software Pipeline**
  - HSV thresholding is not robust; strong illumination (e.g., sunlight or reflections) causes poor filtering
  - Hard-coded corner cases lack flexibility

https://github.com/YeChen-coder/RCCarRelated

04 Future Exploration

Motivation for CNN-Based Steering

Limitations of Traditional Computer Vision

Manual Feature Engineering:
Reliance on edge detection, thresholding, and geometric heuristics.

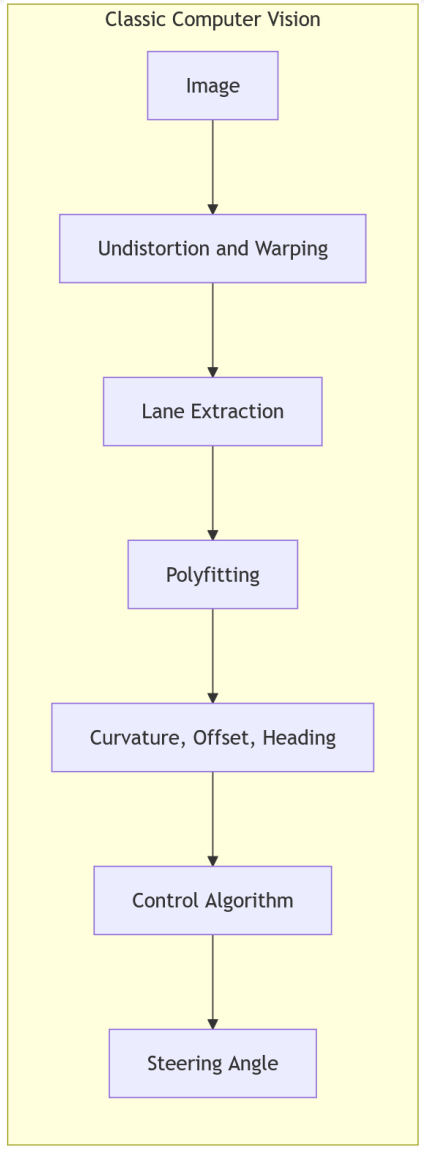
Environmental Sensitivity:
Fails under dynamic lighting (shadows/glare) and structural ambiguities (faded/blocked lane markings).

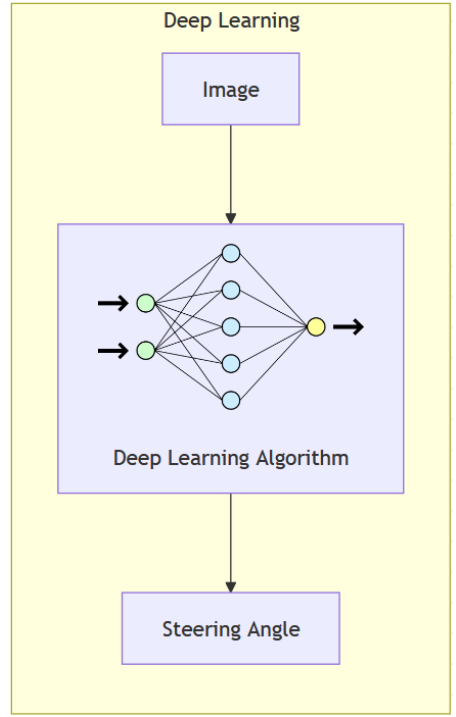
Scalability Challenges:
Requires frequent recalibration (HSV thresholds) for new environments.

Advantages of Deep Learning Solutions

End-to-End Learning:
Direct pixel-to-steering mapping without manual feature engineering.

Robustness:
Learns latent patterns from numerous examples.





04 Future Exploration

Software-based Experiment Setup

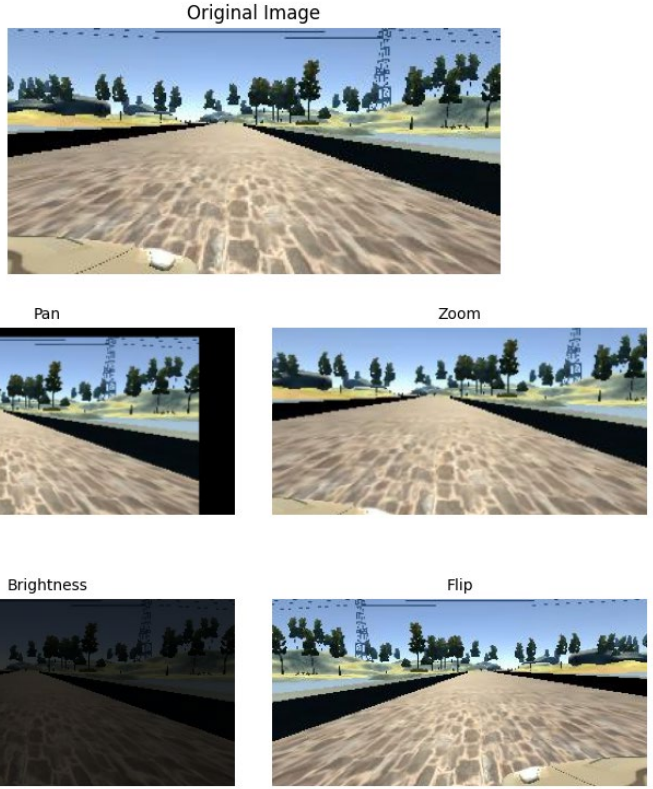
Simulation Environment
Udacity's Self Driving Car Simulator

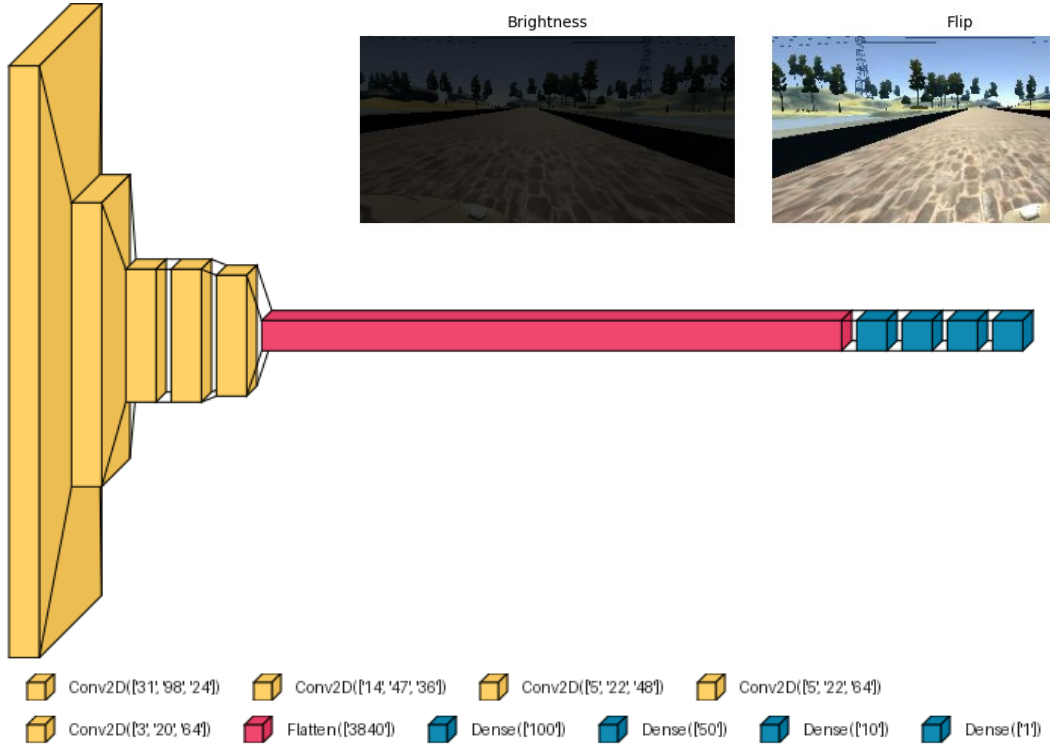
Dataset
https://github.com/rslim087a/track/
Collected from 3 cameras (center, left, right)
Includes steering angles, throttle, reverse, and speed

Data Processing
Bin Balancing
Random Affine Transformation
Side Cams with steering angle correction (±0.15)

Model
NVIDIA PilotNet
5 convolutional layers (ELU activation, dropout)
4 fully connected layers (ELU activation)

Evaluation
Validation Loss (MSE)
Human Observation (lane adherence, recovery from deviation)





04 Future Exploration

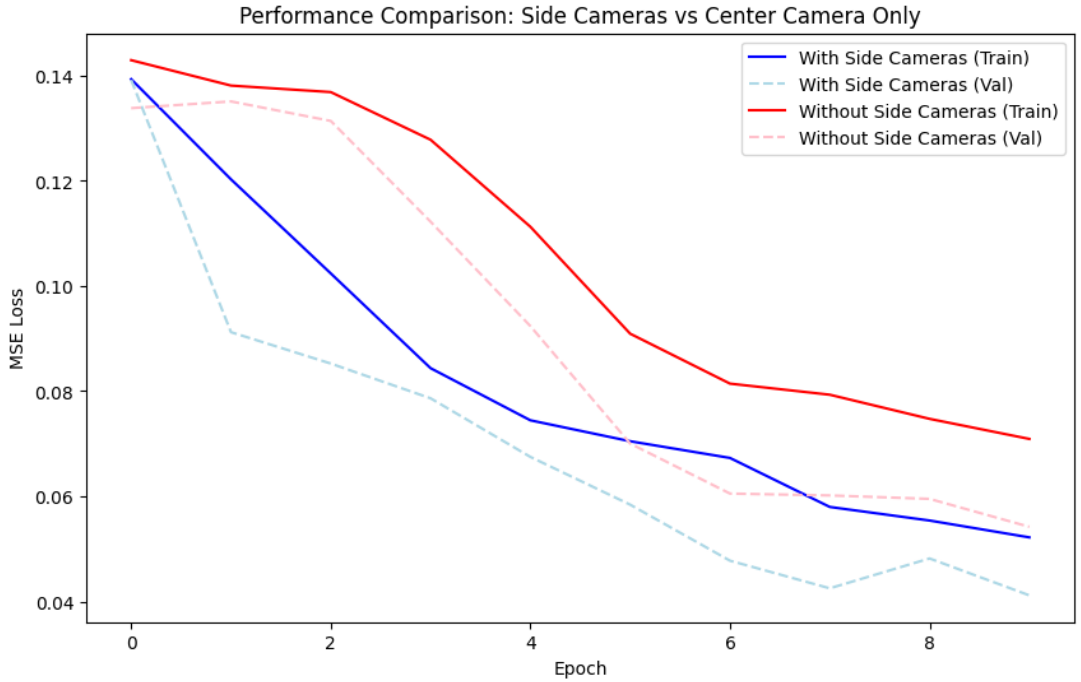
https://github.com/tzway/e2e-selfdrive

Key Challenge in Porting CNN Based Steering to RC Car

Missing Side Cameras
RC car has only a front-facing camera.
No data regarding lateral displacement.

Comparative Experiment: 3-Camera vs. Center-Camera Training
Replicated center cam images as side cam images for center-cam only data to ensure data balance
Trained with same arch (batch=100, lr=1e-3, epochs=10)
Used the same validation set for comparison

Val Loss: 3-Cam (0.041) vs. Center-Cam (0.054)
Observation: 3-Cam recovered more drastically from drifting while the Center-Cam in some circumstances failed to keep in the lane



Conclusion and Porting Suggestions
Prioritize sensor diversity, add more cameras, add sensors like IMU to gain spatial information
Adjust the CNN layout based on specific tasks/environments (input image dimensions, output dimensions, depths)
Pair CNN predictions with rule-based corrections for fail-safe maneuvers

04 Future Exploration

RC Car Platform Exploration

Robot Operating System (ROS)

https://www.diyrobocars.com/

Thank you!
Feel free to reach out!

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Methodology

01 02 03 04 GOAL

01 Image Capture & Preprocessing

Undistortion, Bird-eye View Transformation

02 Lanes Detection & Polynomial Fitting

Color Space Transformation, HSV Threshold Filtering, Sliding Window Filtering, 2-degree Polynomial Fitting

03 Lane Geometry

Lane Curvature, Offset from center, Heading Angle

04 PID Control

Proportional-Integral-Derivative Control, output to steering angle

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Demo Video

Hardware Introduction

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Demo Video

Process

Demonstration

In Debug Mode

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Demo Video

Full Operation in Auto-Run Mode (Reversed Route)

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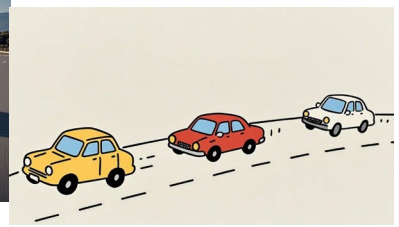
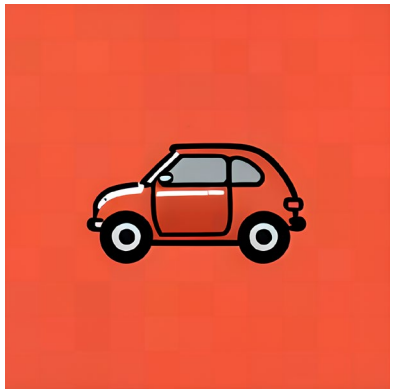
Demo Video

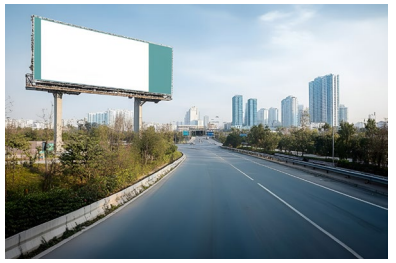
~~Failed Prototype~~

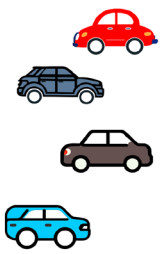
Intellectual Awakening

图片素材自取
请复制使用









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01

工　作　总　结

Pleaseaddaclearbusinesstemplateforthetitlecontenty
ouwanttoaddPleaseaddaclearbusinesstemplat

高速行车安全出行PPT模板

CLEAN, MINIMALIST, FLAT, POWERFUL AND FLEXIBLE POWERPOINT TEMPLATE, PERFECT FOR BUSINESS, CORPORATE FLEXIBLE POWERPOINT OR PERSONAL USE.

汇报人：XXX　时间：20XX年XX月XX日

点击添加标题文字

添加标题

双击输入替换内容，轻松设计高效办公。请点击此处添加具体内容。双击输入替换内容，轻松设计高效办公。请点击此处添加具体内容。双击输入替换内容，轻松设计高效办公。

点击添加标题文字


此部分内容作为文字排版占位显示 （建议使用主题字体）
标题文本预设
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标题文本预设

点击添加标题文字

01 02 03 04 GOAL

01 标题文本预设

此部分内容作为文字排版占位显示
（建议使用主题字体）

02 标题文本预设

此部分内容作为文字排版占位显示
（建议使用主题字体）

03 标题文本预设

此部分内容作为文字排版占位显示
（建议使用主题字体）

04 标题文本预设

此部分内容作为文字排版占位显示
（建议使用主题字体）

点击添加标题文字

01 **标题文本预设**
此部分内容作为文字排版占位显示
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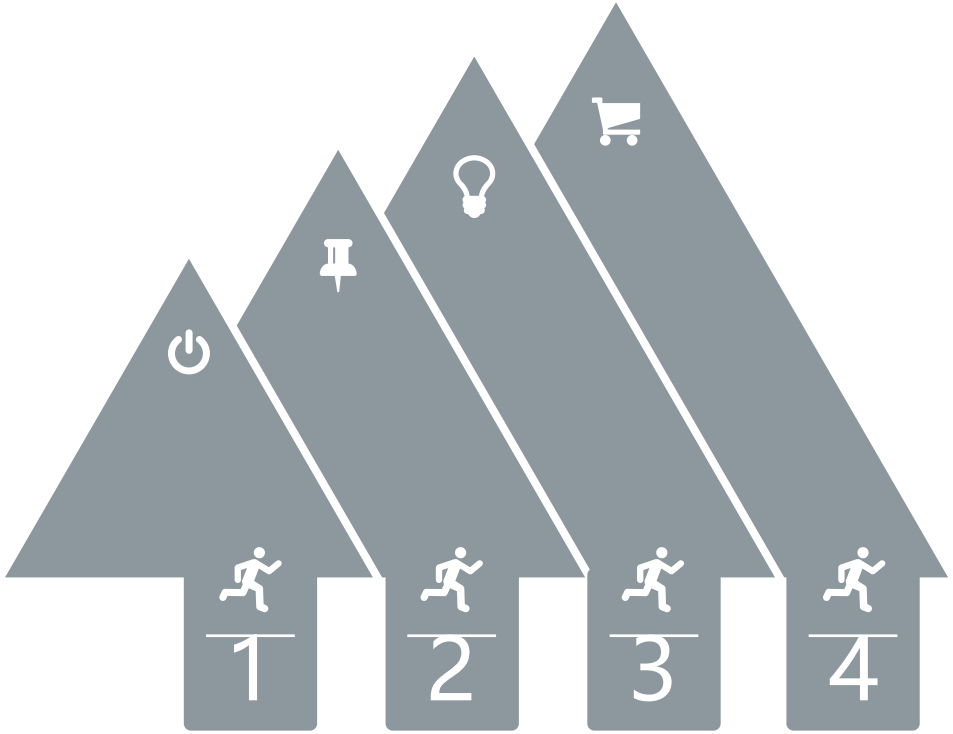
04 **标题文本预设**
此部分内容作为文字排版占位显示
（建议使用主题字体）



02

存在问题

Pleaseaddaclearbusinesstemplateforthetitlecontenty
ouwanttoaddPleaseaddaclearbusinesstemplat

点击添加标题文字

标题文本预设
此部分内容作为文字排版占位显示
（建议使用主题字体）

标题文本预设
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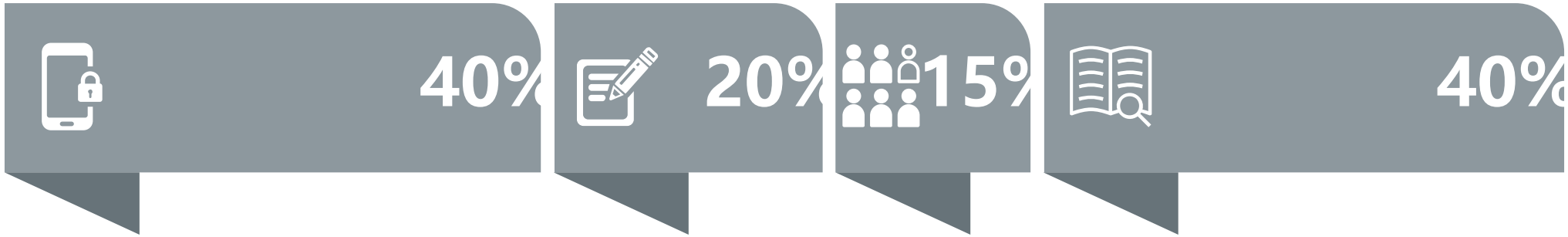

标题文本预设
此部分内容作为文字排版占位显示
（建议使用主题字体）

标题文本预设
此部分内容作为文字排版占位显示
（建议使用主题字体）

工作内容概述

添加标题

在这里输入你的正文阐述与关键词标题相关的具体内容，若字数太多酌情删减文案在这里输入你的正文阐述与关键词标题相关的具体内容在这里输入你的正文阐述与关键词标题相关的具体内容

添加标题

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工作内容概述

在这里输入你的正文阐述与关键词标题相关的具体内容，若字数太多酌情删减文案在这里输入你的正文阐述在这里输入你的正文阐述与关键词标题相关的具体内容

添加标题

在这里输入你的正文阐述与关键词标题相关的具体内容，若字数太多酌情删减文案

添加标题

在这里输入你的正文阐述与关键词标题相关的具体内容，若字数太多酌情删减文案

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工作内容概述

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添加标题

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工作内容概述

01

添加标题

添加详细文本描述，建议与标题相关并符合整体语言风格。添加详细文本描述，建议与标题。添加详细文本描述添加详细文本描述，建议与标题相关并符合整体语言风格。添加详细文本描述，建议与标题。添加详细文本描述

02

添加标题

添加详细文本描述，建议与标题相关并符合整体语言风格。添加详细文本描述，建议与标题。添加详细文本描述添加详细文本描述，建议与标题相关并符合整体语言风格。添加详细文本描述，建议与标题。添加详细文本描述

03

添加标题

添加详细文本描述，建议与标题相关并符合整体语言风格。添加详细文本描述，建议与标题。添加详细文本描述添加详细文本描述，建议与标题相关并符合整体语言风格。添加详细文本描述，建议与标题。添加详细文本描述

点击添加标题文字

标题文本预设

此部分内容作为文字排版占位显示 （建议使用主题字体）

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点击添加标题文字

此部分内容作为文字排版占位显示
（建议使用主题字体）

点击添加标题文字

添加标题

- 输入替换内容输入替换内容.
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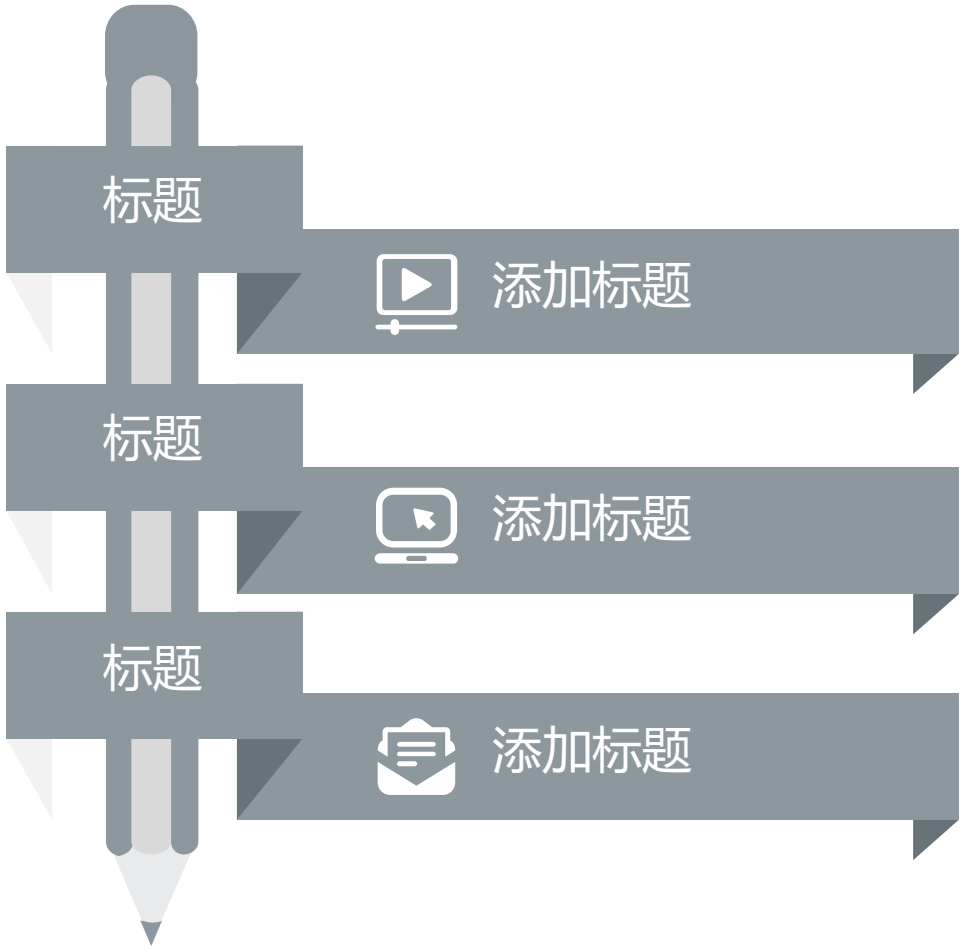
03

改　正　措　施

Pleaseaddaclearbusinesstemplateforthetitlecontenty
ouwanttoaddPleaseaddaclearbusinesstemplat

点击添加标题文字



添加标题

此处添加详细文本描述，建议与标题相关并符合整体语言风格，语言描述尽量简洁。

添加标题

此处添加详细文本描述，建议与标题相关并符合整体语言风格，语言描述尽量简洁。

添加标题

此处添加详细文本描述，建议与标题相关并符合整体语言风格，语言描述尽量简洁。

点击添加标题文字

标题文本预设

此部分内容作为文字排版占位显示（建议使用主题字体）

标题文本预设

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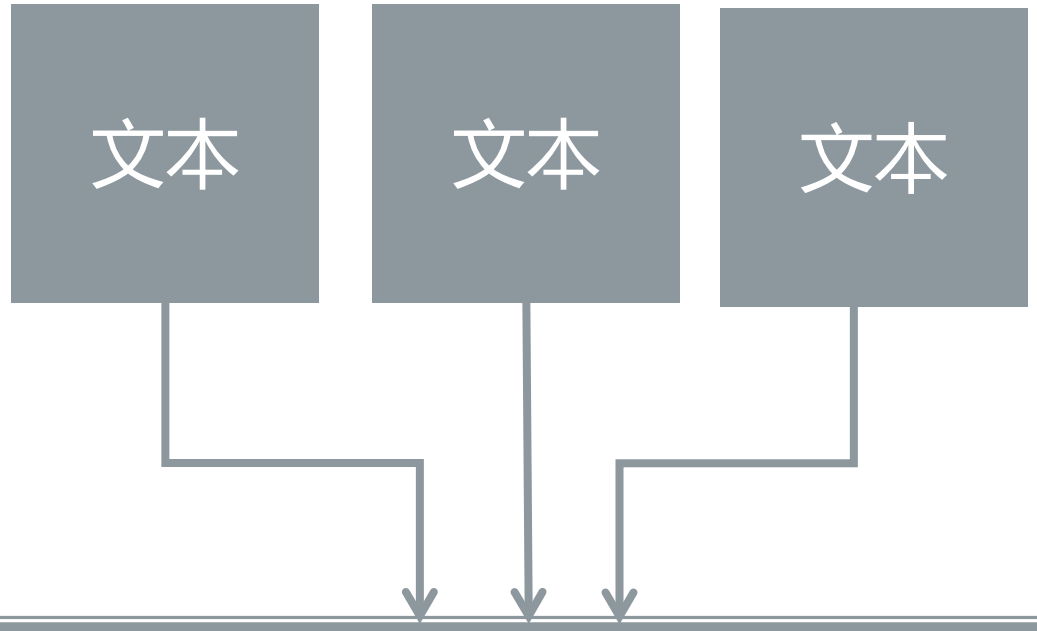
点击添加标题文字



您的标题请写在这里

您的内容打在这里，或者通过复制您的文本后，在此框中选择粘贴，并选择只保留文字。您的内容打在这里，或者通过复制您的文本后，在此框中选择粘贴，并选择只保留文字。

点击添加标题文字

标题文本预设

输入替换内容输入替换内容输入替换内容输入替换内容输入替换内容输入替换内容

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标题文本预设

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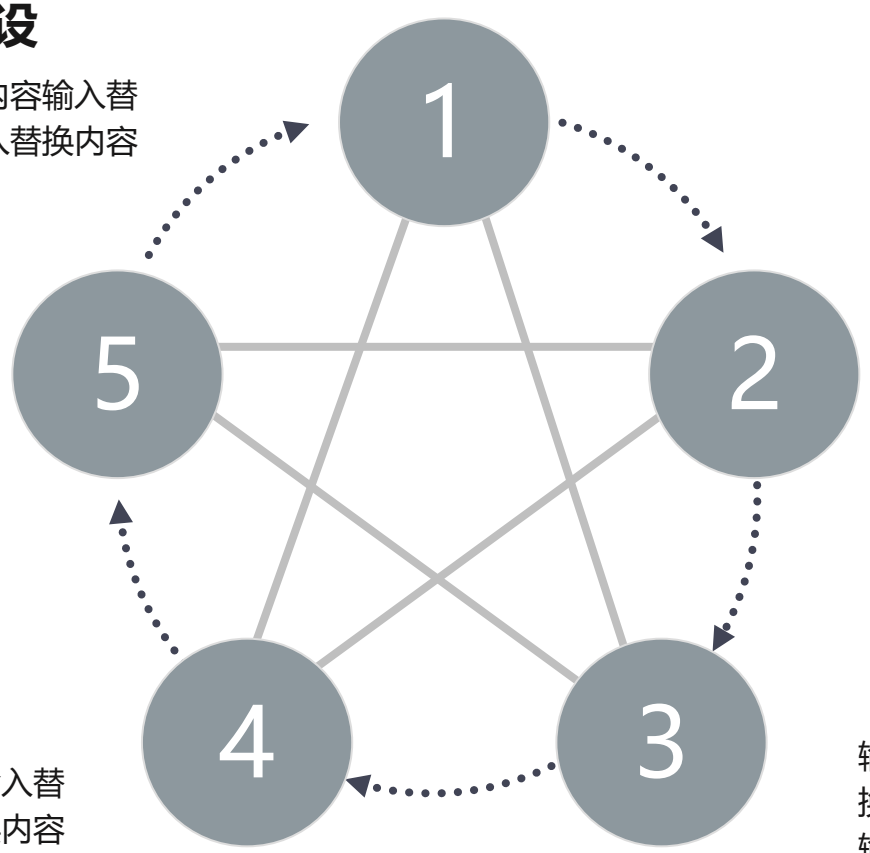

点击添加标题文字

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04

未来展望

Pleaseaddaclearbusinesstemplateforthetitlecontenty
ouwanttoaddPleaseaddaclearbusinesstemplat

点击添加标题文字

小标题

小标题

小标题

小标题

输入替换内容点击添加内容文字输入替换内容点击添加内容文字输入替换内容点击添加内容文字输入替换内容点击添加内容文字输入替换内容点击添加内容文字

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点击添加标题文字

请替换文字内容

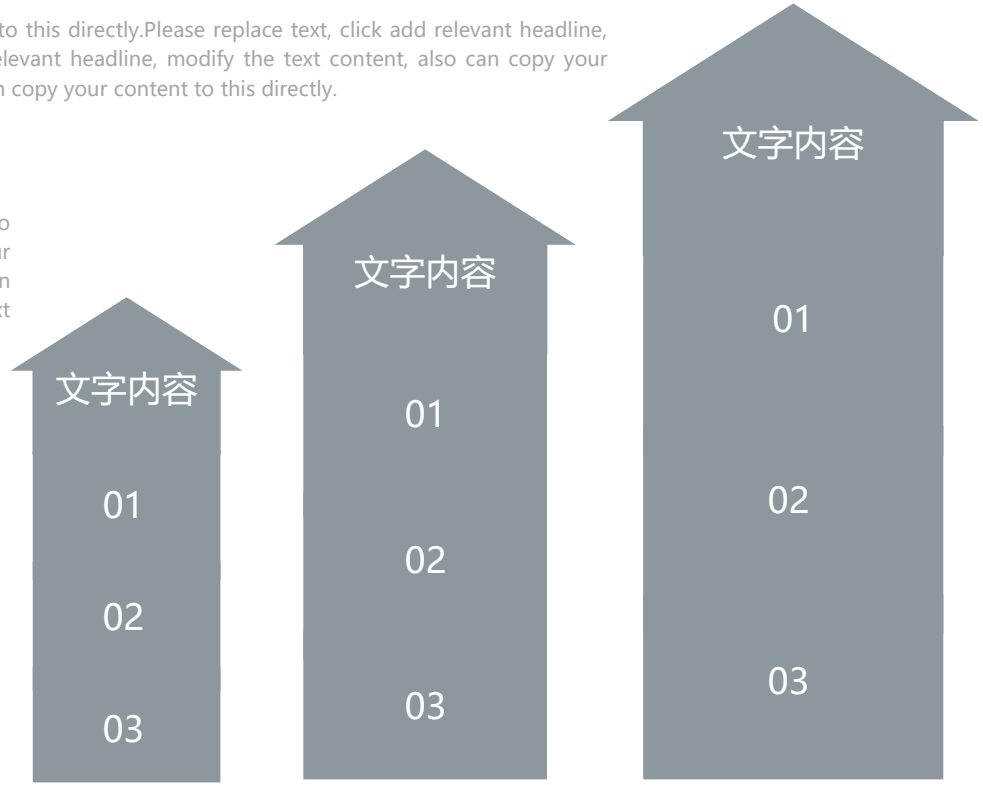
Please replace text, click add relevant headline, modify the text content, also can copy your content to this directly.Please replace text, click add relevant headline, modify the text content, also can copy your content to this directly.Please replace text, click add relevant headline, modify the text content, also can copy your content to this directly.Please replace text, click add relevant headline, modify the text content, also can copy your content to this directly.

请替换文字内容

Please replace text, click add relevant headline, modify the text content, also can copy your content to this directly.Please replace text, click add relevant headline, modify the text content, also can copy your content to this directly.Please replace text, click add relevant headline, modify the text content, also can copy your content to this directly.Please replace text, click add relevant headline, modify the text content, also can copy your content to this directly.

请替换文字内容

Please replace text, click add relevant headline, modify the text content, also can copy your content to this directly.Please replace text, click add relevant headline, modify the text content, also can copy your content to this directly.请替换文字内容，修改文字内容，也可以直接复制你的内容到此。



点击添加标题文字

请替换文字内容
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请替换文字内容
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点击添加标题文字

输入替换内容

感 谢 各 位 的 观 看

CLEAN, MINIMALIST, FLAT, POWERFUL AND FLEXIBLE POWERPOINT TEMPLATE, PERFECT FOR BUSINESS, CORPORATE FLEXIBLE POWERPOINT OR PERSONAL USE.

汇报人：XXX　时间：20XX年XX月XX日

未来工作规划

在这里输入你的正文阐述与关键词标题相关的具体内容，若字数太多在这里输入你的正文阐述与关键词标题相关的具体内容在这里输入

在这里输入你的正文阐述与关键词标题相关的具体内容，若字数太多在这里输入你的正文阐述与关键词标题

在这里输入你的正文阐述与关键词标题相关的具体内容，若字数太多在这里输入你的正文阐述与关键词标题

未来工作规划

小标题

在这里输入你的正文阐述与关键词标题相关的具体内容

小标题

在这里输入你的正文阐述与关键词标题相关的具体内容

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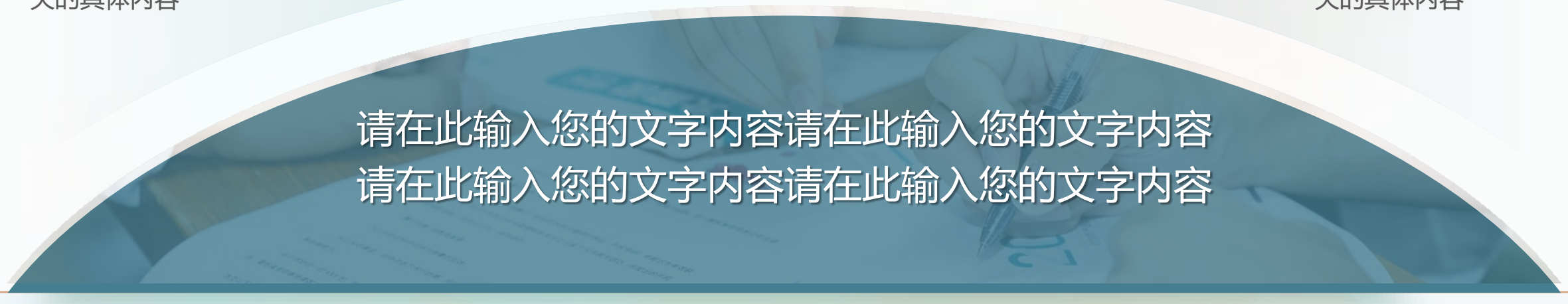

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请在此输入您的文字内容请在此输入您的文字内容

未来工作规划

添加标题

在这里输入你的正文阐述与关键词标题相关的具体内容，若字数太多酌情删减文案在这里输入你的正文阐述在这里输入你的正文阐述在这里输入你的正文阐述与关键词标题相关的具体内容，若字数太多酌情删减文案在这里输入你的正文阐述在这里输入你的正文阐述

添加标题

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未来工作规划

添加标题

在这里输入你的正文阐述与关键词标题相关的具体内容

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未来工作规划

添加标题

- 在这里输入你的正文阐述与关键词标题相关的具体内容
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- 在这里输入你的正文阐述与关键词标题相关的具体内容

存在问题分析

添加标题文本

添加标题

添加详细文本描述，建议与标题相关并符合整体语言风格。添加详细文本描述，建议与标题

添加标题

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存在问题分析

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添加标题

添加详细文本描述，建议与标题相关并符合整体语言风格。添加详细文本描述，建议与标题添加详细文本描述，建议与标题相关并符合整体语言风格。添加详细文本描述，建议与标题添加详细文本描述

添加标题

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添加标题

添加详细文本描述，建议与标题相关并符合整体语言风格。添加详细文本描述，建议与标题添加详细文本描述，建议与标题相关并符合整体语言风格。添加详细文本描述，建议与标题添加详细文本描述

存在问题分析

添加标题

在这里输入你的正文阐述与关键词标题相关的具体内容，若字数太多在这里输入你的正文阐述与关键词标题相关的具体内容在这里输入你的正文阐述与关键词标题相关的具体内容，若字数太多在这里输入你的正文阐述与关键词标题相关的具体内容

添加标题

在这里输入你的正文阐述与关键词标题相关的具体内容，若字数太多在这里输入你的正文阐述与关键词标题相关的具体内容

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