一种结合四旋翼无人机与轮腿结构的自平衡双足机器人

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课题背景

- 目前主流的机器人方向：无人机，轮腿机器人，双足机器人
- 无人机：机动性强，无视地面障碍，但续航短，作业能力弱
- 轮腿机器人：机动性强，适应不同路面，但没有明显应用场景
- 双足机器人：避障能力，综合能力强，但没有明显应用场景
- 以上机器人都有很强的能力，但因为各自的缺点，实际价值不如他们的能力

www.zcool.com.cn/work/ZMTg0MDcxNDA=.html?

www.infoq.cn/article/ay9gs8czhpltbfw2vmih

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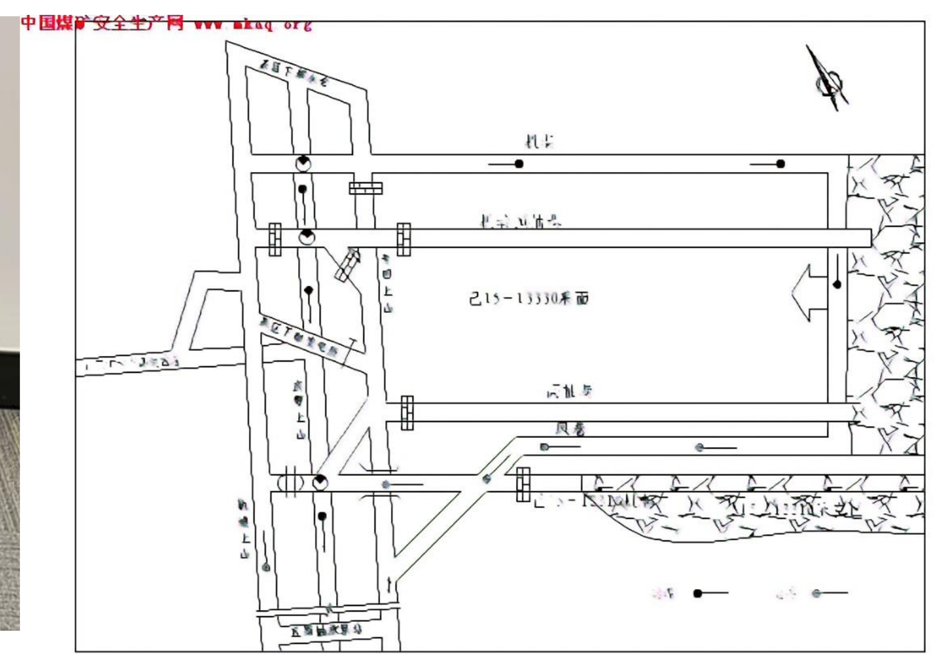
课题目标

- 结合上述三种机器人的特点，设计一款陆空两栖机器人
- 在普通路面上上用轮式前进，复杂路面下用腿跨越前进，飞行情况下用无人机
- 使机器人获得灵活移动，能在复杂环境下作业的特点
- 在运动单元完成后，结合应用场景设计应用单元，使机器人具有实际应用价值
- 使机器人可以用于地震搜救，矿井检测等应用场景

机器人示意图



矿井横截面示意图

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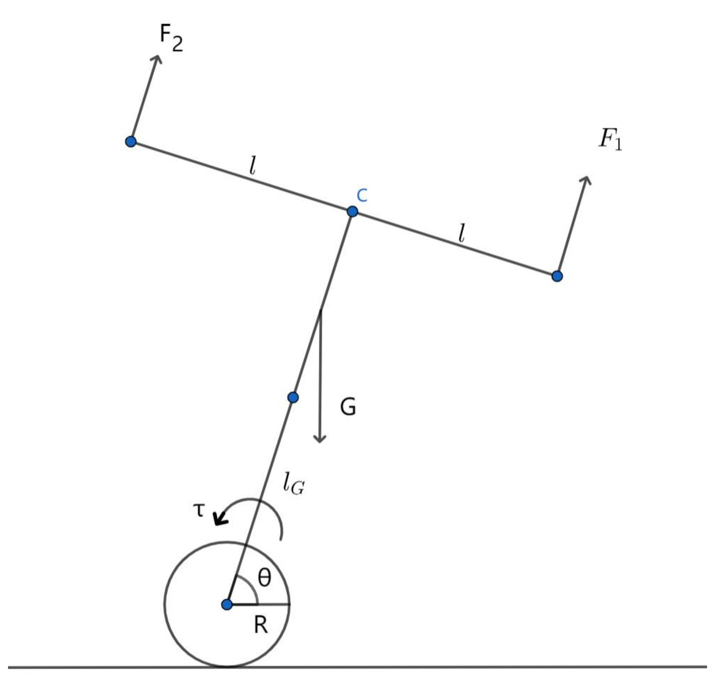
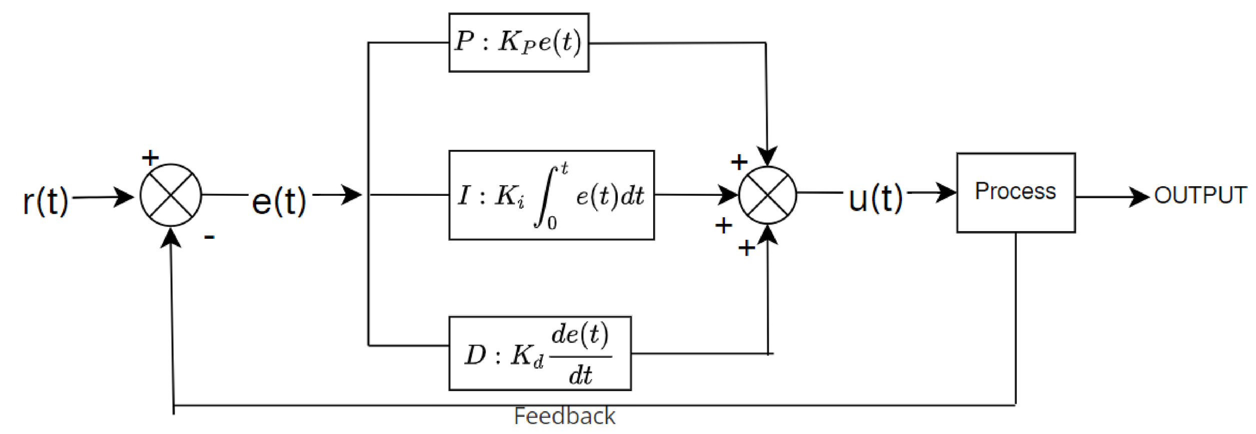
原理设计



- 上方是四旋翼无人机，下方是两条分别有两个自由度的腿，最下方是轮子
- 动力学分析：

$$\tau_{clockwise} = G * l_G * cos\theta + F_2 * l$$
$$\tau_{counterclockwise} = \tau + F_1 * l$$
$$\tau_{counterclockwise} - \tau_{clockwise} = I * \alpha$$

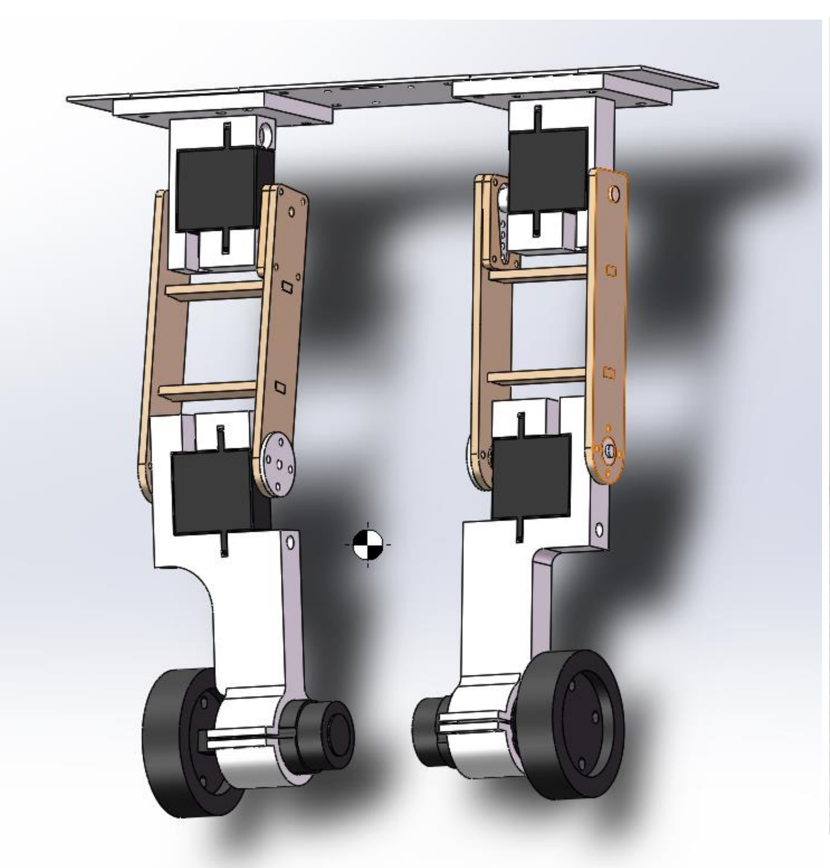
- 该项目控制算法大体采用PID算法

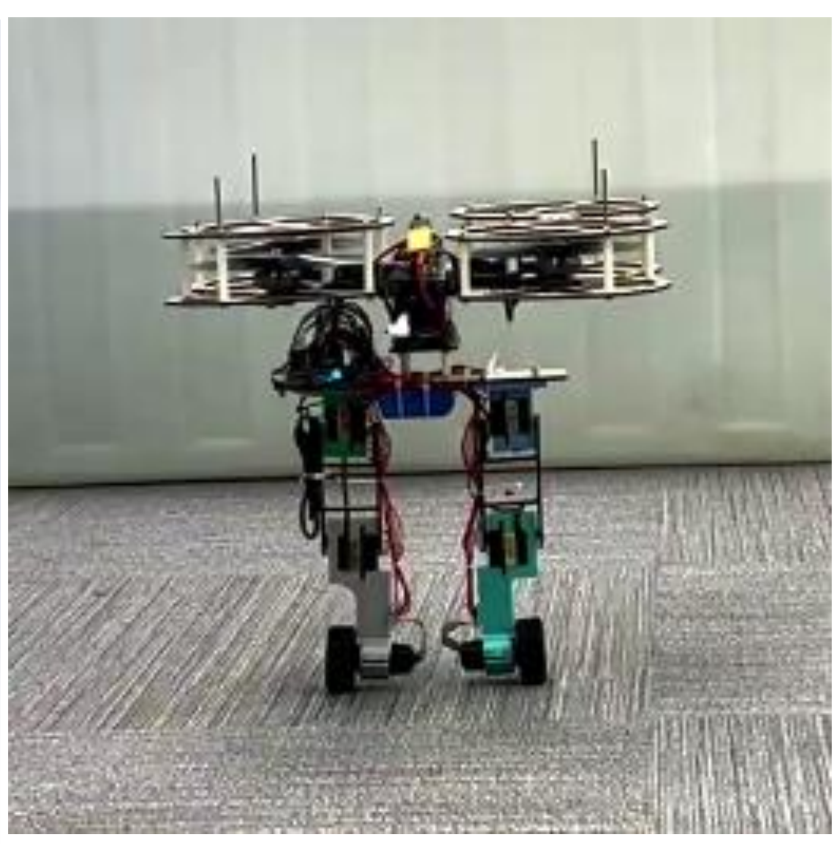


结构设计

第一代机器人结构：

- 使用Solidworks完成轮腿部分的3D建模
- 使用3D打印零件和木板拼接
- 用舵机控制髋关节和膝关节，减速有刷电机作为轮子动力
- 采用开源机架，但设计了桨叶保护结构





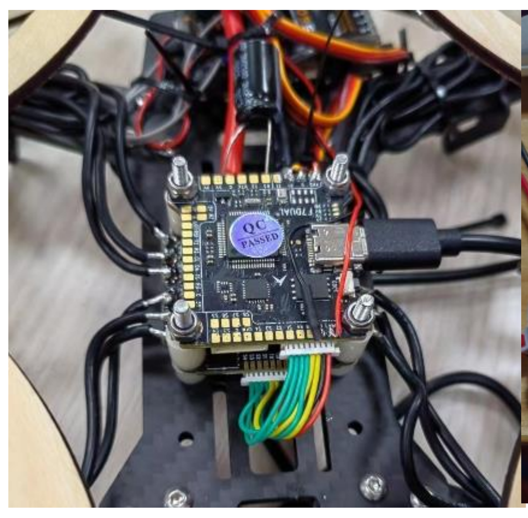
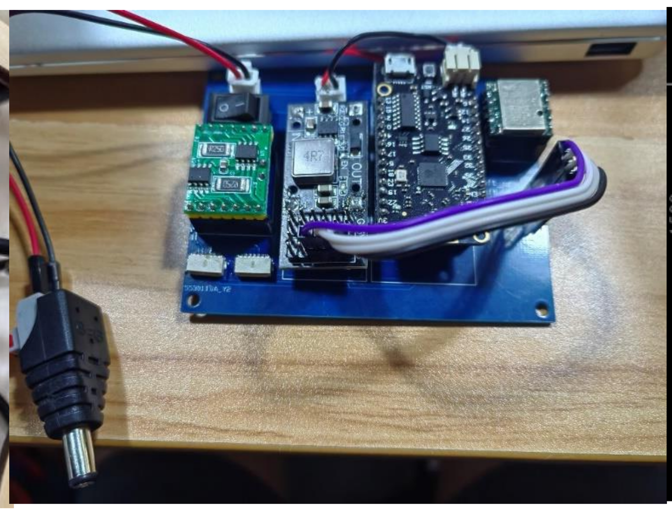
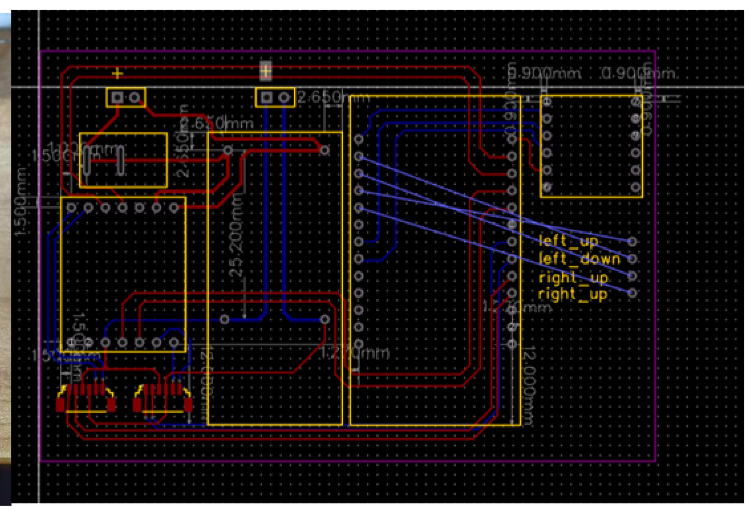
第二代机器人结构改进：

- 采用自己设计的机架，简化桨叶保护结构
- 在轮子异侧加上从动轮（原因在实验部分）
- 取消木板结构，使结构更稳定
- 设计减重方法，使整体结构变轻（从1600g到1450g）

电子设计

硬件设计

- 无人机飞控模块包含了各种传感器，以及无刷电机驱动
- 轮腿部分进行了PCB板的绘制，采用ESP32进行主控，JY62陀螺仪作为姿态反馈

运动模式设计

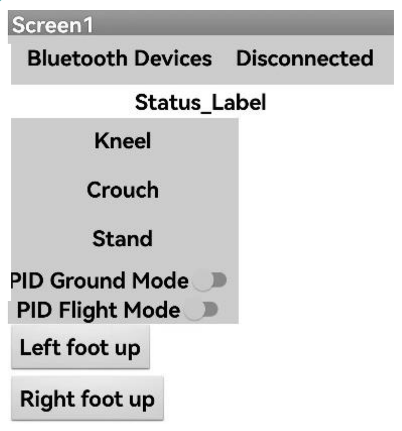
- 通过PID算法来完成静态平衡与动态平衡
- 通过开关不同的PID环，机器人可以完成从跪下，到蹲起，到站立的平衡

	跪下	蹲起	站立	载腿飞行
无人机x轴角度PID环	√	√	√	√
无人机y轴角度PID环	√	√	√	√
无人机z轴角度PID环	√	√	√	√
无人机高度位移PID环				√
无人机x/z轴位移PID环				√
轮腿姿态PID环(蹲起)		√		
轮腿姿态PID环(站立)			√	

程序设计

```
pid->p_out = pid->kp * pid->err[NOW];
pid->i_out += pid->ki * pid->err[NOW];
pid->d_out = pid->kd * (pid->err[NOW] - pid->err[LAST]);
```

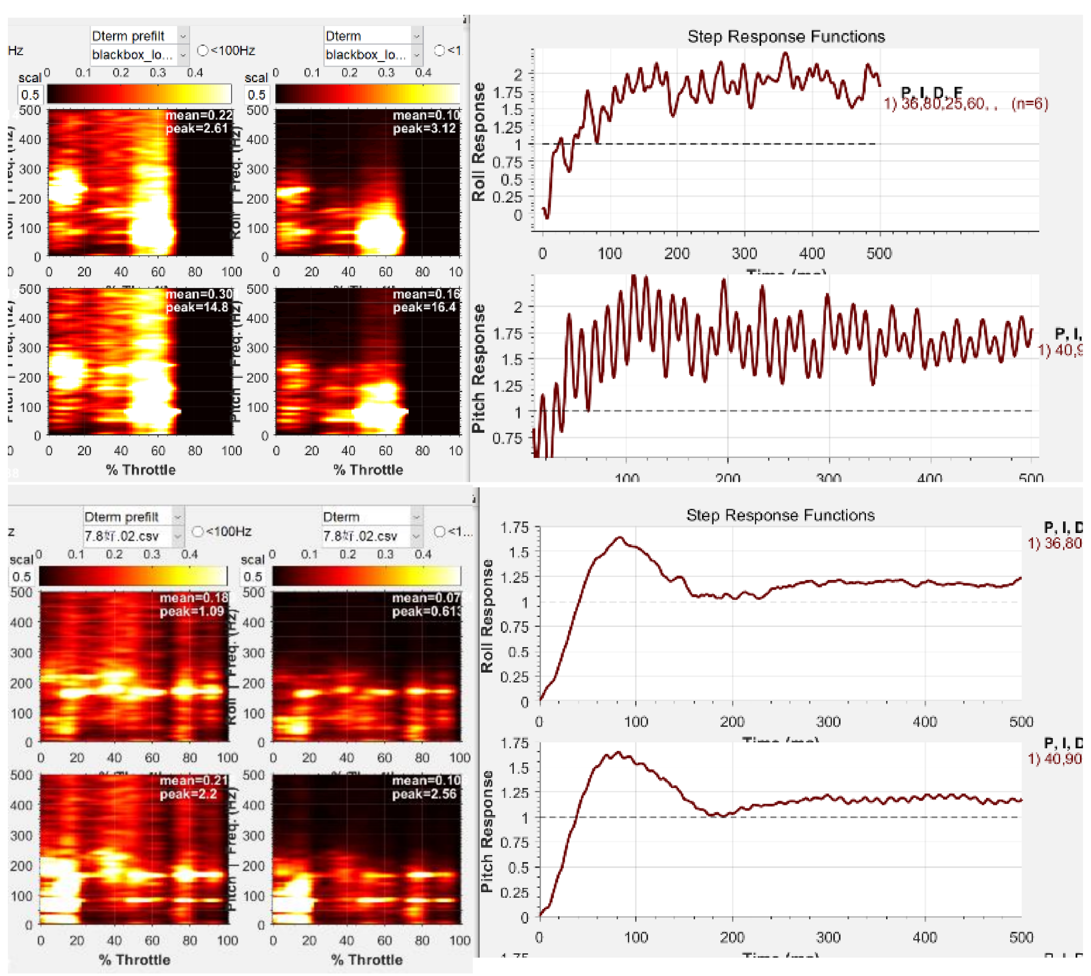
- 通过PWM信号来控制舵机和电机
- 通过电机内置的霍尔编码器读取电机转速信息，完成电机转速环的闭环控制
- 通过陀螺仪读取姿态信息，完成姿态环的闭环控制
- 自制APP进行蓝牙遥控



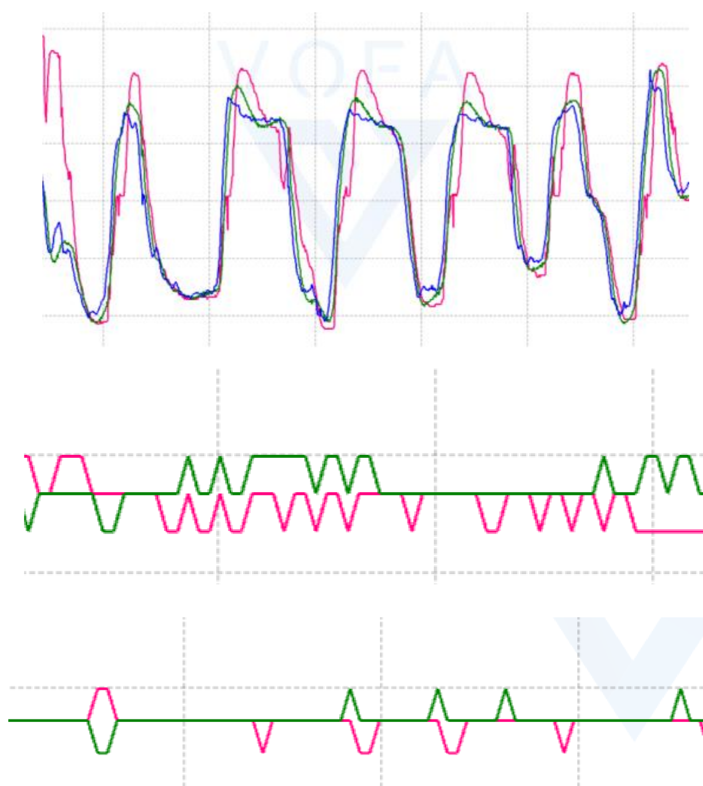
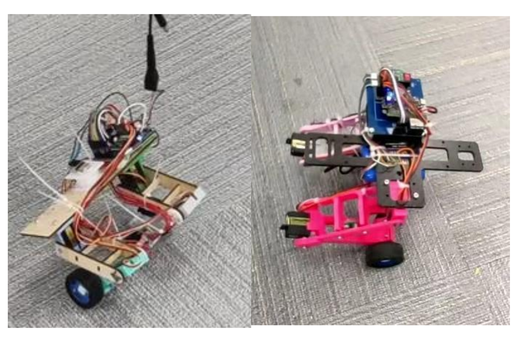
实验与讨论

- 实验部分分为无人机部分，轮腿部分和结合后的实验
- 无人机部分主要是各种参数的调整
- 轮腿部分是调参，控制频率的设定，和滤波器的设计
- 结合部分是PID环的结合实验和载重实验

无人机部分



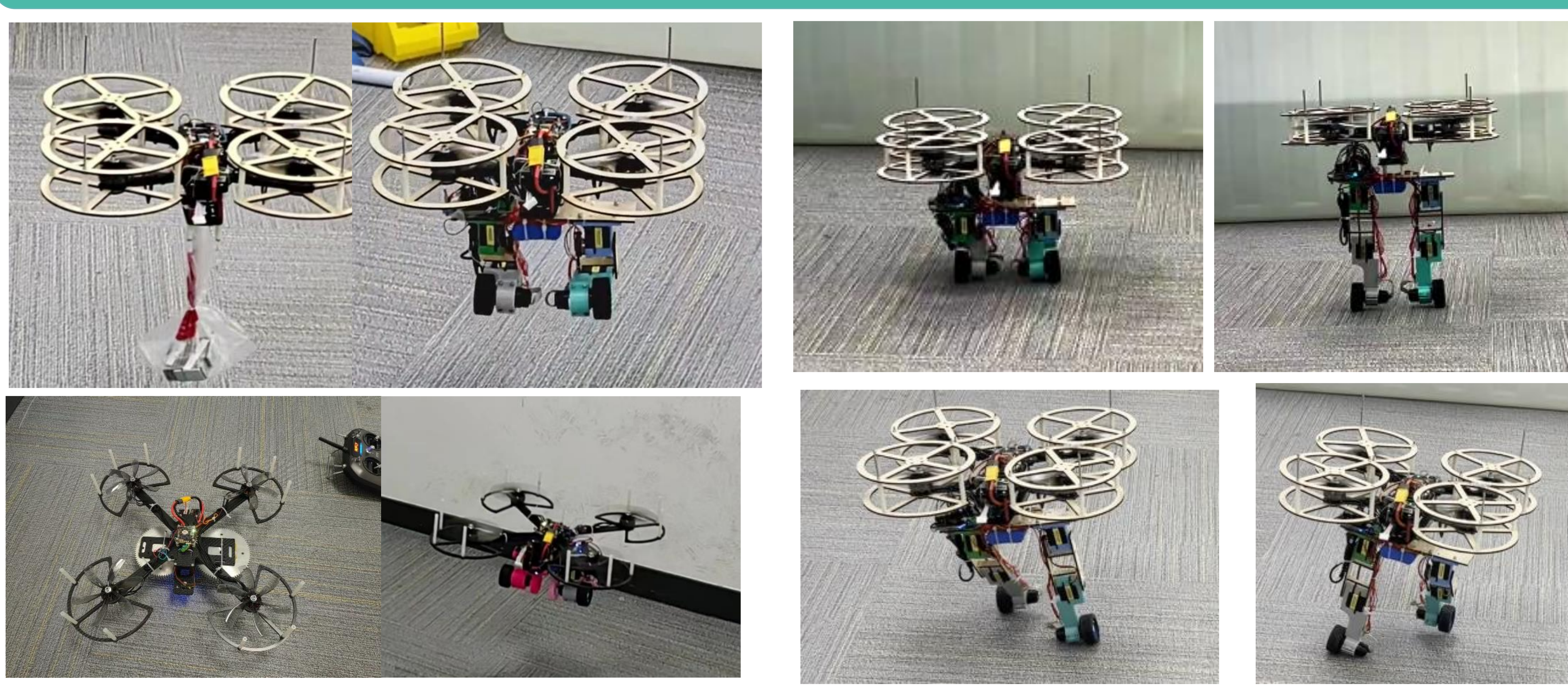
轮腿部分

实验结论

- 机器人可以完成载腿飞行
- 机器人可以完成从跪下，蹲起，到直立的静态平衡
- 机器人可以在不同姿态下轮式前进
- 机器人可以在摔倒后调整姿态重新起飞
- 机器人还无法很好的完成步态，单腿站立时系统会混乱
- 基于问题更改了第二版，还在实验中

结合部分



总结

- 该项目通过结合四旋翼无人机和双足轮腿机器人，设计了一款新型陆空两栖机器人
- 机器人目前具备了静态平衡和轮式前进的能力，在改进的结构和算法下，很快能完成迈步前进从而避障
- 希望未来在机器人上加入应用单元，例如摄像头，热成像仪，以适配应用场景

A Self-Balancing Bipedal Robot
Combining Quadcopter UAV and Wheel-Leg Structure

Yuyang Wang (Shanghai Pinghe School)

Background

- Current three mainstream directions in robotics: UAVs, wheeled-leg robots, and bipedal robots
- UAV: strong maneuverability; short battery life and limited operational capabilities
- Wheel leg robot: strong mobility; lack clear application scenarios
- Bipedal robot: obstacle avoidance; lack clear application scenarios

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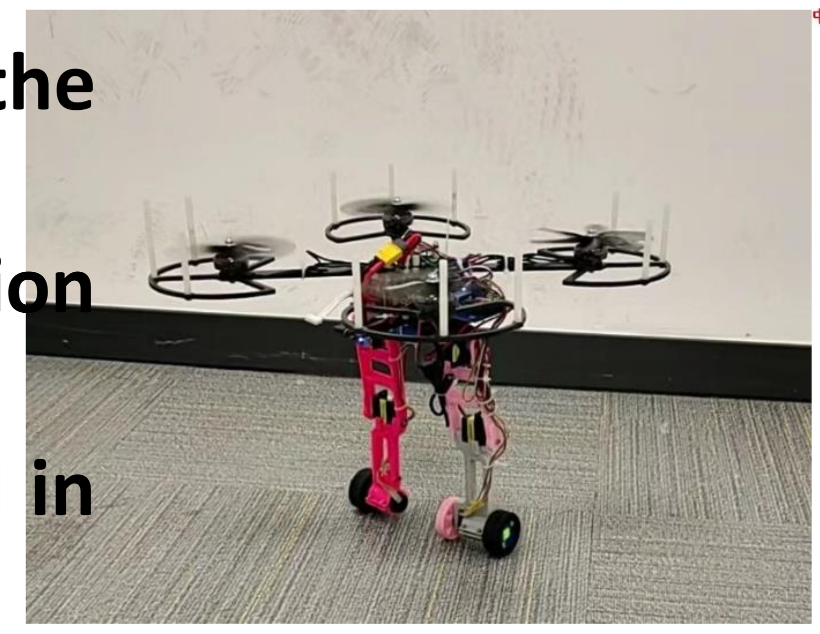
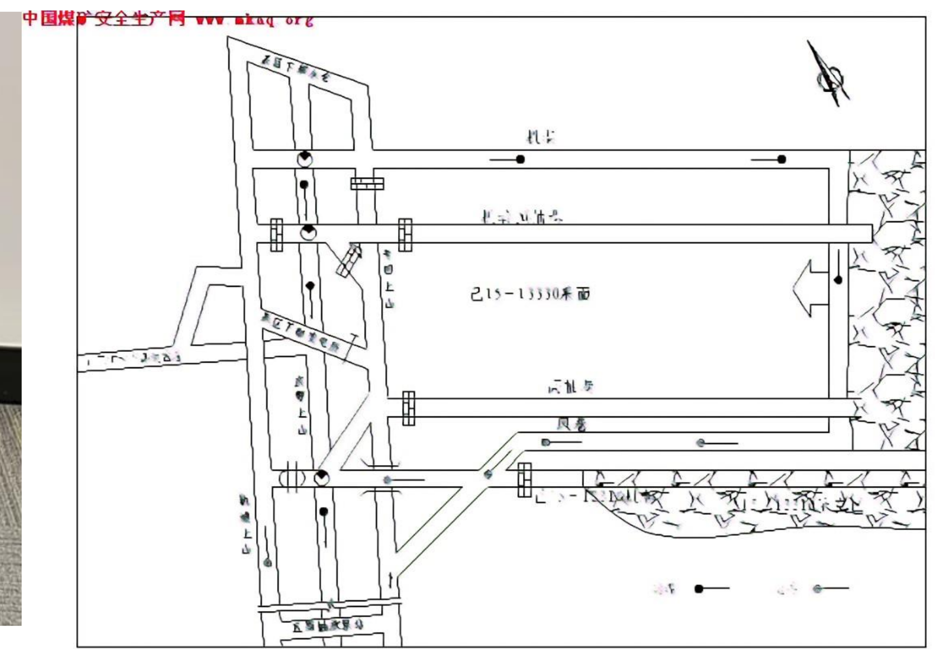
mt.sohu.com/20180402/n533756802.shtml

Objectives

- Design a versatile land-air amphibious robot that combines the three characteristics
- Wheeled locomotion for regular surfaces, legged locomotion for complex terrains, and UAV capabilities for flight
- The robot should offer flexible mobility and ability to travel in complex environment
- Should be designed with application-specific units
- Applications such as earthquake rescue and mining exploration



Overall Robot



Mine Cross Section

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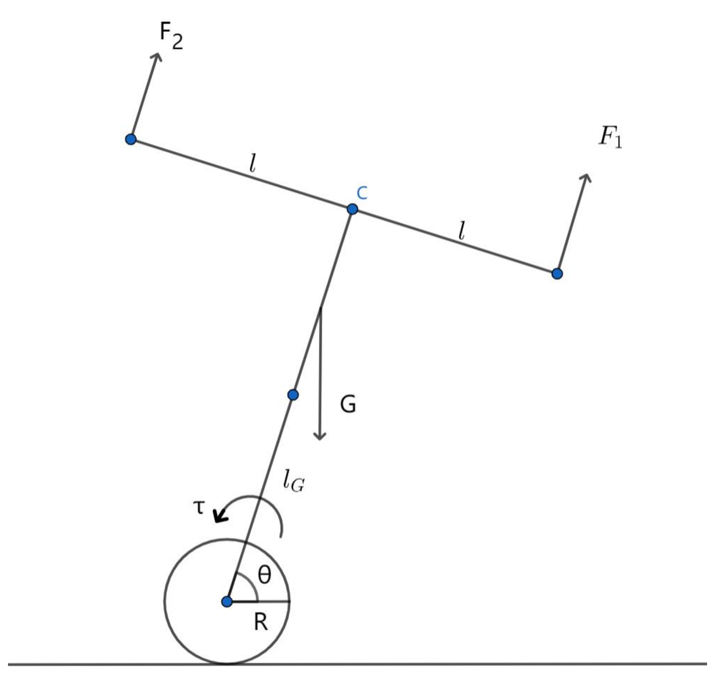
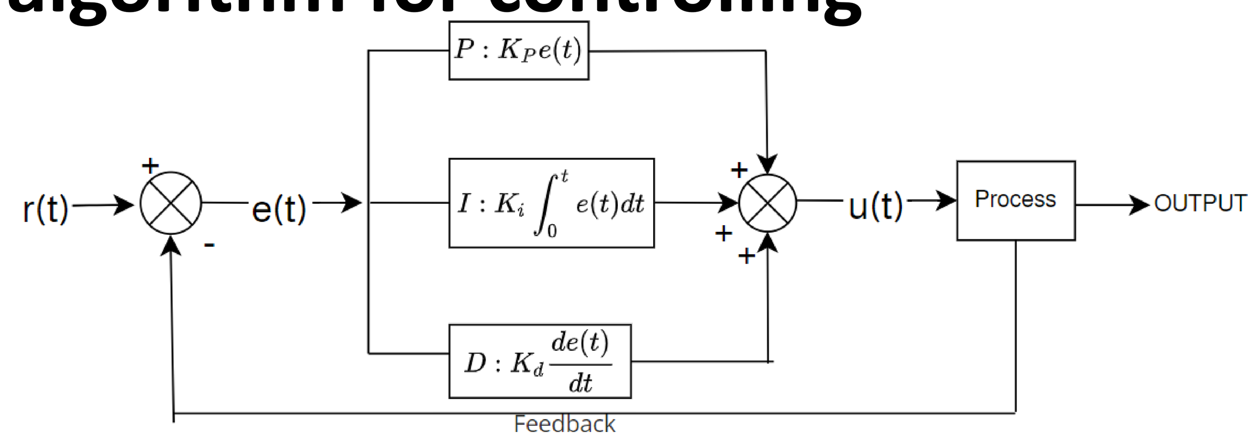
Principle Designing



- A UAV on top, two legs with two degrees of freedom each in the middle, and wheels at the bottom.

$$\tau_{clockwise} = G * l_G * cos\theta + F_2 * l$$
$$\tau_{counterclockwise} = \tau + F_1 * l$$
$$\tau_{counterclockwise} - \tau_{clockwise} = I * \alpha$$

- This projects generally adopts PID algorithm for controlling



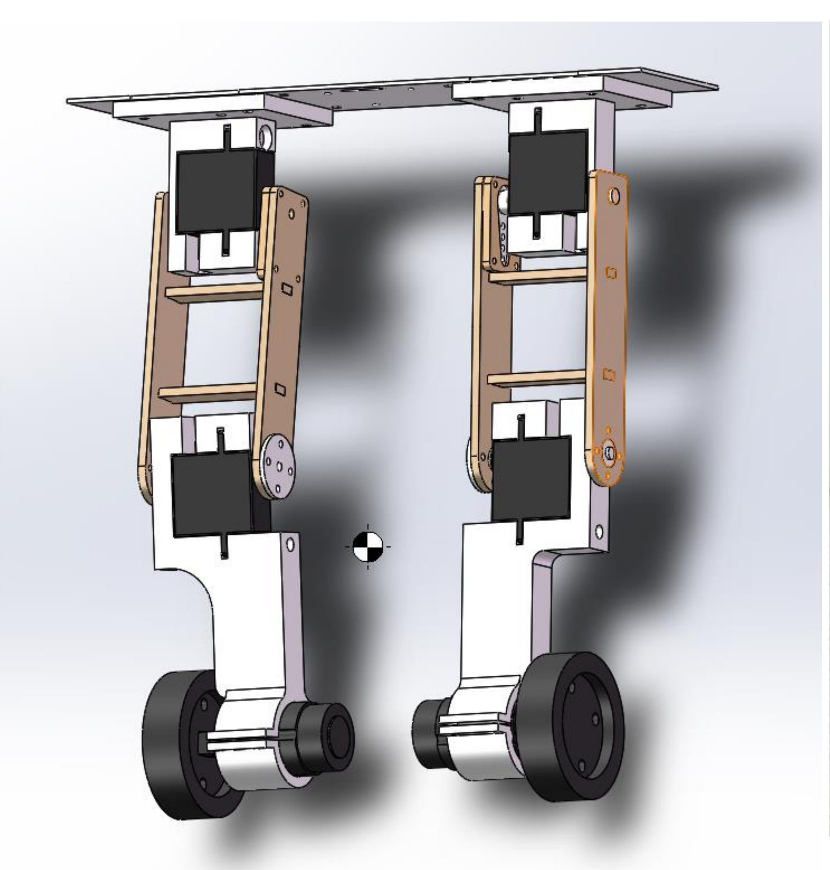
Structural Designing

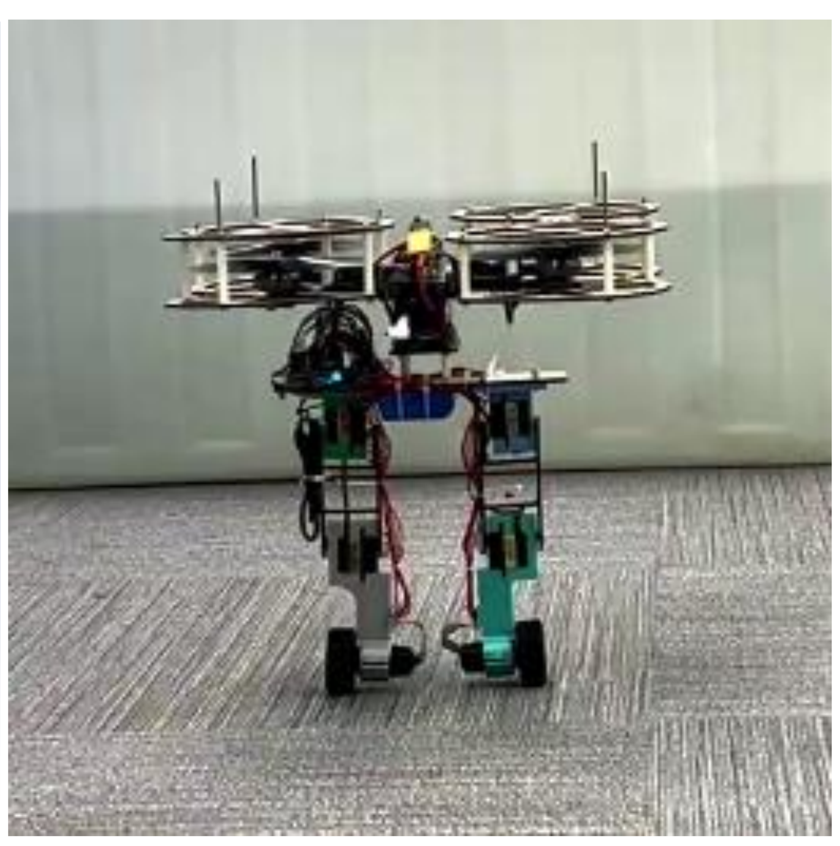
Structure Version Ⅰ:

- Solidworks for 3D modelling
- 3D printed parts and laser-cut wooden board
- Servos and motors for legs and wheels
- UAV with propeller protection strucutre

Structure Version Ⅱ:

- Simplified and lighter UAV structure
- All 3D printed, more stable
- Engaged wheel on each foot
- Lighter overall structure （1600g to 1450g）

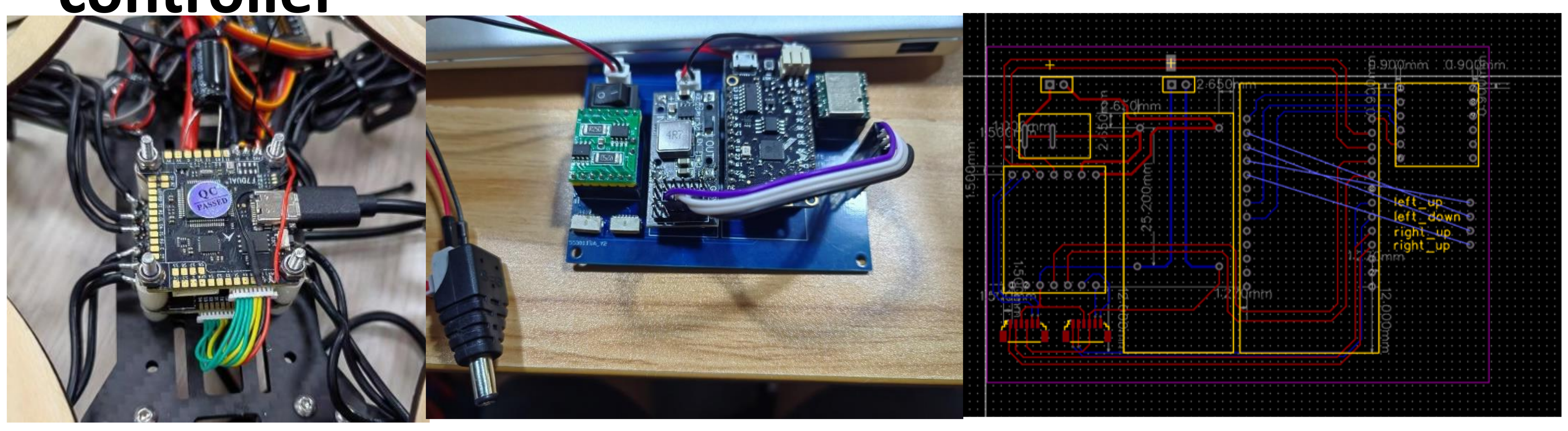




Electronic Designing

Hardware Designing

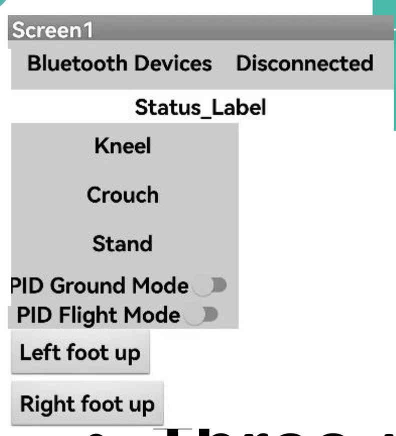
- The UAV flight controller module incorporates various sensors and brushless motor drivers.
- The wheeled-leg section involves the design of a PCB board and utilizes an ESP32 as the main controller



Program and Software Designing

```
pid->p_out = pid->kp * pid->err[NOW];
pid->i_out += pid->ki * pid->err[NOW];
pid->d_out = pid->kd * (pid->err[NOW] - pid->err[LAST]);
```

- Control the servos and motors through PWM signals.
- Hall encoder as feedback to close-loop control the motors
- Gyro as feedback to control the posture
- Self-designed APP to control the robot with Bluetooth



Motion Designing

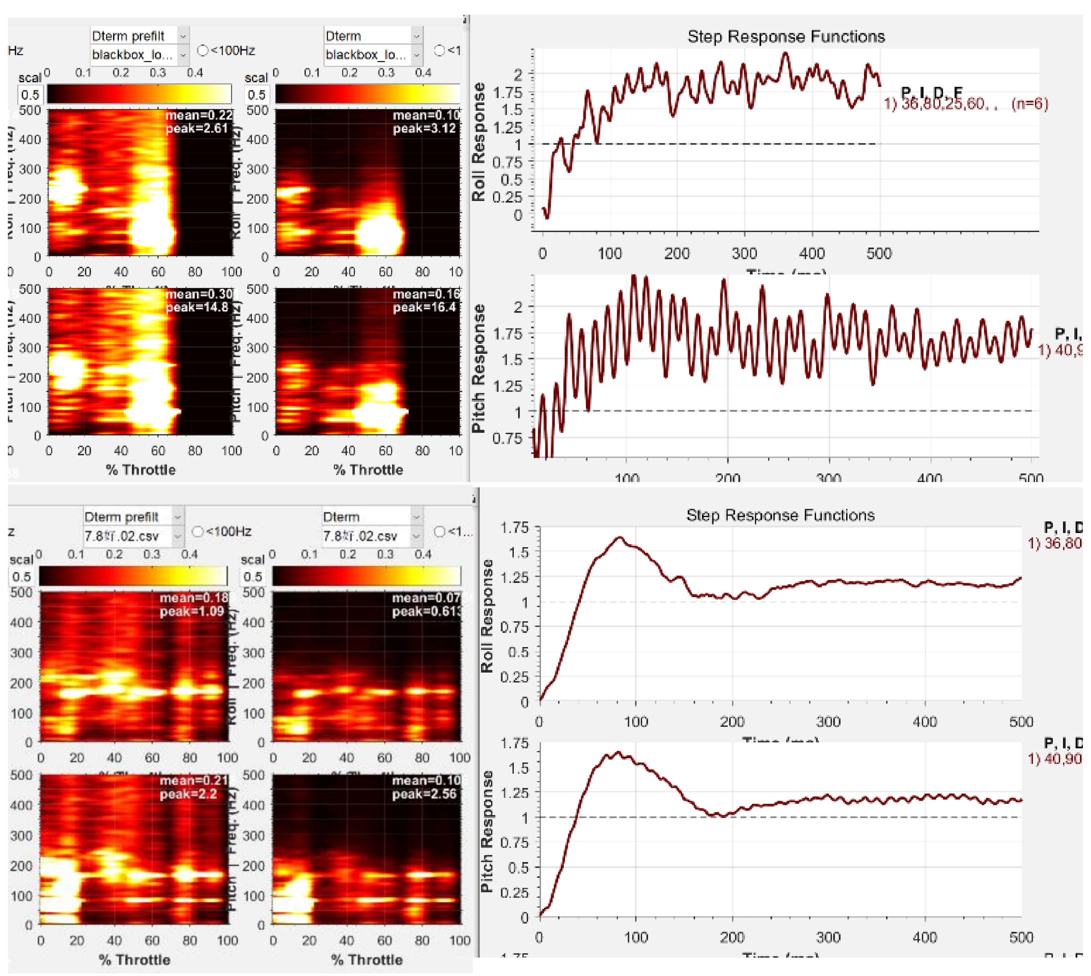
- The static and dynamic balance of the robot is achieved through PID algorithms.
- By switching between different PID loops, the robot can transition from kneeling to crouching position, and to standing

	Kneel	Crouch	Stand	Fly
UAV X-axis Angle PID Loop	√	√	√	√
UAV Y-axis Angle PID Loop	√	√	√	√
UAV Z-axis Angle PID Loop	√	√	√	√
UAV Height Position PID Loop				√
UAV X/Z axis Position PID Loop				√
Wheeled-Leg Crouch PID Loop		√		
Wheeled-Leg Stand PID Loop			√	

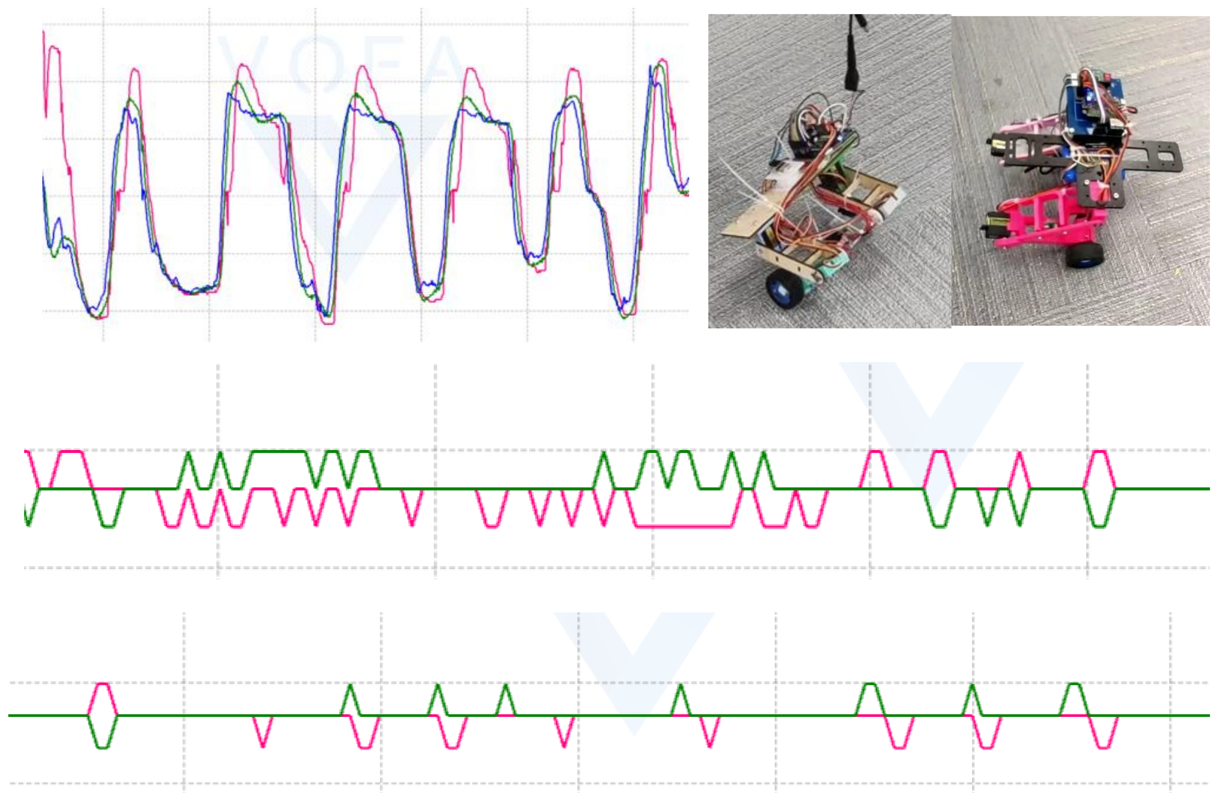
Experiments and Discussions

- Three parts: the UAV section, the wheeled-leg section, and the combined experiments.
- The UAV section: parameter adjustments.
- The wheeled-leg section: parameter adjustments, control frequency setting, and filter design.
- Combined section: PID loop design and payload testing.

UAV Experiments



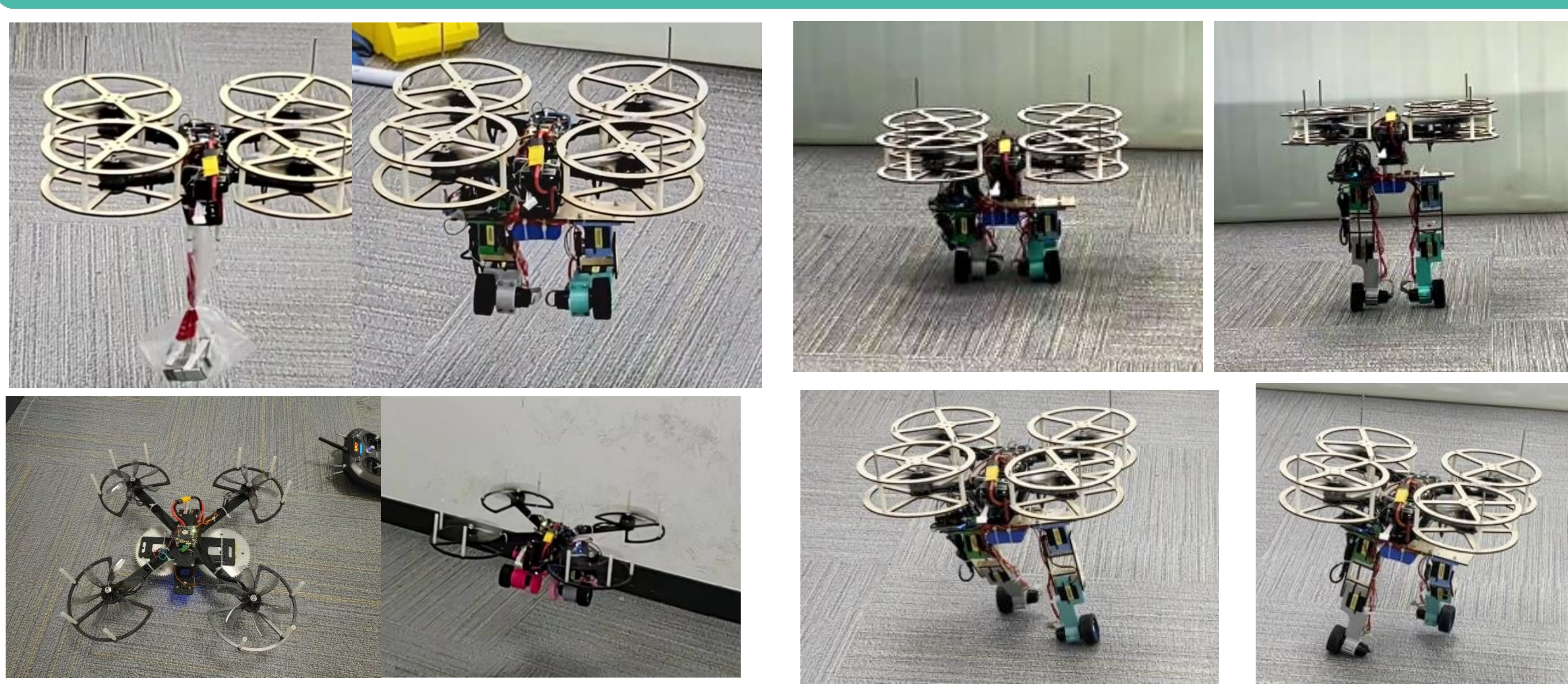
Wheel-leg Experiments



Discussions

- The robot can fly with legs.
- Static balance when kneel, crouch, stand
- Wheeled motion under different state
- Adjust posture after falling and take off again
- Can't stride forward yet because the system will become chaotic
- Structure redesigned based on problems is still under experiment

结合部分



Conclusions

- The project combines a quadcopter UAV and a bipedal wheeled-legged robot to design a novel land-air amphibious robot.
- The robot currently possesses static balance and wheeled locomotion capabilities.
- Soon be able to take steps and navigate obstacles.
- Plan to integrate modules such as cameras and thermal imaging sensors to adapt to various application scenarios.