ME331 机器人建模与控制

视觉控制机械臂及压力控制机械爪

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1 研究背景及动机 Background and Motivation

研究背景和动机 Background and Motivation

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1. 远程控制

疫情爆发让我们再一次意识到了距离和客观自然条件对于我们工作发展的阻碍性。通过映射人类动作能够摆脱空间的束缚完成远程任务。

2. 对接VR虚拟现实

虚拟现实和5G的发展将原本以娱乐方式为主的VR设备开辟了更广阔的用途，通过视觉识别人体姿态，从而实现虚拟世界与现实世界的交互。创造VR+机器人的控制模式。单个机械臂或机械手的控制和驱动，未来可以应用在更类人体的机器人身上，甚至创造出VR控制的机器人分身。

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研究方法 Methods

机械臂模型设计与搭建

视觉识别处理

正逆运动学计算

机械臂舵机控制

压力传感器的使用

机械臂模型搭建 Robot arm model construction

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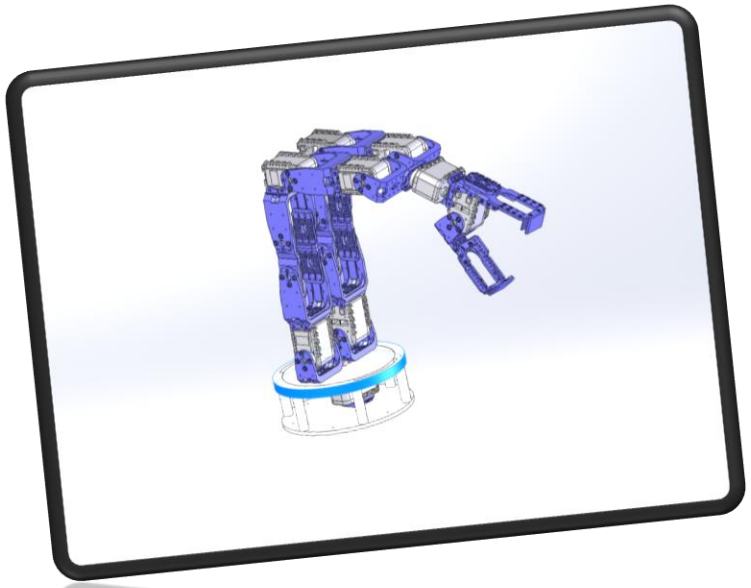
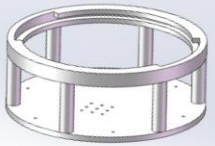
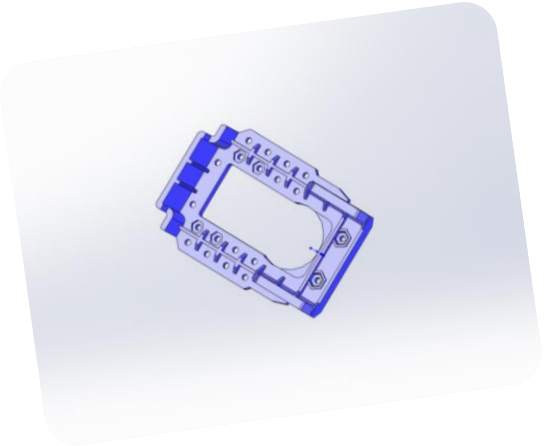
- Solidworks
  - 零件及装配体建模



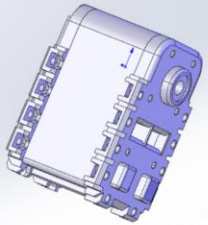
转盘框架

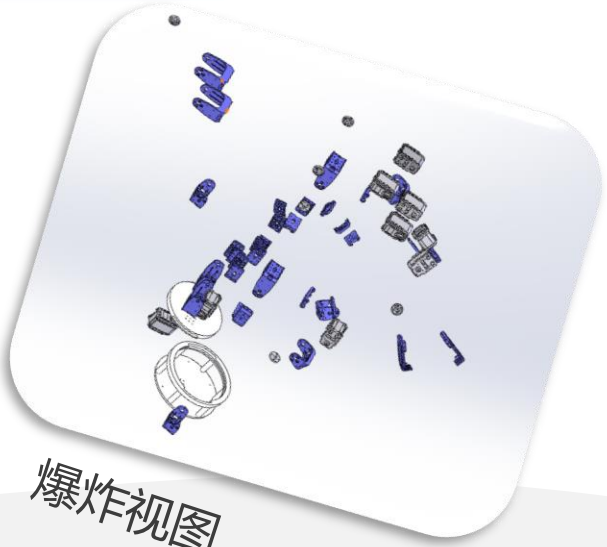




夹爪

电机





爆炸视图

机械臂模型搭建 Robot arm model construction

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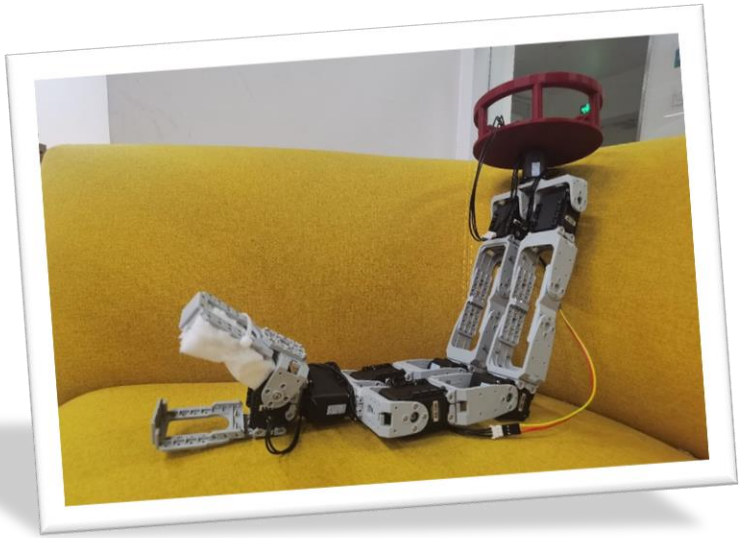
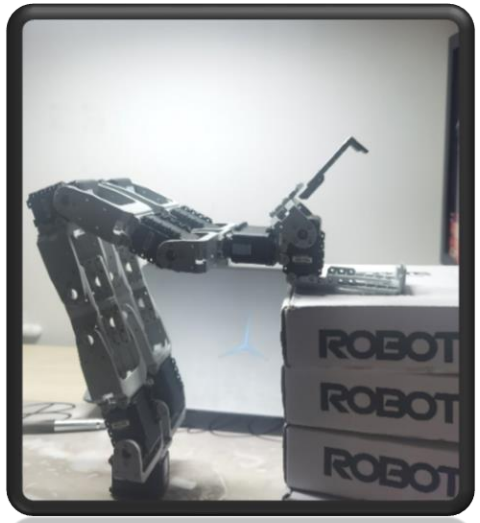
- 实物
  - 零件组装及3D打印



五自由度机械臂

3D打印转盘



零件拼装

机械臂模型搭建 Robot arm model construction

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- 存在问题
  - 零件拼装部分，现有零件无法很好地固定并联的电机，因此购入了双头螺丝进行固定，但仍不是很稳定。
  - 3D打印部分由于打印尺寸的误差以及粗糙度问题，无法很好地按预想实现圆盘的转动，同时也因为没有合适的载体去安装圆台，所以临时将圆台作为安放单片机和提供手持握把的工具。
- 改进想法
  - 夹爪部分比较粗糙，夹取实现较为困难，可以自己新建一个零件进行优化。
  - 3D打印的公差控制上吸取教训，加大内外圈公差，保证基本转动。
  - 转台部分还是需要轴承，单凭打印的结构无法顺滑地实现转动。

视觉识别处理Mediapipe

- 考虑到在视觉识别方面，Python已经十分成熟了，所以使用Python的Opencv来进行视觉的读取和分析，由于我们最终的目标需要实现机械手臂在空间中进行，需要手臂上各个关节的坐标，但是考虑到笔记本电脑摄像头只能读取到特定点在平面上的坐标，所以我们需要可以由连续的平面图像得到特定点的3维坐标。

- Meidapipe获取真实世界的3D训练数据、运用AR 合成数据生成，使用于3D对象检测的 ML 管道，将虚拟对象放置到具有 AR 会话数据的场景中，这使我们能够利用相机姿势、检测到的平面和估计的照明来生成物理上可能的位置，并使用与场景匹配的照明。相较于昂贵的3D相机，Mediapipe使用更加方便的解决方案。

视觉识别处理poseDetector

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```python
class poseDetector():
    def __init__(self, mode=False, upBody=False, smooth=True,
                 detectionCon=0.5, trackCon=0.5):

        self.mode = mode
        self.upBody = upBody
        self.smooth = smooth
        self.detectionCon = detectionCon
        self.trackCon = trackCon

        self.mpDraw = mp.solutions.drawing_utils
        # self.mpPose = mp.solutions.pose
        # self.pose = self.mpPose.Pose(self.mode, self.upBody, self.smooth,
        self.pose = mp.solutions.pose.Pose(static_image_mode=self.mode, smooth_landmarks=self.smooth,
                                           min_detection_confidence=self.detectionCon,
                                           min_tracking_confidence=self.trackCon)
```

- static_image_mode
- smooth_landmarks
- min_detection_confidence
- min_tracking_confidence

视觉识别处理findPose()

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- 首先，我们将创建原始图像的副本，以便在预处理时不会丢失原始图像的任何内容。
- 稍后我们会将蓝绿红格式转换为红绿蓝格式。
- 使用 process 函数处理转换后的图像格式的姿势检测。
- 验证并检查是否在图像中检测到地标，使用 draw_landmarks 函数将它们绘制在图像上。
- 将检查显示参数是否允许我们显示结果和输入图像。
- 如果上述条件为真，则显示原始图像以及生成的图像。否则，它只会返回输出图像和结果。

```
def findPose(self, img, draw=True):
    imgRGB = cv2.cvtColor(img, cv2.COLOR_BGR2RGB)
    self.results = self.pose.process(imgRGB)
    if self.results.pose_landmarks:
        if draw:
            self.mpDraw.draw_landmarks(img, self.results.pose_landmarks, mp.solutions.pose.POSE_CONNECTIONS)
    return img
```

视觉识别处理findPosition()

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- 构建数组对关键节点的坐标进行存储
- 判断self.results.pose_landmarks是否为空，
- 使用for循环，在enumerate里遍历self.results.pose_landmarks.landmark
- 得到各个关节的id和它们的位姿，并将他们append到lmList里。

```
def findPosition(self, img, draw=True):
    lmList = []
    if self.results.pose_landmarks:
        for id, lm in enumerate(self.results.pose_landmarks.landmark):
            h, w, c = img.shape
            # print(id, lm)
            cx, cy = int(lm.x * w), int(lm.y * h)
            print(lm.x, lm.y, lm.z)
            lmList.append([id, lm.x, lm.y, lm.z])  # 输出的数据是ID，cx，cy，cz的list
            # if draw:
            #     cv2.circle(img, (cx, cy), 5, (255, 0, 0), cv2.FILLED)
    return lmList
```

视觉识别处理test

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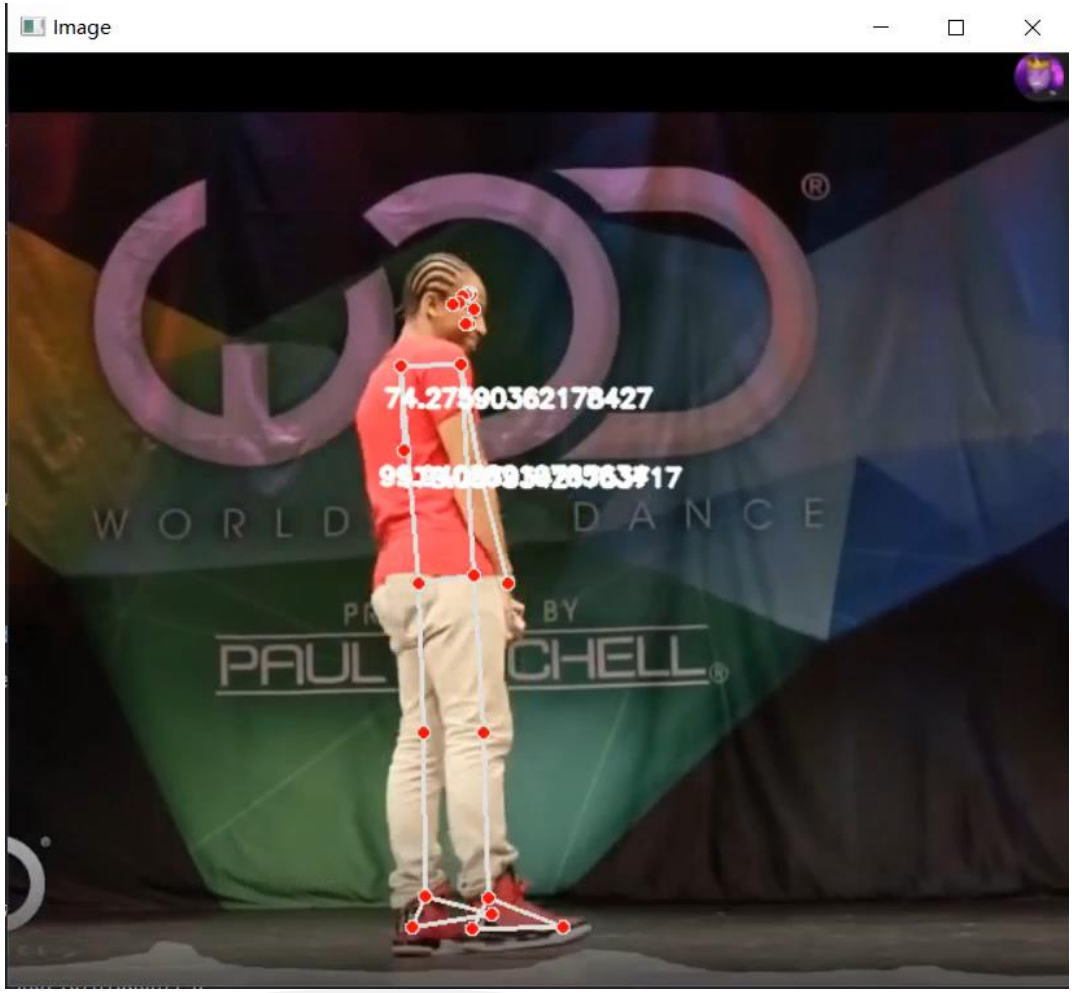

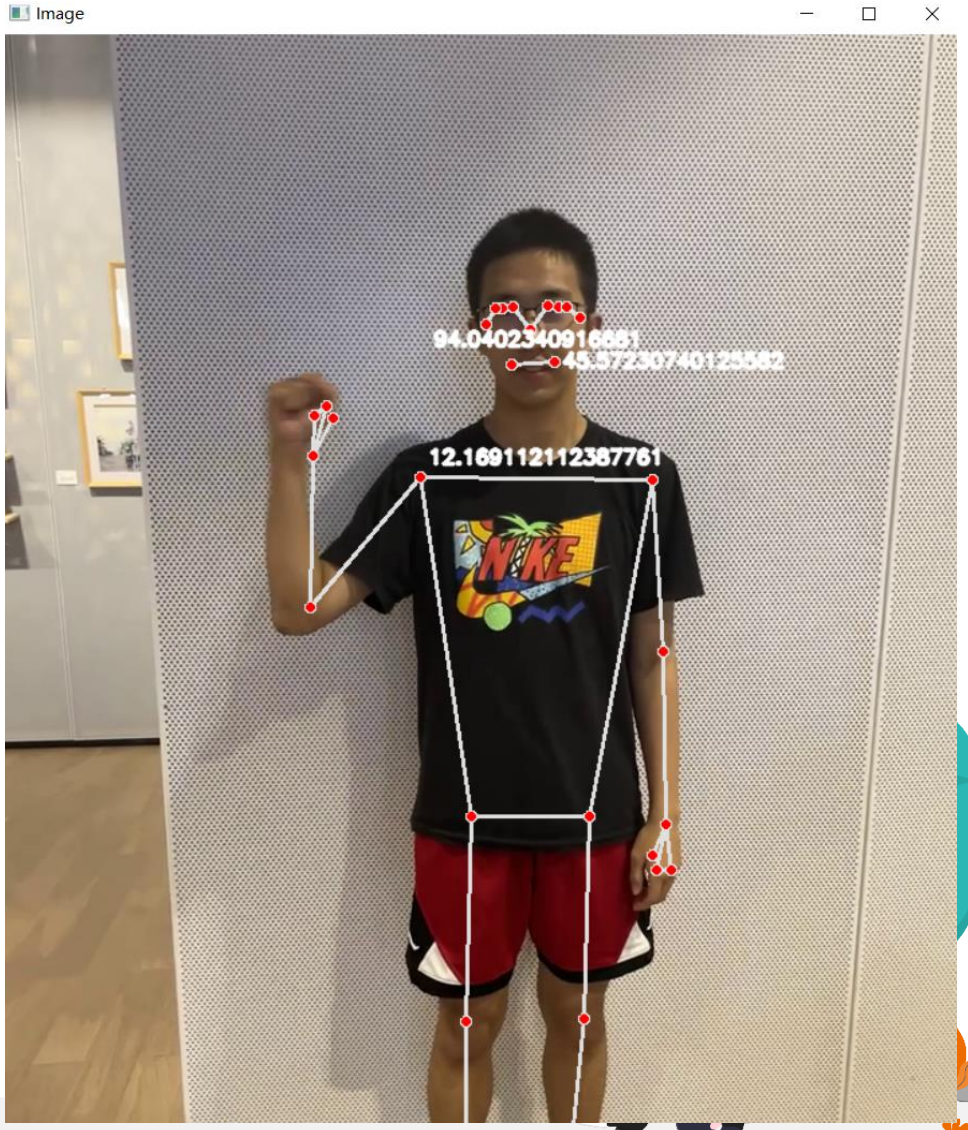

建立动力学模型 IMPORT DYNAMIC MODEL

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利用MATLAB建立动力学模型

包括：

各关节质量

质心位置

各关节的惯性张量

```
%动力学参数
data = [
    % Ixx Iyy Izz Ixy Ixz Iyz xc yc zc m
      33434.735,    13371.342,    21162.848,      -474.874,      346.942,      15764.997,      -3.0688,      -166.5226,    143.0081,    0.513;
      9187.248,    21141.778,    29269.7,      13041.865,      -478.874,      296.759,      -172.4024,      115.7123,      -3.1772,      0.496;
       3333.58,    1033.429,    3949.954,      95.417,      -8.46,      231.071,      -54.0912,      96.6759,      -6.1275,      0.2501;
       628.201,      473.478,      973.895,      446.626,      -84.689,      98.694,      -48.3163,      56.2822,      -11.4767,      0.1335;
      420.577,      431.195,      63.216,      -10.502,      -51.925,      -73.812,      10.1699,      14.6280,      68.5056,      0.0741
     ];
```

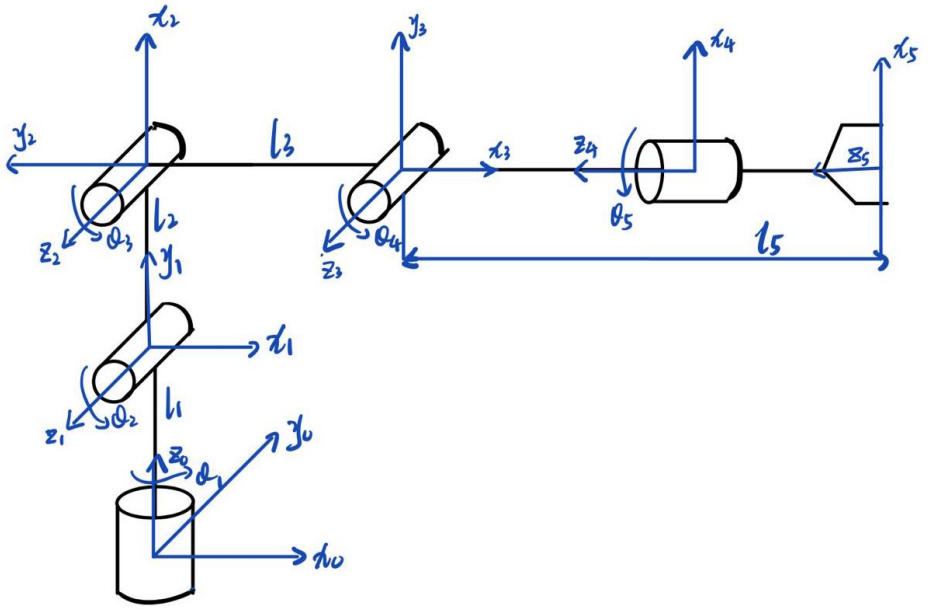
正逆运动学计算

- 正运动学
- 5-DOFs
- $\boldsymbol{l_1}$ = 3cm, $\boldsymbol{l_2}$ = 20cm, $\boldsymbol{l_3}$ = 10cm, $\boldsymbol{l_5}$ = 3cm

```
%正运动学
l1 = 3; l2 = 20; l3 = 10; l5 =3;
A1 = [cos(a1) 0 -sin(a1) 0;sin(a1) 0 cos(a1) 0;0 -1 0 l1;0 0 0 1];
A2 = [cos(a2) -sin(a2) 0 l2*cos(a2);sin(a2) cos(a2) 0 l2*sin(a2);0 0 1 0;0 0 0 1];
A3 = [cos(a3) -sin(a3) 0 l3*cos(a3);sin(a3) cos(a3) 0 l3*sin(a3);0 0 1 0;0 0 0 1];
A4 = [cos(a4) 0 -sin(a4) 0;sin(a4) 0 cos(a4) 0;0 -1 0 0;0 0 0 1];
A5 = [cos(a5) -sin(a5) 0 0;sin(a5) cos(a5) 0 0;0 0 1 l5;0 0 0 1];
T2 = A1*A2*A3*A4*A5;
```

DH表

关节	θ_i	d_i	a_i	α_i
1	$\boldsymbol{\theta_1}^*$	$\boldsymbol{l_1}$	0	-π/2
2	$\boldsymbol{\theta_2}^*$	0	$\boldsymbol{l_2}$	0
3	$\boldsymbol{\theta_3}^*$	0	$\boldsymbol{l_3}$	0
4	$\boldsymbol{\theta_4}^*$	0	0	π/2
5	$\boldsymbol{\theta_5}^*$	$\boldsymbol{l_5}$	0	0



正逆运动学计算

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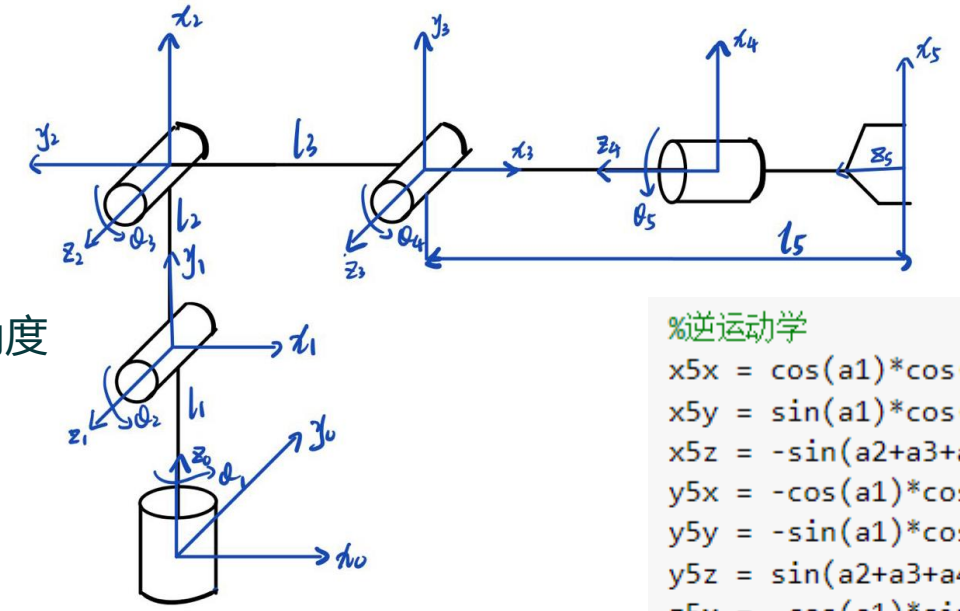
- 逆运动学
- 求解每个关节角度



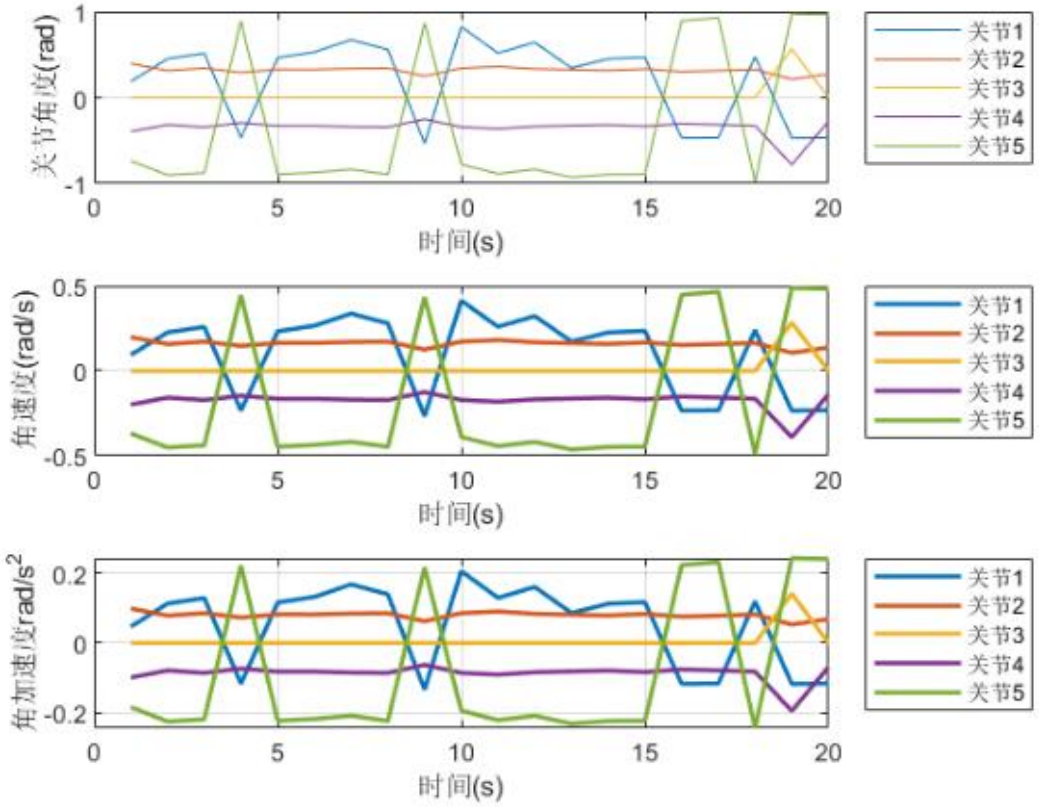
DH表

关节	θ_i	d_i	a_i	α_i
1	θ_1^*	l_1	0	-π/2
2	θ_2^*	0	l_2	0
3	θ_3^*	0	l_3	0
4	θ_4^*	0	0	π/2
5	θ_5^*	l_5	0	0

```
%逆运动学
x5x = cos(a1)*cos(a2+a3+a4)*cos(a5)+sin(a1)*sin(a5);
x5y = sin(a1)*cos(a2+a3+a4)*cos(a5)+cos(a1)*sin(a5);
x5z = -sin(a2+a3+a4)*cos(a5);
y5x = -cos(a1)*cos(a2+a3+a4)*sin(a5)+sin(a1)*cos(a5);
y5y = -sin(a1)*cos(a2+a3+a4)*sin(a5)-sin(a1)*cos(a5);
y5z = sin(a2+a3+a4)*sin(a5);
z5x = -cos(a1)*sin(a2+a3+a4);
z5y = -sin(a1)*sin(a2+a3+a4);
z5z = cos(a2+a3+a4);
p5x = cos(a1)*(-l5*sin(a2+a3+a4)+l3*cos(a2+a3)+l2*cos(a2));
p5y = sin(a1)*(-l5*sin(a2+a3+a4)+l3*cos(a2+a3)+l2*cos(a2));
p5z = l1-l2*sin(a2)-l3*cos(a2+a3)-l5*cos(a2+a3+a4);

i = l1-l5*cos(a2+a3+a4)-p5z;
j = p5x*cos(a1)+p5y*sin(a1)+l5*sin(a2+a3+a4);
q1 = real(atan2(p5y,p5x))
q2 = real(atan2(i*(l2+l3*cos(a3))-j*l3*sin(a3),i*l3*sin(a3)+j*(l2+l3*cos(a3))))
q3 = real(acos((i^2+j^2-l2^2-l3^2)/2/l2/l3))
q4 = real(0-q2-q3)
q5 = real(cos(a2+a3+a4)*q1-2*atan2(x5y,x5x))
```

轨迹规划



轨迹仍不够平滑

还存在些许问题

机械臂舵机控制

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```
% The first group
% Add Dynamixel#2 goal position value to the Syncwrite storage
dxl_addparam_result = groupSyncWriteAddParam(group_num1, DXL2_ID,  dxl_goal_position11, LEN_MX_GOAL_POSITION)
if dxl_addparam_result ~= true
    fprintf('[ID:%03d] groupSyncWrite addparam failed', DXL2_ID);
    return;
end

% Add Dynamixel#7 goal position value to the Syncwrite parameter storage
dxl_addparam_result = groupSyncWriteAddParam(group_num1, DXL7_ID,  dxl_goal_position12, LEN_MX_GOAL_POSITION)
if dxl_addparam_result ~= true
    fprintf('[ID:%03d] groupSyncWrite addparam failed', DXL7_ID);
    return;
end
```

同步读写

```
 %Write Dynamixel#1 moving speed
write2ByteTxRx(port_num1, PROTOCOL_VERSION, DXL1_ID, ADDR_MX_MOVING_SPEED, dxl_goal_angular_velocity1);
dxl_comm_result = getLastTxRxResult(port_num, PROTOCOL_VERSION);
dxl_error = getLastRxPacketError(port_num, PROTOCOL_VERSION);
if dxl_comm_result ~= COMM_SUCCESS
    fprintf('%s\n', getTxRxResult(PROTOCOL_VERSION, dxl_comm_result));
elseif dxl_error ~= 0
    fprintf('%s\n', getRxPacketError(PROTOCOL_VERSION, dxl_error));
end
 %Write Dynamixel#2 moving speed
write2ByteTxRx(port_num2, PROTOCOL_VERSION, DXL2_ID, ADDR_MX_MOVING_SPEED, dxl_goal_angular_velocity2);
dxl_comm_result = getLastTxRxResult(port_num, PROTOCOL_VERSION);
dxl_error = getLastRxPacketError(port_num, PROTOCOL_VERSION);
if dxl_comm_result ~= COMM_SUCCESS
    fprintf('%s\n', getTxRxResult(PROTOCOL_VERSION, dxl_comm_result));
elseif dxl_error ~= 0
    fprintf('%s\n', getRxPacketError(PROTOCOL_VERSION, dxl_error));
end
 %Write Dynamixel#7 moving speed
 write2ByteTxRx(port_num, PROTOCOL_VERSION, DXL7_ID, ADDR_MX_MOVING_SPEED, dxl_goal_angular_velocity2);
dxl_comm_result = getLastTxRxResult(port_num, PROTOCOL_VERSION);
dxl_error = getLastRxPacketError(port_num, PROTOCOL_VERSION);
if dxl_comm_result ~= COMM_SUCCESS
    fprintf('%s\n', getTxRxResult(PROTOCOL_VERSION, dxl_comm_result));
elseif dxl_error ~= 0
```

电机速度写入控制

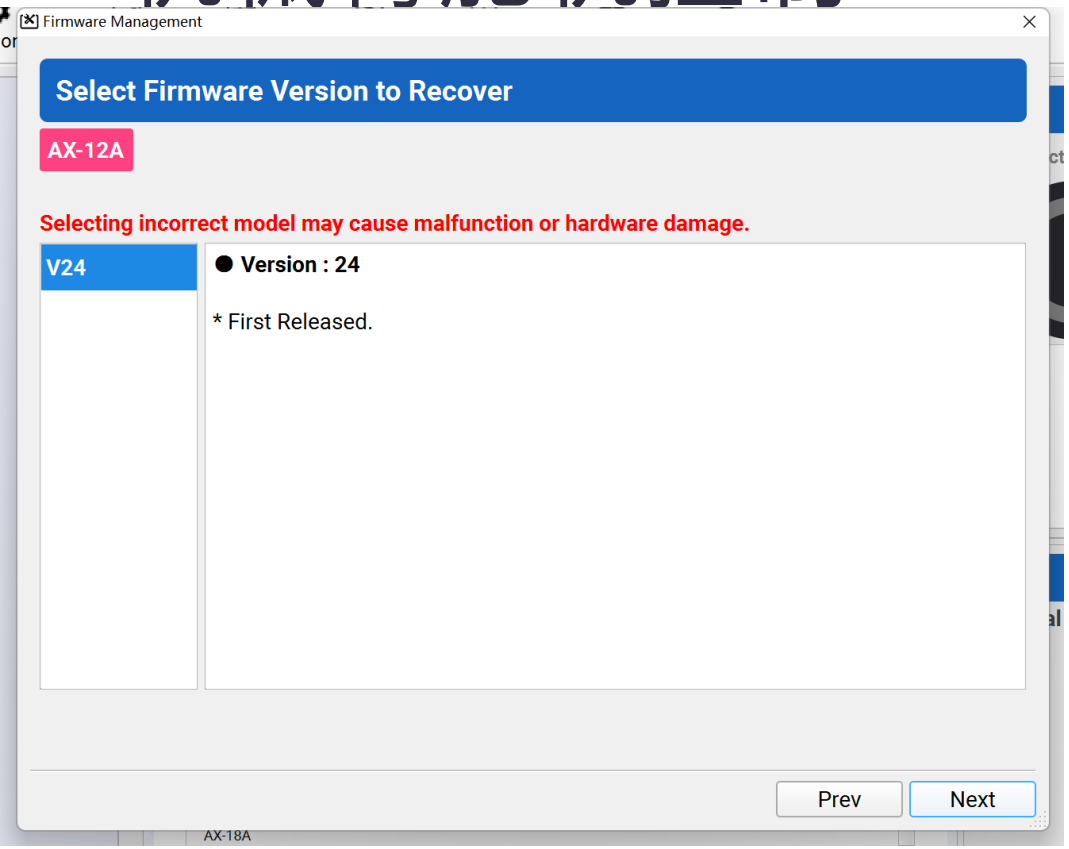
机械臂舵机控制

```
angle1 = a1*180/pi;                                    % Goal position
angle2 = a2*180/pi;                                    %group1
angle3 = a3*180/pi;                                    %group2
angle4 = a4*180/pi;                                    %group3
angle5 = a5*180/pi;
angle6 = 0;
dxl_goal_position11 = [round(angle2*1023/300)+512];
dxl_goal_position12 = [1023-(round(angle2*1023/300)+512)];
dxl_goal_position21 = [round(angle3*1023/300)+512];
dxl_goal_position22 = [1023-(round(angle3*1023/300)+512)];
dxl_goal_position31 = [round(angle4*1023/300)+512];
dxl_goal_position32 = [1023-(round(angle4*1023/300)+512)];
dxl_goal_position1 = [1023];
dxl_goal_position5 = [round(angle5*1023/300)+512];
dxl_goal_position6 = [round(angle6*1023/300)+512];
```

电机协同转动

Wizard电机调试

机械臂舵机控制



电机未知问题

启动固件修复

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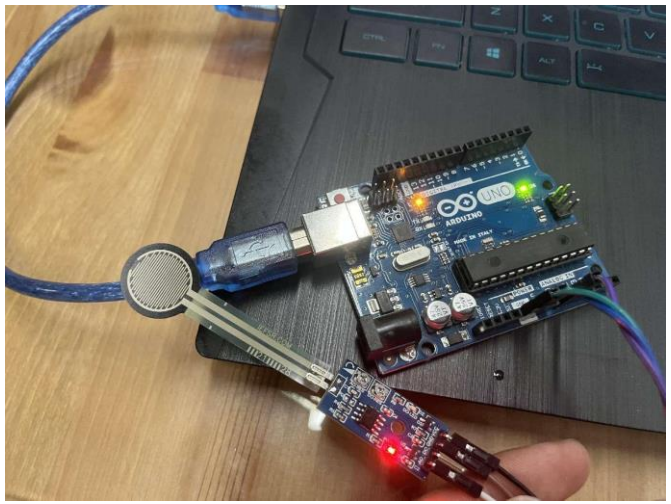
运动角度对接

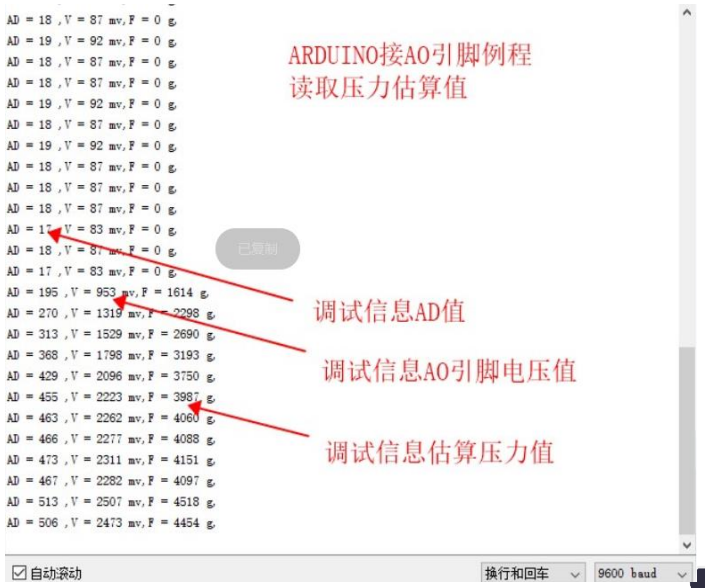
```
angle1 = a1*180/pi;                                    % Goal position
angle2 = a2*180/pi;                                    %group1
angle3 = a3*180/pi;                                    %group2
angle4 = a4*180/pi;                                    %group3
angle5 = a5*180/pi;
angle6 = 0;
dx1_goal_position11 = [round(angle2*1023/300)+512];
dx1_goal_position12 = [1023-(round(angle2*1023/300)+512)];
dx1_goal_position21 = [round(angle3*1023/300)+512];
dx1_goal_position22 = [1023-(round(angle3*1023/300)+512)];
dx1_goal_position31 = [round(angle4*1023/300)+512];
dx1_goal_position32 = [1023-(round(angle4*1023/300)+512)];
dx1_goal_position1 = [1023];
dx1_goal_position5 = [round(angle5*1023/300)+512];
dx1_goal_position6 = [round(angle6*1023/300)+512];
omega1 = qt(1);                                % Goal angular velocity(rad/s)
omega2 = qt(2);                                %group1
omega3 = qt(3);                                %group2
omega4 = qt(4);                                %group3
omega5 = qt(5);
omega6 = 1023;
```

压力传感机械爪

- 传感模块设计
  - 选用20g~6000g薄膜压力传感器，适配与常见开发板
  - 采用Arduino检测薄膜压力传感器信息，方便后续在操纵者这一端进行应用和开发（通过arduino开发力触觉反馈手套）但我们同样可以通过转换器直接将模拟信号传输给电脑。



压力传感模块



数据组成

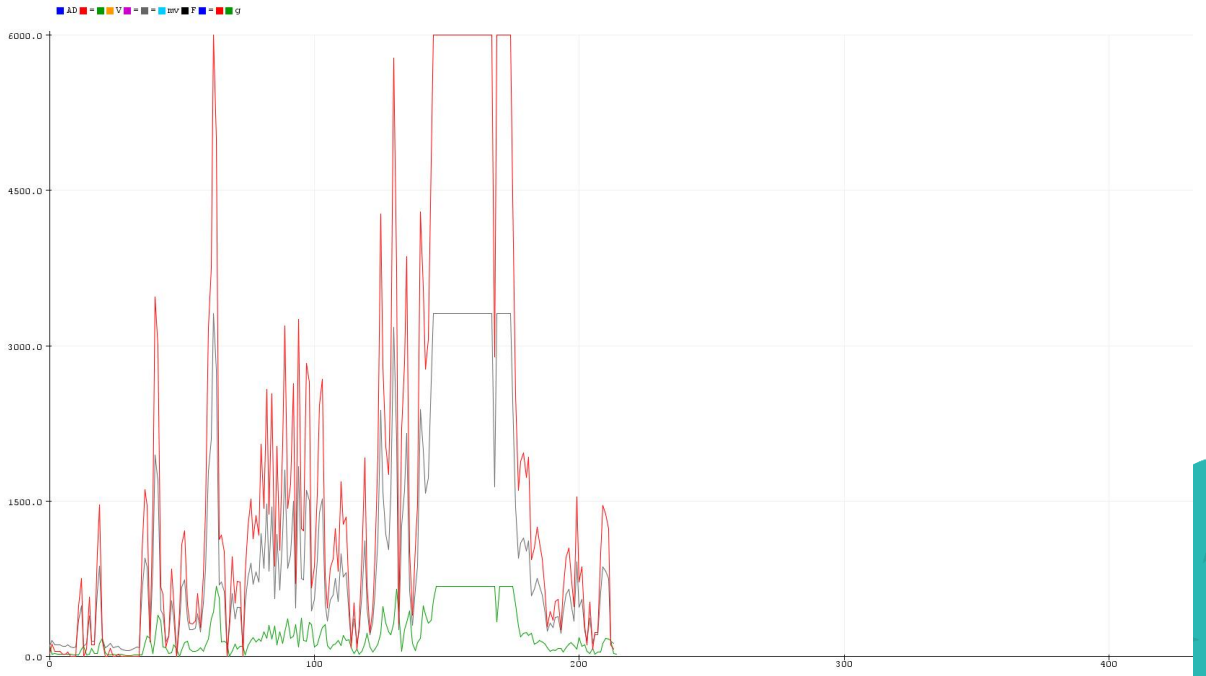
压力传感机械爪

- 传感模块数据读取

COM1

```
02:44:00.301 -> AD = 27 ,V = 131 mv,F = 77 g,
02:44:00.301 -> AD = 26 ,V = 127 mv,F = 70 g,
02:44:00.301 -> AD = 26 ,V = 127 mv,F = 70 g,
02:44:00.301 -> AD = 26 ,V = 127 mv,F = 70 g,
02:44:00.301 -> g,
02:44:00.301 -> AD = 27 ,V = 131 mv,F = 77 g,
02:44:00.301 -> AD = 26 ,V = 127 mv,F = 70 g,
02:44:00.301 -> AD = 26 ,V = 127 mv,F = 70 g,
02:44:00.301 -> AD = 26 ,V = 127 mv,F = 70 g,
02:44:01.850 -> setup end!
02:44:01.850 -> AD = 291 ,V = 1422 mv,F = 2490 g,
02:44:02.157 -> AD = 410 ,V = 2003 mv,F = 3576 g,
02:44:02.466 -> AD = 368 ,V = 1798 mv,F = 3193 g,
02:44:02.774 -> AD = 324 ,V = 1583 mv,F = 2791 g,
02:44:03.044 -> AD = 173 ,V = 845 mv,F = 1412 g,
02:44:03.350 -> AD = 31 ,V = 151 mv,F = 115 g,
02:44:03.657 -> AD = 87 ,V = 425 mv,F = 627 g,
02:44:03.963 -> AD = 17 ,V = 83 mv,F = 0 g,
```

串口信息结构



电压及压力检测大小

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3

研究成果及问题 Results and Problems

研究成果 Research Achievement

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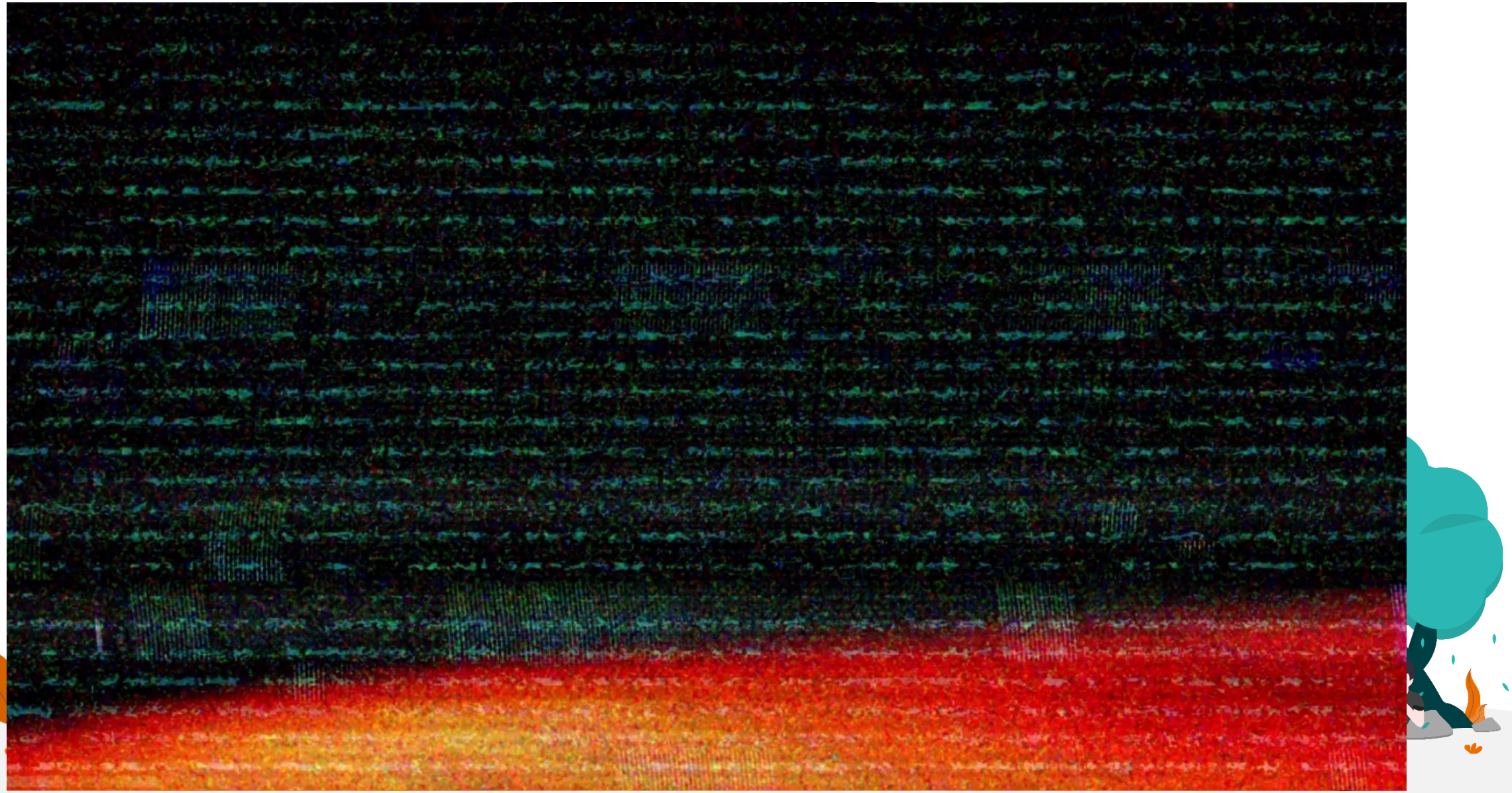

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4 未来发展和应用 Future Expectations

未来发展和应用 Future Expectations

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- 远程遥控作业
- 手术领域

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感谢

您的观看和收听

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Q&A