同行专家业内评价意见书编号：20250854460

附件1

浙江工程师学院（浙江大学工程师学院）
同行专家业内评价意见书

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申报工程师职称专业类别（领域）：电子信息

浙江工程师学院（浙江大学工程师学院）制

2025年05月27日

填表说明

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一、个人申报

（一）基本情况【围绕《浙江工程师学院（浙江大学工程师学院）工程类专业学位研究生工程师职称评审参考指标》，结合该专业类别(领域)工程师职称评审相关标准，举例说明】

1.对本专业基础理论知识和专业技术知识掌握情况(不少于200字)

基础知识方面，熟练掌握自动控制相关理论，包括传统的PID控制理论、现代控制理论（如状态空间法、根轨迹法、频域法等），智能控制算法（如模糊控制、滑模控制、神经网络等），数学基础良好，掌握微积分、线性代数、最优化理论、微分方程等。专业技术知识方面，掌握PID参数调节方法、稳态和动态性能分析，熟使用工具如MATLAB/Simulink进行系统建模、仿真和验证，理解工业控制中的传感器原理、执行器控制以及与控制系统的接口，熟悉计算机编程语言Python，掌握神经网络搭建和训练方法。

2.工程实践的经历(不少于200字)

参与校企合作项目：面向生物制药过程的数字化关键技术研究。针对目前生物制药企业普遍存在的产检分离、产业数字化程度低等，利用物联网、人工智能和大数据等技术，通过构建药物制剂行业车间关键工艺节点和分析、测试的混合感知系统，初步实现含产品质量、效率等要素的生产态势全息可视化分析；研究生产流程的在线检测、监测多源信息融合技术和生产故障的智能预警技术。由浙江大学台州研究院组织，在乐普制药科技有限公司开展实践。在实践过程中，主要负责生产车间空调控制系统的测试与改进。运用控制理论对系统进行建模，使用先进的控制算法提高系统温湿度的控制效果，运用神经网络模型和系统机组的历史数据进行了故障诊断和负荷预测，取得了一定效果。参与开发机器视觉外包装检测系统，能够有效识别包装上的信息并剔除错误产品。

3.在实际工作中综合运用所学知识解决复杂工程问题的案例（不少于1000字）

在药品生产车间中，精确控制温湿度对于保障产品质量至关重要。然而，在实际的药品生产企业中，变风量空调系统常常面临诸多挑战，如高延迟性、大惯性和回路之间的耦合问题。随着时间推移，设备的老化和外界环境的变化进一步加剧了这些问题，导致空调系统的能耗增加和运行故障频发的现象。

为了解决这些问题，以某药品生产车间的空调系统为研究对象，以提升室内温湿度控制精度和预测系统状态为出发点，展开了深入的工程研究。以下是在研究过程中需要解决的主要工程问题和具体工作：

1. 系统建模与分析

首先，详细分析了变风量空调系统的结构组成及其工作原理。基于热力学定律，建立了空调系统温湿度动态变化的数学模型。这些模型包括末端执行器、传感器、空调房间、加热器和表冷器等关键组件，为后续的控制算法测试和优化奠定了基础。

2. 控制策略优化

针对变风量空调房间温度独立控制的问题，测试了加热器和表冷器的动态特性，并验证了建立的数学模型的准确性。搭建了串级PID控制模型，其中主回路用于温度控制，副回路则负责风量控制。通过仿真测试，评估了系统的温度控制性能。针对系统存在的滞后性和大惯性问题，提出了模糊PID控制和Smith预估补偿相结合的温度控制策略。实验结果显示，这种控制器显著提升了系统的动态响应能力。为了进一步优化模糊控制器的效果，引入了灰狼算法用于优化量化因子和比例因子，以提高控制效果和稳定性。

3. 解耦控制策略研究

针对空调系统在温湿度控制过程中存在的耦合现象，开展了解耦控制策略的研究。采用了可实现性较强的前馈补偿解耦方法，以及基于RBF神经网络的逆系统解耦方案，对温湿度控制

系统进行了解耦设计。为了应对系统的动态响应慢、非线性和鲁棒性差等问题，引入了滑模控制策略，构建了温湿度双通道滑模控制器。实验表明，相比传统的PID控制，滑模控制系统具有更快的响应速度、更小的超调量和更强的抗干扰能力。尽管滑模控制存在固有的抖振问题，但通过将模糊控制与滑模控制相结合，成功通过模糊推理自适应调节趋近律参数，实现了系统在快速响应的同时显著改善了稳定性和平滑性。

4. 运行状态预测与故障预警

最后，根据空调机组SCADA系统的历史监测数据，开展了空调机组运行状态的故障预警研究。提出了主成分分析和非线性状态估计相结合的方法，建立了空调系统故障预测模型。通过对三个月历史数据进行训练，并用持续一周的数据进行验证，验证了PCA-NEST模型在检测空调系统故障方面的有效性。此外，还使用长短期记忆神经网络对系统电负荷进行预测，基于温度、湿度和用电量等数据进行训练和验证。实验结果显示，Bi-LSTM负荷预测模型具有较高的准确性，为空调系统的节能优化提供了重要参考。

综上所述，研究旨在通过深入分析空调系统的工作原理和研究关键组件的动态特性，优化控制策略并建立预测模型，从而提升药品生产车间空调系统的稳定性、节能性和运行效率。通过这些工作，为药品生产企业提供可靠的技术支持，确保产品质量和生产效率的持续提升。

（二）取得的业绩（代表作）【限填3项，须提交证明原件（包括发表的论文、出版的著作、专利证书、获奖证书、科技项目立项文件或合同、企业证明等）供核实，并提供复印件一份】

1.
公开成果代表作【论文发表、专利成果、软件著作权、标准规范与行业工法制定、著作编写、科技成果获奖、学位论文等】

成果名称	成果类别 [含论文、授权专利（含发明专利申请）、软件著作权、标准、工法、著作、获奖、学位论文等]	发表时间/授权或申请时间等	刊物名称/专利授权或申请号等	本人排名/总人数	备注
Temperature control system of tablet workshop based on fuzzy PID controller and Smith predictor	会议论文	2024年07月24日	第35届中国过程控制会议论文集	1/3	

2.其他代表作【主持或参与的课题研究项目、科技成果应用转化推广、企业技术难题解决方案、自主研发设计的产品或样机、技术报告、设计图纸、软课题研究报告、可行性研究报告、规划设计方案、施工或调试报告、工程实验、技术培训教材、推动行业发展中发挥的作用及取得的经济社会效益等】

作为第四负责人参与科研项目：面向制药过程的数字化关键技术研究，项目经费300万元。参与开发基于机器视觉的外包装检测系统，能够准确剔除具有错误信息的物件，提高了企业生产效率。改进制药车间空调的自动化控制系统，提升了生产过程的环境稳定性，保障了生产过程的温湿度准确性，一定程度上解决了企业的技术难题。

<table>
<tr><td colspan="2">（三）在校期间课程、专业实践训练及学位论文相关情况</td></tr>
<tr><td>课程成绩情况</td><td>按课程学分核算的平均成绩： 88 分</td></tr>
<tr><td>专业实践训练时间及考核情况(具有三年及以上工作经历的不作要求)</td><td>累计时间： 1 年（要求1年及以上）
考核成绩： 80 分</td></tr>
<tr><td colspan="2">本人承诺</td></tr>
<tr><td colspan="2">个人声明：本人上述所填资料均为真实有效，如有虚假，愿承担一切责任，特此声明！

申报人签名：</td></tr>
</table>

22260485

二、日常表现考核评价及申报材料审核公示结果

日常表现考核评价	非定向生由德育导师考核评价、定向生由所在工作单位考核评价： ☑优秀　　☐良好　　☐合格　　☐不合格 德育导师/定向生所在工作单位分管领导签字（公章）：　2025 年 5 月 28 日
申报材料审核公示	根据评审条件，工程师学院已对申报人员进行材料审核（学位课程成绩、专业实践训练时间及考核、学位论文、代表作等情况），并将符合要求的申报材料在学院网站公示不少于5个工作日，具体公示结果如下： ☐通过　　☐不通过（具体原因：　　　　） 工程师学院教学管理办公室审核签字（公章）：　　年　月　日

中共浙江大学工程师学院委员会

浙 江 大 学 研 究 生 院

攻读硕士学位研究生成绩表

学号：22260485	姓名：计博言	性别：男	学院：工程师学院	专业：电子信息	学制：2.5年
毕业时最低应获：24.0学分		已获得：27.0学分		入学年月：2022-09	毕业年月：
学位证书号：		毕业证书号：			授予学位：

学习时间	课程名称	备注	学分	成绩	课程性质	学习时间	课程名称	备注	学分	成绩	课程性质
2022-2023学年秋季学期	工程技术创新前沿		1.5	82	专业学位课	2022-2023学年秋冬学期	研究生英语		2.0	86	公共学位课
2022-2023学年秋季学期	研究生英语基础技能		1.0	82	公共学位课	2022-2023学年夏季学期	研究生论文写作指导		1.0	92	专业学位课
2022-2023学年冬季学期	自然辩证法概论		1.0	89	公共学位课	2022-2023学年春夏学期	智能装备与创新设计实践		4.0	89	专业选修课
2022-2023学年秋冬学期	工程伦理		2.0	81	公共学位课	2022-2023学年夏季学期	智能装备创新设计案例分析		2.0	87	专业学位课
2022-2023学年冬季学期	工程中的有限元方法		2.0	99	专业选修课	2022-2023学年春夏学期	高阶工程认知实践		3.0	83	专业学位课
2022-2023学年冬季学期	新时代中国特色社会主义理论与实践		2.0	93	公共学位课	2022-2023学年夏季学期	工程师创新创业思维		2.0	92	专业选修课
2022-2023学年冬季学期	产业技术发展前沿		1.5	83	专业学位课		硕士生读书报告		2.0	通过	

说明：1. 研究生课程按三种方法计分：百分制，两级制（通过、不通过），五级制（优、良、中、及格、不及格）。

2. 备注中“*”表示重修课程。

学院成绩校核章：

成绩校核人：张梦依

打印日期：2025-06-03

第 35 届中国过程控制会议（CPCC2024）

录用通知

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首先感谢您对中国过程控制会议的支持！

第 35 届中国过程控制会议论文审稿工作已经全部结束。经过程序委员会的严格评审，我们高兴地通知您，您的以下论文已被录取。我们在此诚挚地邀请您参加将于 2024 年 7 月 25-27 日在中国·三亚举办的 CPCC2024 并宣读您的成果。

论文编号: 0142

题目: Temperature control system of tablet workshop based on fuzzy PID controller and Smith predictor

作者: Boyan Ji, Wenjun Yan, Daiyuan Huang

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会议程序安排、住宿等信息，您可以访问会议网站 http://2024.cn-tcpc.org/ 获取更多会议最新相关信息。

再次感谢您对中国过程控制会议的支持！期待在中国·三亚与您相聚！

如果您有任何问题欢迎您随时与会议秘书处联系。

李少远

第 35 届中国过程控制会议程序委员会主席

2024 年 5 月 30 日

Temperature control system of tablet workshop based on fuzzy PID controller and Smith predictor

Boyan Ji[1], Wenjun Yan[2], Daiyuan Huang[1]

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Abstract: The air conditioning system in the tablet workshop exhibits issues with temperature control accuracy and significant time delay. This study constructs models of the air-conditioned room and the main equipment of the air conditioner based on thermodynamic principles. A cascade PID temperature control system is designed to control the temperature, where the main circuit is the temperature control loop and the minor circuit is the air volume control loop. To enhance dynamic performance and mitigate time delay effects, a control system integrating fuzzy PID and Smith predictor is designed. Simulation models are developed to evaluate the system in Simulink. The results demonstrate that while the cascade PID control system meets basic temperature control requirements and demonstrates anti-disturbance capabilities, it exhibits slow response times and persistent overshoot. Conversely, the fuzzy PID and Smith predictor control system displays superior dynamic performance with faster response rates, effectively mitigating time delays to a certain extent.

Key Words: Air conditioning system; Cascade PID; Fuzzy PID; Smith predictor; Simulation model

1 Introduction

In order to ensure the quality of tablet production, precise and stable temperature control within the workshop is of paramount importance. Despite advancements in production facilities leading to enhanced productivity and tablet quality, issues such as equipment aging have resulted in unstable temperature control within the workshop[1]. Seasonal temperature fluctuations further exacerbate these challenges, posing a significant bottleneck in the tablet manufacturing process.

While a centrally controlled air conditioning system is in place, it suffers from hysteresis and inadequate control precision[2]. Although PID controllers are commonly utilized in industrial processes due to their convenience, stability, and simplicity, traditional PID controllers struggle to achieve optimal performance for the air conditioning system within the tablet workshop[3].

This study aims to address these challenges by building models for key components of the air conditioning system within the tablet workshop including sensors, actuators and air-conditioned room. A cascade PID temperature control system will be designed in Simulink with parameters tuned through attenuation curves. Furthermore, a fuzzy PID control combined with a Smith predictor system will be implemented to enhance performance. The feasibility of this approach will be verified through simulation results obtained using MATLAB/Simulink compared against conventional PID systems.

2 Models of main components

There is an end equipment in the Variable Air Volume (VAV)which is used to adjust the air volume in the room. The workshop relies on this equipment to change the temperature, including sensors, controller, and actuators.

The Variable Air Volume (VAV) system includes an end equipment for adjusting the air volume in the room, which is essential for temperature control. This equipment consists of sensors, controllers and actuators. The main controller receives input of the error between the set point and actual temperature from the sensor, calculates it using an algorithm, and then exports it. The sub-controller receives input of the error in air volume and controls the valve accordingly to adjust air volume and temperature[4]. Figure. 1 illustrates the temperature control system in a tablet-producing workshop.

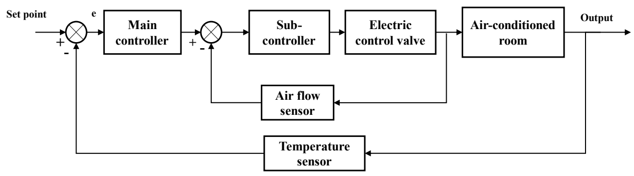


Fig. 1: The temperature control system in the tablet production workshop

2.1 The model of Air-conditioned room

According to the principle of conservation of energy, the rate of change of heat stored in a room is equal to the difference between the energy flowing into the room and the energy flowing out of the room per unit time[5]. The mathematical expression is:

$$Q_{in} - Q_{out} = c_1 \frac{dt_n}{dt} \quad (1)$$

i.e.

$$c_1 \frac{dt_n}{dt} = (L\rho_\alpha c_\alpha t_s + q_n) - \left(L\rho_\alpha c_\alpha t_n + \frac{t_n - t_o}{r}\right) \quad (2)$$

Where Q_{in} represents the energy flowing into the room(kJ/s), Q_{out} denotes the energy exported from the room(kJ/s), L(m^3/h) is the air volume, t_n (°C) and t_s (°C) are the temperature of the room and the temperature of the air, respectively.

Where ρ_α represents air density(kg/m^3), c_α is air Specific Heat Capacity(kJ/(kg•°C)), q_n is heat release of the thermal load(kJ), t_o stands for outdoor temperature and r is thermal resistance of the room.

Equation (2) can be rewritten as follows:

$$c_1 \frac{dt_n}{dt} = \mathrm{L}\rho_\alpha c_\alpha (t_s - t_n) + q_n - \frac{t_n - t_o}{r} \tag{3}$$

When the room is in dynamic equilibrium, the energy flowing into the room is equal to energy exported from the room, and the temperature gradient is 0:

$$\frac{dt_n}{dt} = 0 \tag{4}$$

Each physical variable is in steady state:

$$t_n = t_{n0}, q_n = q_{n0}, t_o = t_{o0}, L = L_0 \dots\dots \tag{5}$$

When the dynamic equilibrium is broken, the room is in a state of transitional state:

$$t_n = t_{n0} + \Delta t_n, q_n = q_{n0} + \Delta q_n \tag{6}$$

$$t_o = t_{o0} + \Delta t_o, L = L_0 + \Delta L \tag{7}$$

By substituting Equation (6), (7) into Equation (3), the model is obtained as:

$$\frac{c_1}{L_0\rho_\alpha c_\alpha + \frac{1}{r}} \frac{d\Delta t_n}{d_t} + \Delta t_n = \frac{\Delta L \rho_\alpha c_\alpha (t_s - t_{n0})}{L_0\rho_\alpha c_\alpha + \frac{1}{r}} + \frac{\Delta q_n + \frac{\Delta t_0}{r}}{L_0\rho_\alpha c_\alpha + \frac{1}{r}} \tag{8}$$

Equation(8) can be simplified as：

$$T\frac{d\Delta t_n}{d_t} + \Delta t_n = K_1 \Delta L + K_2 \Delta q \tag{9}$$

T, K_1, K_2 is specifically:

$$T = \frac{c_1}{L_0\rho_\alpha c_\alpha + \frac{1}{r}},\ K_1 = \frac{\rho_\alpha c_\alpha (t_s - t_{n0})}{L_0\rho_\alpha c_\alpha + \frac{1}{r}},$$

$$K_2 = \frac{1}{L_0\rho_\alpha c_\alpha + \frac{1}{r}},\ \Delta q = \Delta q_n + \frac{\Delta t_o}{r} \tag{10}$$

Where T represents time constant of thermal inertia in the room, K_1 represents the amplification of difference between the supply and return air volumes, which is called scale factor of forward channel. K_2 is the amplification of heat in the room transferring through the wall, which is called the scale factor of disturbance channel. Δq is temperature variation because of heat changes inside and outside[6]. After Laplace transform, Equation (9) can be described as follows:

$$G_1(s) = \frac{\Delta t_n(s)}{\Delta L(s)} = \frac{K_1}{Ts+1} \tag{11}$$

$$G_2(s) = \frac{\Delta t_n(s)}{\Delta q(s)} = \frac{K_2}{Ts+1} \tag{12}$$

Where $G_1(s)$ is transfer function between temperature and air-conditioned room, $G_2(s)$ is transfer function between temperature and disturbance channel.

In the actual situation, there is delay in each part. Considering the influence of hysteresis and the universality of the model, transfer functions are rewritten as:

$$G_1(s) = \frac{\Delta t_n(s)}{\Delta L(s)} = \frac{K_1 e^{-\tau s}}{Ts+1} \tag{13}$$

$$G_2(s) = \frac{\Delta t_n(s)}{\Delta q(s)} = \frac{K_2 e^{-\tau s}}{Ts+1} \tag{14}$$

Where τ is delay time.

2.2 Models of end equipment

The actuator of the control system is an electric regulating air valve. In the minor loop, sub controller is used to control the air volume, which sends control signal to the valve and adjust it's opening to change air volume exported to the room. In this way, the temperature of workshop is controlled and the load meets requirement. The actuator mainly consists of DC motor and regulating valve, the former can transform the electric energy input into mechanical energy. In air conditioning system, the regulating valve is usually ideal flow characteristic which means equal percentage flow characteristics[7]. Therefore, the input of valve is electric current and the output is air volume. The transfer function can be expressed as:

$$G_z(s) = \frac{1}{T_z s + 1} \tag{15}$$

Where T_Z is time constant.

The sensor in the main loop is utilized for temperature measurement within a specified area and to transmit feedback signals to the control system for performance optimization. Meanwhile, the volume sensor in the minor loop primarily measures air flow by detecting heat dissipation as air passes through it, thus reflecting air volume. This difference in thermal resistance generates a change in resistance, which is then processed into an electrical signal and transmitted to the controller[8-9]. The controller subsequently regulates the electric valve based on this feedback of air volume. Similarly, the temperature sensor operates on changes in resistance value to convert temperature signals into electrical ones for transmission to the controller. In accordance with heat balance principles, this sensor model can be described as:

$$t_f = t_h + \tau \frac{dt_h}{dt} \tag{16}$$

Where t_f represents the temperature of medium around, t_h is the temperature of thermal resistance and τ is time constant.

3 Cascade PID control system

The Dimensions of the workshop and air changes are presented in Table. 1, including the length(L), width(W) and height(H). Historical data from the air conditioner system has been obtained to determine the air changes per hour (N). These data will be utilized to calculate each parameter of transfer functions.

Table. 1 Relevant data of the workshop.

L (m)	W (m)	H (m)	N
18	12	3	18

Assuming that the air is supplied from one side of the air conditioner, the transfer delay can be described as:

$$\tau = \frac{9}{N} = 0.5min = 30s \tag{17}$$

The time constant of the room is shown below:

$$T = \frac{90}{N} = 5min = 300s \quad (18)$$

The proportionality coefficient of the room is:

$$K = \frac{1}{1 + \frac{52}{N}\left(\frac{1}{L} + \frac{1}{W} + \frac{1}{H}\right)} = 0.423 \quad (19)$$

Table. 2 shows the initial temperature of the room (t_{n0}), the temperature of the air (t_s), the air density (ρ_α) and air Specific Heat Capacity (c_α).

Table. 2 Thermal parameters of the workshop

t_s (°C)	t_{n0} (°C)	ρ_α(kg/m^3)	c_α(kJ/(kg•°C)
18	24	1.2	1.01

According to Equation (10),

$$K_1 = \left| K \frac{(t_s - t_{n0})}{L} \right| = 3.380 \quad (20)$$

$$K_2 = \frac{K}{L\rho_\alpha c_\alpha} = 0.465 \quad (21)$$

The transfer function of the room can be described as:

$$G_1(s) = \frac{3.38e^{-30s}}{300s + 1} \quad (22)$$

The transfer function of disturbance is:

$$G_2(s) = \frac{0.465e^{-30s}}{300s + 1} \quad (23)$$

Figure. 2 shows the cascade PID control system of the air conditioner system. The main loop functions as a temperature control loop while the minor loop is responsible for regulating the air volume.

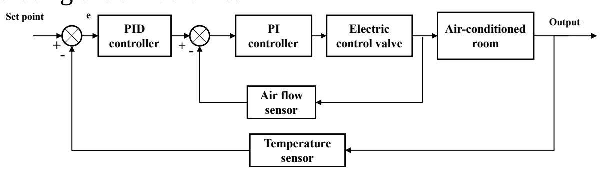


Figure. 2 Cascade PID control system of temperature.

According to Equation (15), the transfer function of the electric regulating valve is shown as:

$$G_v(s) = \frac{1}{10s + 1} \quad (24)$$

The transfer function of the air volume sensor is:

$$G_f(s) = \frac{0.67}{s + 1} \quad (25)$$

And the transfer function of the temperature sensor can be described as:

$$G_t(s) = \frac{1}{30s + 1} \quad (26)$$

Establish the simulation model in Simulink, as shown in Figure. 3.

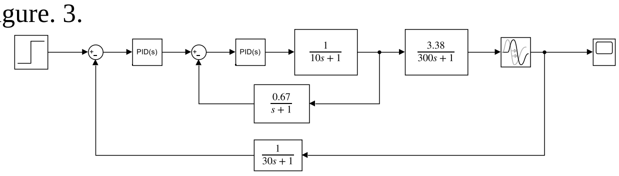


Figure. 3 Simulation model of cascade PID control system.

For a conventional PID controller, the equation of output u(t) in the time domain is:

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \quad (27)$$

3.1 Simulation results

Use the attenuation curves to tune the PID parameters. When the system is stable, put the main loop closed and set the proportional at 100%. Set the integral to maximum and differential to 0. Tune the minor loop through the 4:1 attenuation curve and get the proportional δ_{2s} and oscillation period T_{2s}. Treating the minor loop as a link of the main loop, substitute the parameters of sub-controller into it and use the same way to tune the parameters of main controller. Table. 4 shows the tuning methods of different controller types.

Table. 3 PID parameters tuning rules of attenuation curves

Type	δ	T_I	T_D
P	δ_k	-	-
PI	$1.2\delta_k$	$0.5T_k$	-
PID	$0.8\delta_k$	$0.3T_k$	$0.1T_k$

After tuning, the main controller parameters are shown in Table. 4

Table. 4 PID parameters after tuning.

PID parameter	K_P	K_I	K_D
Main controller	1.5	0.003	41
Minor controller	3.1	0.0015	

The response curve of temperature is shown in Figure. 4,

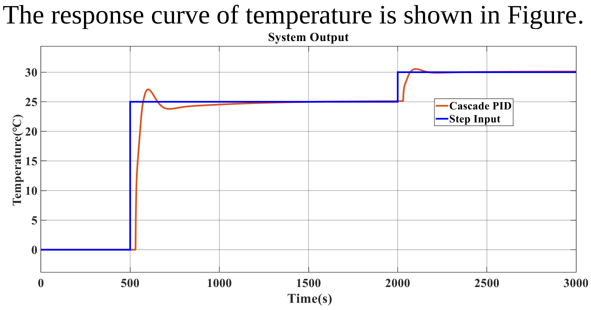


Figure. 4 Simulation curve of workshop temperature

As the curve shows, the set temperature changes to 25°C at 500 seconds and 30°C at 2000 seconds. The system uses about 1000 seconds to reach the first set point and the steady state error is less than 0.1°C. When the set point changes, the temperature of the room is able to follow the reference. The maximum overshoot and setting time are shown in Table. 5.

Table. 5 The maximum overshoot and setting time of temperature response curves

	Maximum overshoot	Setting time(s)
First step	8.4%	478.88
Second step	10.8%	60.89

In actual situation of the air conditioner, the system will be disturbed. The model of disturbance in the context of an air conditioning system can be defined as the external factors that affect the system's performance. These disturbances may include heat exchange through walls, roofs, adjacent rooms, and other equipment:

$$Q = S \cdot K \cdot \Delta T \quad (28)$$

Where Q is heat release, S represents the heat transfer area, K is heat transfer coefficient and ΔT is temperature difference. The area of the roof, windows, interior walls, and exterior walls should be measured respectively. The heat transfer coefficient of roof and outer wall is 0.65W/m^2, the coefficients of windows and interior wall are 2.8W/m_2 and 0.5W/m_2. Temperature difference between two rooms is set as 5°C, while the average difference between indoor and outdoor is 15°C in Zhejiang Taizhou in winter. The disturbance model, as depicted in Figure 5, involves sinusoidal signals as the input.

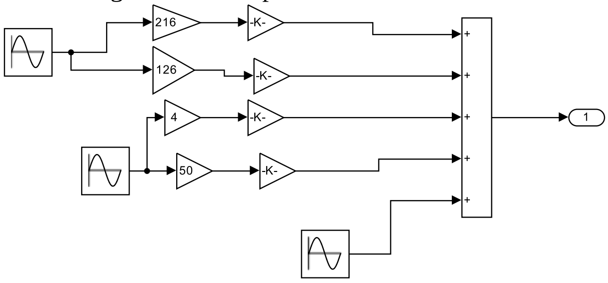


Figure. 5 Simulation model of disturbance

Add the disturbance at 1700 seconds, the response curve of temperature is shown in Figure. 6.

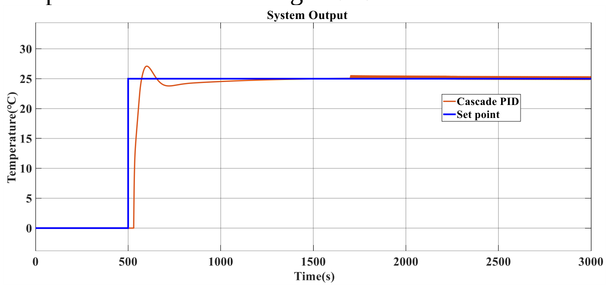


Figure. 6 Simulation curve of workshop temperature with disturbance.

As depicted in the figure, small fluctuations near the set point occur when the system is affected by disturbances, indicating that the system possesses a certain capacity to resist disturbances.

In conclusion, the conventional PID controller is capable of meeting the fundamental control requirements of the temperature system. However, tuning the PID parameters is inconvenient and results in slow response. Despite adjustments to the parameters, overshoot persists as an issue. Additionally, hysteresis proves to be a challenging problem to resolve.

4 Fuzzy PID controller and Smith Predictor

4.1 Fuzzy PID controller

Fuzzy logic control is an automatic control strategy based on expert knowledge, which consolidates various fuzzy logic rules derived from practical experience and implements control through a computer. The primary process involves variable definition, fuzzification, knowledge base utilization, logical judgment, and defuzzification[10-11]. A Fuzzy PID controller integrates a component of fuzzy logic control into the PID control system, incorporating human tuning experience when adjusting PID parameters.

Based on the characteristics of the air conditioning system, a two-dimensional fuzzy controller can be utilized. The inputs for the fuzzy controller are the error (E) and the error rate (Ec). The outputs are PID parameters K_P, K_I, K_D. The linguistic values are described as negative big (NB), negative small (NS), zero (ZO), positive small (PS), positive big (PB). The universe of discourse of variables are listed in Table. 5.

Table. 5 Universes of discourse of input and output

E	E_C	K_P	K_I	K_D
[-6,6]	[-6,6]	[0,3]	[0,0.01]	[-5,5]

The membership functions are linear. Taking input E as an example, the corresponding membership function is illustrated in Figure. 7.

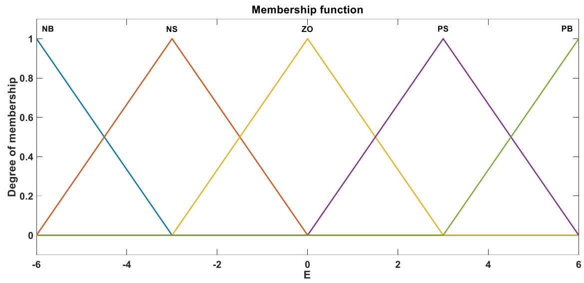


Figure. 7 The membership function of error E.

The error E is partitioned into five segments, as illustrated in Figure 7. Based on the magnitude of E, the membership function indicates the corresponding linguistic category and membership degree.

According to varying values of E and E_C, PID controller parameters have distinct requirements. When E is large, K_P should be set to a higher value and K_D should should be smaller in order to achieve a fast response and superior tracking performance. Additionally, integral effect is greater, leading to an increase in overshoot. Therefore, K_I should be set to a smaller value. If E is at a moderate value, K_P and K_D should be should be set to smaller values, while K_I should be be adjusted to a moderate value. This will help in reducing the overshoot and increasing the response speed. When E is small, K_P and K_I should be set to greater values in order to reduce the steady-state error and avoid oscillation. If EC is large, K_D should be smaller and vice versa[12].

On the basis of rules above, the parameters tuning rules are summarized in Table. 6.

Table. 6 The fuzzy control rules of K_P.

EC/E	NB	NS	ZO	PS	PB
NB	PB	PS	PS	PS	ZO
NS	PS	PS	PS	ZO	NS
ZO	PS	PS	ZO	NS	NS
PS	PS	ZO	NS	NS	NS
PB	ZO	NS	NS	NS	NB

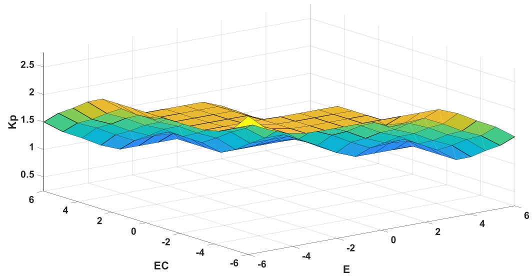
Table. 7 The fuzzy control rules of K_I.

EC/E	NB	NS	ZO	PS	PB
NB	NB	NS	NS	NS	ZO
NS	NB	NS	NS	ZO	PS
ZO	NS	NS	ZO	PS	PS
PS	NS	ZO	PS	PS	PB
PB	ZO	PS	PS	PS	PB

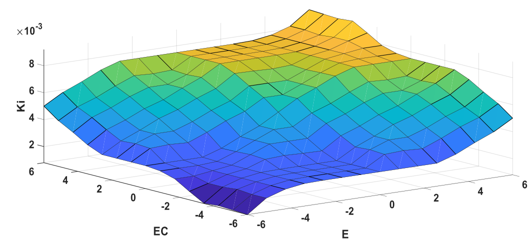
Table. 8 The fuzzy control rules of K_D.

EC/E	NB	NS	ZO	PS	PB
NB	PS	NB	NB	NB	PS
NS	ZO	NS	NS	NS	ZO
ZO	ZO	NS	NS	NS	ZO
PS	ZO	ZO	ZO	ZO	ZO
PB	PB	PS	PS	PS	PB

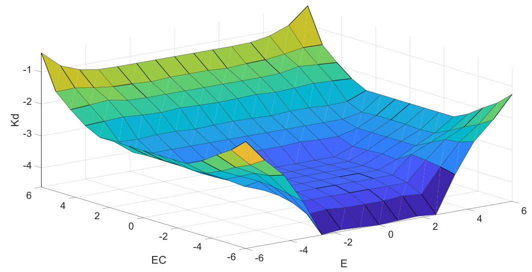
The fuzzy inference method employed is the Mamdani algorithm, and the process of defuzzification utilizes the centroid algorithm. Build the fuzzy logic controller according to the rules in MATLAB. The result of Surface observer is shown in Figure. 8.



(a)



(b)



(c)

Figure. 8 The surface view of the PID parameters (a) K_P; (b) K_I; (c) K_D.

The Surface observer shows how the PID parameters varies with E and EC.

4.2 Smith Predictor

To address the challenge of time delay in PID controller, the Smith predictor is introduced as a solution. It involves estimating the dynamic characteristics of the system under basic disturbance and implementing predictive compensation through the predictor. In this way, the controlled variable which has time delay is reflected ahead to the regulator[13]. The compensated equivalent transfer function eliminates time delay, enabling the controller to act in advance. The overshoot is reduced and the controlled process is faster[14]. The process of Smith-predictor is depicted in Figure. 9.

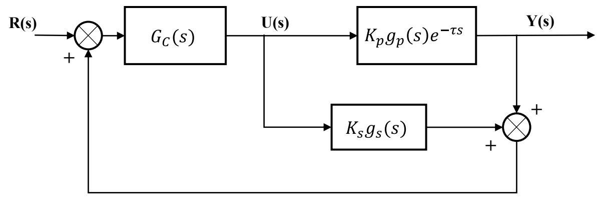


Figure .9 The principle of compensation control of Smith predictor.

Where $K_p g_p(s)$ is the transfer function of the plant except for the time delay. $K_s g_s(s)$ represents the transfer function of Smith-predictor. If a predictor is present in the system, the transfer function between U(s) and Y(s) can be described as the sum of two parallel channels:

$$\frac{Y'(s)}{U(s)} = K_p g_p(s)e^{-\tau s} + K_s g_s(s) \tag{29}$$

To eliminate the delay of the controller, Equation (29) should be adjusted to:

$$\frac{Y'(s)}{U(s)} = K_p g_p(s) \tag{30}$$

Therefore, the transfer function of Smith-predictor is:

$$K_s g_s(s) = K_p g_p(s)(1 - e^{-\tau s}) \tag{31}$$

The predictor can effectively mitigate the impact of significant time delays on the transition process, resulting in a similar outcome to a system without time delay. The closed-loop transfer function is:

$$\frac{Y(s)}{R(s)} = \frac{K_p G_c(s) g_p(s) e^{-\tau s}}{1 + K_p G_c(s) g_p(s)} \tag{32}$$

As for the air-conditioning room, K_P=3.38, T_I=300, τ=30. The transfer function of Smith-predictor is described as:

$$G_S(s) = \frac{3.38(1 - e^{-30s})}{(300s + 1)} \tag{33}$$

4.3 Simulation results

Build the simulation model as Figure. 10 shows in Simulink.

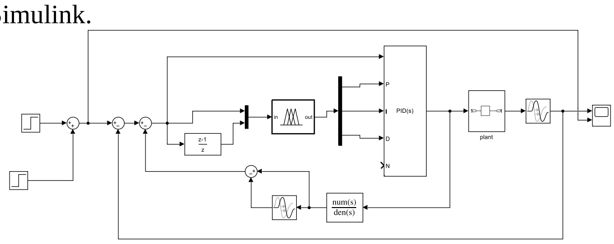


Figure. 10 Simulation model of fuzzy PID controller and Smith predictor system.

The set point for the temperature is 25°C at 500 seconds and increases to 30°C at 2000 seconds. The time delay is 30 seconds. Figure 11 illustrates the step response of both the conventional PID system and the Smith predictor, as well as the fuzzy PID system.

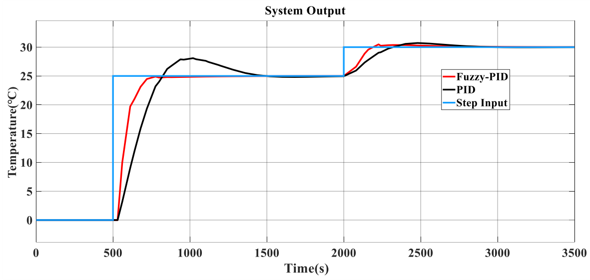


Figure. 11 Temperature simulation curves of fuzzy PID and conventional PID.

When utilizing the Smith predictor and fuzzy PID controller, there is minimal to no overshoot in the system, and the response speed is notably faster compared to the conventional PID controller. The step response for a delay time of 100 seconds is depicted in Figure 12.

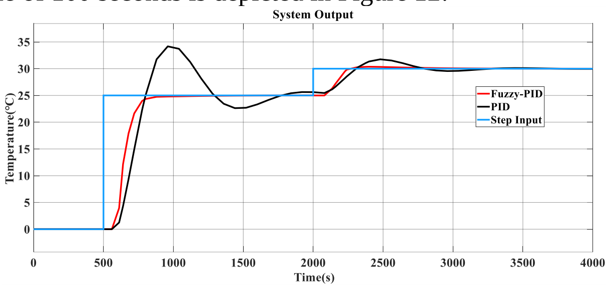


Figure. 12 Temperature simulation curves of fuzzy PID and conventional PID with 100 seconds time delay.

It is evident from the figure that the conventional PID system is significantly impacted by time delay. The overshoot and regulation time increase notably as the delay time increases. In contrast, the system with Smith predictor and fuzzy PID controller demonstrates greater adaptability to time delay. The response curve only exhibits a delay on the timeline, but there is no change in system performance.

Based on the simulation results, it is evident that the Smith predictor and fuzzy PID system offer superior control precision, faster response speed, and effectively mitigate the impact of time delay. This ultimately enhances the dynamic performance of the system.

5 Conclusions

In this paper, a model of the air conditioning system within the tablet workshop is built based on thermodynamic principles and the actual system structure. A cascade PID control system is designed and simulated by the software of MATLAB/Simulink, with PID parameters tuned using attenuation curves. Analysis of response curves and disturbance addition demonstrates that while the system meets basic temperature control requirements, it exhibits slow response times and persistent overshoot.

To address these limitations, a control approach combining fuzzy logic PID and Smith predictor is proposed. Fuzzy rules and universes of discourse are established based on experience in tuning PID parameters. The controller intelligently determines parameters based on error and error rate, resulting in improved response speed, stability, and minimal overshoot during operation. Additionally, the Smith predictor compensates for time delay within the system. The proposed method effectively controls the temperature within the tablet workshop while overcoming limitations associated with conventional PID controllers. Furthermore, this algorithm can be easily implemented on computers and is suitable for air conditioning systems as well as other systems characterized by significant time delays.

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合同编号：

技术开发（委托）合同

项目名称：面向制药过程的数字化关键技术研究

甲方（委托方）：浙江大学台州研究院

乙方（受托方）：浙江大学

签订地点：浙江省杭州市西湖区

执行期限：2023 年 1 月 1 日至 2024 年 12 月 31 日

<table>
<tr><td rowspan="2">本情况（可不填）</td><td>合作情况说明</td><td colspan="3">……药业前期在实验室自动化领域有项目合作，近来在制药生产连续化、自动化装置改造达成合作意向。
（2）与荣耀生物在连续反应釜有关工艺参数的检测及控制领域有深入的交流，并达成项目成果在该公司应用的意向。</td></tr>
<tr><td>联系人</td><td>乐普药业：王海翔，荣耀生物：陈仁尔</td><td>电话/手机</td><td></td></tr>
<tr><td>项目研究内容关键技术技术经济指标研究基础</td><td colspan="4">1. 主要研究内容：

针对目前生物制药企业普遍存在的产检分离、产业数字化程度低等，利用物联网、人工智能和大数据等技术，通过构建药物制剂行业车间关键工艺节点和分析、测试的混合感知系统，初步实现含产品质量、效率等要素的生产态势全息可视化分析；研究生产流程的在线检测、监测多源信息融合技术和生产故障的智能预警技术；基于生产大数据的设备运维优化策略及基于过程分析技术（PAT）和实时发布测试（RTRT）技术的联合质量控制技术，实现生产的稳定和产品质量提升；研究数字孪生技术在试制生产线上的仿真及测试应用，大幅缩短开发周期，降低研发成本。

2. 拟解决的关键技术：
以生物医药产业数字化为核心，围绕典型药企连续性生产的关键技术问题，企业自动化、智能化生产中的信息孤岛问题，以及仿制药生产环节的仿真和一致性分析问题展开研究，并提供解决方案。
拟解决的关键技术包括：
1、确立关键生产工艺点，实施相关生产设备的自动化改造、提升和研发，实现连续生产模式的生产流程再造；
2、实现工艺流程的协同互联，构建以工艺点、生产线和车间级为支撑的生产态势感知网络；
3、构建比较完备的企业资源数字化、协同网络化、产业智能化的技术方案，实现对企业基础设施和资源的数字化、信息化改造；大范围按需动态配置资源、实现产业链上下游在线交易、服务和协同；依据企业发展规律和不同部门的个性化需求深度挖掘和智能配置资源，最终实现产业智能。
4、逐步建立基于数字化构建企业开放价值生态。基于数字化构建产业开放价值生态，更精准挖掘用户需求，更大范围动态整合配置资源及基于网络的产业链协作。

3. 主要技术经济指标：

（1）主要成果指标：
突破生物制造连续生产在线检测的瓶颈问题，构建具有自主知识产权的药物制剂、仿制药、创新药等制造流程的数智管理体系，在实验室数字化 PAT 和 RTRT 融合技术和全质量控制技术领域实现国内引领、国际先进。开发在线</td></tr>
</table>

测试装置两套，研发具有智能算法和优化控制策略的厂级智能管理软件一套；申请发明专利 4 项，发表 SCI/EI 论文 3 篇，培养研究生 3 名。

（2）主要技术指标：

完成在线检测系统两套，环境温度控制精度≤2℃，湿度 40%~70%，实现与药品离线检测相关指标大于 2 个，指标精度与实验室同类指标相关性≥90%；厂级智能管理系统实现至少两个关联生产车间及分析、质控实验室的互联，现场检测点≥30，故障预警响应时间≤1 秒。

（3）主要经济指标：

帮助合作企业提高年产值 6 千万以上，增加利税 500 万以上。

4. 现有研究基础：

项目组成员长期从事控制理论与控制领域的研究工作，先后承担国家 863 项目、国家重点研发项目、国家自然基金项目和工信部智能制造项目，与华为、民丰造纸、虎山集团等有长期合作，在过程控制领域积累了比较丰富的研发经验，曾获得浙江省科技进步奖和教育部科技进步奖，在大数据应用、人工智能技术开发和智能装备等方向取得丰硕的成果。浙江大学电气学院在大数据、智能设备状态评估与运维决策技术、自学习在线控制、分布式多智能体优化控制等方面获得省部级以上科学奖励 8 项，取得了一批国内外领先的研究成果。

二、项目组成员

姓名	性别	年龄	学历	专业	职称	所在院系	在本项目中的分工
颜文俊	男	57	研究生	自动化	教授	电气学院	项目负责人
包哲静	女	48	研究生	控制科学与工程	副教授	电气学院	生产流程自动化
熊奎翔	男	26	博士生	控制理论与应用	博士生	电气学院	算法架构
计博言	男	23	硕士生	控制理论与应用	硕士生	电气学院	控制算法与编程
潘霖烨	男	24	硕士生	电气工程	硕士生	电气学院	测试
黄韬	男	24	硕士生	电气工程	硕士生	电气学院	系统编程