Multivariable Controller Design for Diesel Engine Air System Control

Important note: The due date is 23/11/2025. Late submission is absolutely not allowed as the grades have to be submitted to the department very soon after the final exam. You may work together with your classmates. But do write your report independently. And the results are supposed to be different from each other as the parameters are based upon your matriculation numbers.

1 Background

Over the past several years, government mandated regulations for diesel engine out emissions-specifically oxides of nitrogen (NOx) and particulate matter (PM) - for both on and off-road vehicles have become increasingly stringent, which is shown in Figure 1. This has resulted in many diesel engine manufacturers adding more complexity to the engine systems: more sensors to better measure and/or model what the engine conditions and emissions are at any given time as a function of operating conditions, and more actuators to allow for simultaneous control of additional variables and an increasing number of performance objectives.

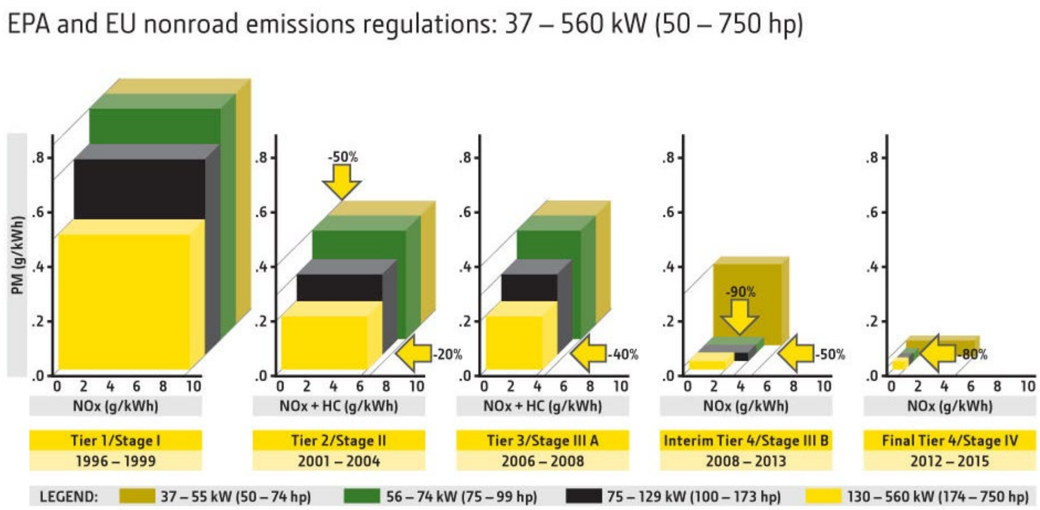

Figure 1 United States Environmental Protection Agency (EPA) emission standards [1]

As diesel engine emissions standards become increasingly stringent, one of the most commonly employed method of emissions reduction by engine manufacturers is active control of inducted air and recirculated exhaust gas (EGR). Commonly, actuators like EGR (Exhaust Gas Recirculation) and VGTs (Variable Geometry Turbochargers) are employed in order to manipulate the flow of gases through a diesel engine to achieve the desired reduction in NOx and PM emissions, as mandated by the US government other governments around the world. A diagram of a common air path layout involving this kind of control strategy is illustrated in Figure 2, where one can see the interactions and internal feedback caused by the EGR loop and turbochargers.

柴油机空气系统控制的多变量控制器设计

重要提示：截止日期为2025年11月23日。严禁迟交，因为成绩必须在期末考试后尽快提交至系里。你可以与同学合作，但报告必须独立完成。由于成绩参数基于学号，各份报告结果应保持差异。

1 背景

近年来，针对柴油发动机排放的政府强制性法规——特别是针对氮氧化物（NOx）和颗粒物（PM）的管控标准，无论是乘用车还是商用车都日趋严格，如图1所示。这一趋势促使众多柴油发动机制造商在系统设计上增加了更多复杂性：通过增设传感器更精准地实时监测和模拟发动机运行状态与排放数据，同时配置更多执行器以实现对新增变量和日益增多的性能指标的同步调控。

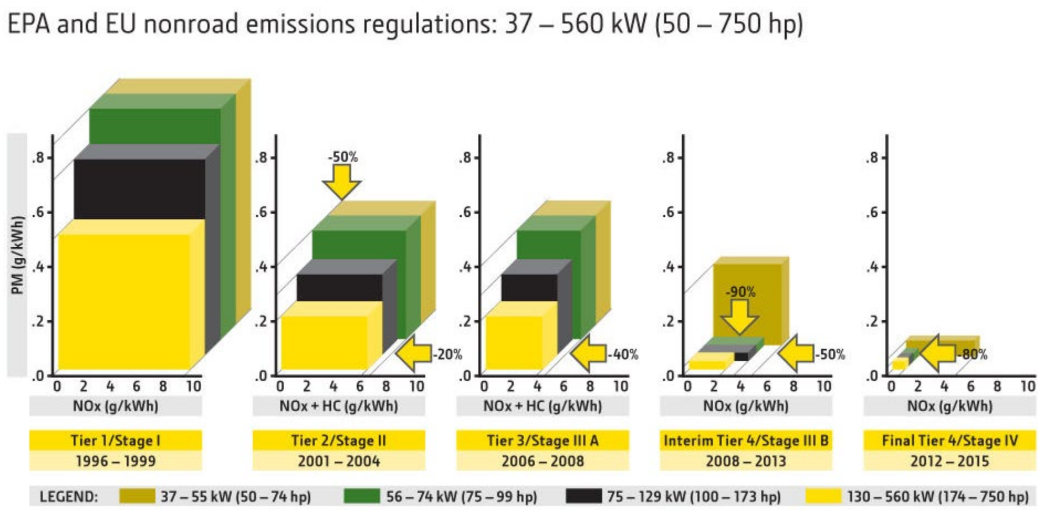

图1美国环境保护局（EPA）排放标准[1]

随着柴油机排放标准日趋严苛，发动机制造商最常用的减排手段之一便是主动控制进气和废气再循环（EGR）。通常采用EGR（废气再循环）和VGT（可变几何涡轮增压器）等执行机构，通过调控柴油机内的气体流动，实现美国政府及全球多国法规要求的氮氧化物（NOx）和颗粒物（PM）排放削减目标。图2展示了这种控制策略的典型空气路径布局示意图，清晰呈现了EGR反馈回路与涡轮增压器之间的动态交互及其内部反馈机制。

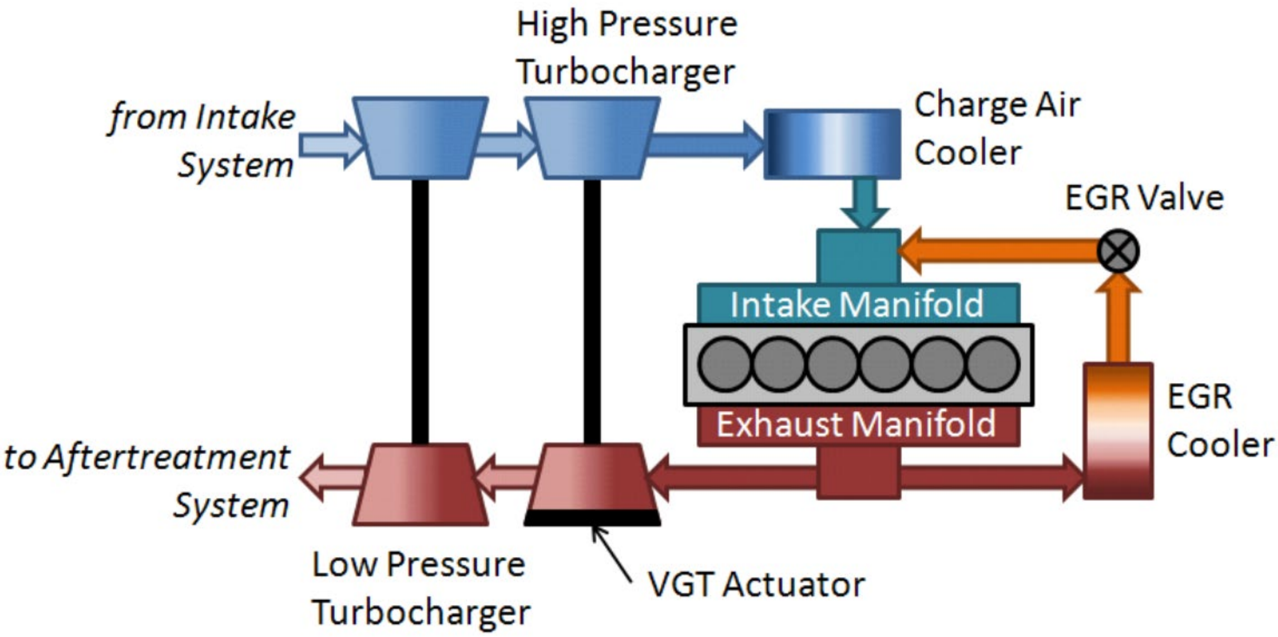

Figure 2 A typical diesel engine system diagram

In practice, the movement of either one of these actuators has a direct impact on the percentage of EGR in the intake manifold as well as the amount of air that can be inducted into the cylinder, resulting in a complex, interactive, multivariable system. Another difficulty of the engine air path control is to balance the engine's customer performance against the mandates of government agencies to reduce emissions, since the introduction of EGR into the air system has a negative impact on the overall fuel economy of the engine. In this mini project, we will model this engine air system as a MIMO linear system and try to control it using the techniques you have learned in *Linear Systems*.

This mini project is adapted from a Master thesis of Iowa State University [2]. To learn more details about the background of this project or the following modeling process, please refer to the complete thesis [2]. You can find its soft copy from NUS library.

2 Modelling

For model-based control, the first step is to build an effective dynamic model for our target plant, i.e., the engine air system in this project. Usually, there are two classes of methods to build a dynamic model, either by first principles or by system identification. For many complex process control applications, it is typically difficult, laborious, and time-consuming to derive a dynamic model from first principle equations. Besides, the acquired non-linear system also requires a significant time for calibration and verification, as well as more advanced control technologies.

Therefore, in the thesis [2], instead of developing a first principles non-linear state-space model of the engine air system, empirical data have been collected from the engine air system, and used to tune a linear fourth order state-space model using the commercially available System Identification Toolbox software of MATLAB. The linearization point selected is the Mode 1 engine certification speed/load operating condition, and this point was selected because it is the point that defines the

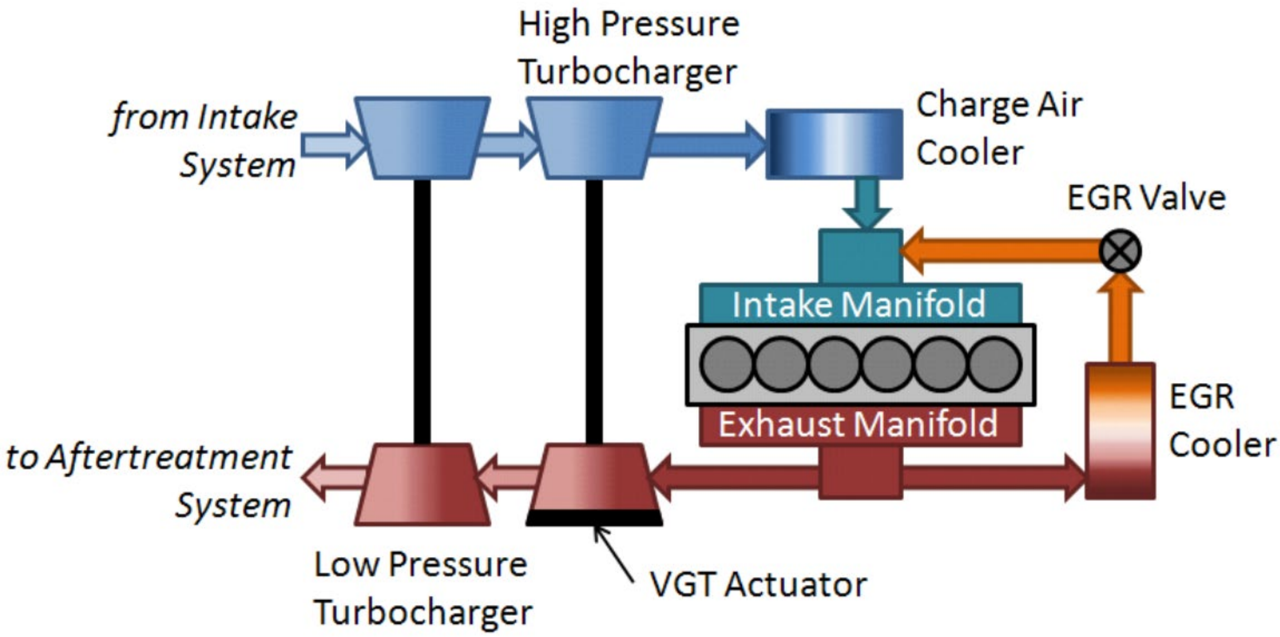

图2一个典型的柴油发动机系统示意图

在实际应用中，这两个执行器的运动都会直接影响进气歧管中EGR的占比，进而改变可吸入气缸的空气量，从而形成一个复杂且相互作用的多变量系统。发动机空气路径控制的另一大难点，在于如何平衡客户对发动机性能的追求与政府机构减排要求之间的矛盾——因为向空气系统引入EGR会降低发动机的整体燃油经济性。在这个小型项目中，我们将把发动机空气系统建模为MIMO维线性系统，并运用*线性系统控制*课程中学到的技术进行调控。

本项目改编自爱荷华州立大学的硕士论文[2]。如需了解项目背景或后续建模流程的更多细节，请参阅完整论文[2]。该论文电子版可在新加坡国立大学图书馆获取。

2 建模

在模型控制领域，首要任务是为目标设备（本项目中的发动机空气系统）建立有效的动态模型。通常有两种建模方法：基于第一性原理的理论建模和系统辨识法。对于许多复杂的工艺控制应用而言，直接从基础方程推导动态模型往往既费时又费力。此外，所获得的非线性系统还需要耗费大量时间进行校准验证，同时还需要采用更先进的控制技术。

因此，在文献[2]的研究中，研究者并未开发基于第一性原理的发动机空气系统非线性状态空间模型，而是直接从该系统采集实测数据，利用MATLAB公司商用系统辨识工具箱软件对四阶线性状态空间模型进行参数优化。选定的线性化基准点是发动机模式1认证速度/负载工况，之所以选择该工况，是因为它正是定义系统特性的关键参数点。

n=4

engine's power rating. The detailed procedures to model this engine system through system identification can be found in [2]. Here we only give the obtained state space model,

$$\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx, \end{aligned} \tag{1}$$

where the manipulated inputs $u = [u_1, \quad u_2]^T$ are the VGT Vane position VGT_{vane} and EGR valve position EGR_{valve} respectively, which as mentioned earlier are common actuators used on diesel engines for air system management and emissions reduction. The outputs $y = [y_1, \quad y_2]^T$ represent the in-cylinder air/fuel ratio (AFR) and intake manifold EGR percentage respectively. Please note that the outputs are not the ratios themselves. The output (or controlled) variables are proprietary modeled incylinder conditions, which correlate well to the previously mentioned in-cylinder air/fuel ratio (AFR) and intake manifold EGR percentage.

Since empirical input/output response data were used to identify the model, the matrices are therefore all full (i.e. all non-zero elements, which is usually not the case for first principles based models) and the states have no direct physical meaning (which is possible as state-space representations are not unique). The obtained system matrices are given as below

$$\begin{aligned}
A &= \begin{bmatrix} -8.8487 + \dfrac{a-b}{5}, & -0.0399, & -5.5500 + \dfrac{c+d}{10}, & 3.5846 \\ -4.5740, & 2.5010 * \dfrac{d+5}{c+5}, & -4.3662, & -1.1183 - \dfrac{a-c}{20} \\ 3.7698, & 16.1212 - \dfrac{c}{5}, & -18.2103 + \dfrac{a+d}{b+4}, & 4.4936 \\ -8.5645 - \dfrac{a-b}{c+d+2}, & 8.3742, & -4.4331, & -7.7181 * \dfrac{c+5}{b+5} \end{bmatrix}, \\
B &= \begin{bmatrix} 0.0564 + \dfrac{b}{10+c}, & 0.0319 \\ 0.0165 - \dfrac{c+d-5}{1000+20a}, & -0.02 \\ 4.4939, & 1.5985 * \dfrac{a+10}{b+12} \\ -1.4269, & -0.2730 \end{bmatrix}, \\
C &= \begin{bmatrix} -3.2988, & -2.1932 + \dfrac{10c+d}{100+5a}, & 0.0370, & -0.0109 \\ 0.2922 - \dfrac{ab}{500}, & -2.1506, & -0.0104, & 0.0163 \end{bmatrix},
\end{aligned} \tag{2}$$

where a, b, c, d represent the last four digits in your matriculation number. For example, if your matriculation number is A0162903M, then $a = 2,\ b = 9,\ c = 0,\ d = 3$, and some parameters in (2) can be computed as follows

发动机的功率等级。通过系统辨识对该发动机系统进行建模的具体方法可参考文献[2]。本文仅给出所获得的状态空间模型。

$$\begin{aligned}\mathbf{x.} &= Ax+Bu \\ y&=Cx,\end{aligned} \tag{1}$$

m=2

其中，被控输入量u=[u 1，u 2]^{T}分别表示VGT$_{水平对置阀}$位置VGT$_{水平对置阀}$位置，如前所述，这类执行器是柴油机用于空气系统管理和排放控制的常用装置。输出量y=[y 1，y 2]^{T}分别对应气缸内空燃比（AFR）和进气歧管氧浓度（EGR百分比）。需要说明的是，这些输出量并非空燃比或氧浓度的直接数值，而是经过建模处理的气缸内部工况参数，与前述气缸空燃比（AFR）和进气歧管氧浓度（EGR百分比）具有良好的对应关系。

由于采用经验输入/输出响应数据进行模型辨识，因此所有矩阵均为满矩阵（即所有非零元素，这通常不适用于基于第一性原理的模型），且各状态均无直接物理意义（由于状态空间表示具有非唯一性，这种情况是可能的）。所得系统矩阵如下所示。

$$A=\begin{bmatrix} -8.8487+\dfrac{a-b}{5}, & -0.0399, & -5.5500+\dfrac{c+d}{10}, & 3.5846 \\ -4.5740, & 2.5010*\dfrac{d+5}{c+5}, & -4.3662, & -1.1183-\dfrac{a-c}{20} \\ 3.7698, & 16.1212-\dfrac{c}{5}, & -18.2103+\dfrac{a+d}{b+4}, & 4.4936 \\ -8.5645-\dfrac{a-b}{c+d+2}, & 8.3742, & -4.4331, & -7.7181*\dfrac{c+5}{b+5} \end{bmatrix},$$

$$B=\begin{bmatrix} 0.0564+\dfrac{b}{10+c}, & 0.0319 \\ 0.0165-\dfrac{c+d-5}{1000+20a}, & -0.02 \\ 4.4939, & 1.5985*\dfrac{a+10}{b+12} \\ -1.4269, & -0.2730 \end{bmatrix}, \tag{2}$$

$$C=\begin{bmatrix} -3.2988, & -2.1932+\dfrac{10c+d}{100+5a}, & 0.0370, & -0.0109 \\ 0.2922-\dfrac{ab}{500}, & -2.1506, & -0.0104, & 0.0163 \end{bmatrix},$$

其中*a*、*b*、*c*、*d*分别是您的学号最后四位数字。例如，如果您的学号是A0162903M，则a=2，b=9，c=0，d=3，(2)式中的部分参数可按如下方式计算

我的学号：A0318401R
a = 8, b = 4, c = 0, d = 1

$$2.5010*\frac{d+5}{c+5}=2.5010*\frac{3+5}{0+5}=4.0016,$$
$$0.2922-\frac{ab}{500}=0.2922-\frac{2\times 9}{500}=0.2562, \quad (3)$$
$$0.0165-\frac{c+d-5}{1000+20a}=0.0165-\frac{0+3-5}{1000+20*2}=0.0184.$$

Note that in the model (1), the four state variables x have no physical meaning since they are determined by system identification. Therefore, in reality these state variables cannot be measured directly. However, for the purpose of control system design practice in this mini project, we may assume the state variables can be measured with some sensors in specific questions of next part.

3 Control System Design

After all, we get a linear state space model (1) for the engine air system. In the following, different control strategies will be explored to achieve control of this system. We will target both the regulation and set point tracking problems. The initial condition for this system is assumed to be $x_0 = [0.5,\ -0.1,\ 0.3,\ -0.8]^T$.

3.1 Design specifications

The transient step response performance specifications for all the outputs y in state space model (1) are as follows:

1) The overshoot is less than 10%.
2) The 2% settling time is less than 20 seconds.

Note: (a) This transient response is checked by giving a step reference signal for each input channel, i.e., [1, 0] and [0, 1], with zero initial conditions; (b) For all the following task 1) to 5), your control system should satisfy this performance specification and you are supposed to finish the required investigation for each task as well.

3.2 Tasks

Your study should include, but not limited to

1) Assume that you can measure all the four state variables, design a state feedback controller using the pole place method, simulate the designed system, check the step responses and show all the four state responses to non-zero initial state with zero external inputs. Discuss effects of the positions of the poles on system performance, and also monitor control signal size. In this step, both the disturbance and set point can be assumed to be zero. (15 points)
2) Assume that you can measure all the four state variables, design a state feedback controller using the LQR method, simulate the designed system, check the step responses and show all the state responses to non-zero initial state with zero external inputs. Discuss effects of weightings Q and R on system performance, and also monitor control signal size. In this step, both the disturbance

$$
\begin{aligned}
&2.5010*\frac{d+5}{c+5}=2.5010*\frac{3+5}{0+5}=4.0016,\\
&0.2922-\frac{ab}{500}=0.2922-\frac{2\times 9}{500}=0.2562, \qquad (3)\\
&0.0165-\frac{c+d-5}{1000+20a}=0.0165-\frac{0+3-5}{1000+20*2}=0.0184.
\end{aligned}
$$

注意在模型(1)中，x这四个状态变量没有物理意义，因为它们是由系统辨识确定的，因此在现实中这些状态变量不能直接测量，但是为了本小项目的控制系统设计实践的目的，在下一部分的某些问题中，我们可以假设状态变量可以用一些传感器来测量。

3 控制系统设计

毕竟，我们得到了发动机空气系统的线性状态空间模型(1)。在接下来的章节中，我们将探索不同的控制策略来实现对该系统的控制。我们将同时解决调节和设定点跟踪问题。假设该系统的初始条件为x_0=[0.5，-0.1，3，-0.8]^T。

3.1 设计规范

状态空间模型(1)中所有输出y的瞬态阶跃响应性能规范如下：

1) 超调量小于10%。
2) 2%沉降时间小于20秒。

注：(a)通过为每个输入通道施加阶跃参考信号（即[1,0]和[0,1]），在初始条件为零的情况下验证瞬态响应；(b)对于后续任务1)至5)，您的控制系统需满足该性能规范，并完成每个任务的必要研究。

$\dot{x}=Ax+Bu=(A-BK)x$ $\quad K=\begin{bmatrix} K_{11} & K_{12} & K_{13} & K_{14}\\ K_{21} & K_{22} & K_{23} & K_{24}\end{bmatrix}$

$n\times m \to 4\times 2$

$r=[1,0]$ or $[0,1]$

$\dot{x}=(A-BK)x+r$

3.2 任务

您的研究应包括，但不限于 x_1, x_2, x_3, x_4 $\quad u=-Kx$

r: step response

$F=I$

1) 假设可以测量所有四个状态变量，使用极点位置法设计状态反馈控制器，对设计的系统进行仿真，检查阶跃响应，并显示所有四个状态在非零初始状态和零外部输入下的响应。讨论极点位置对系统性能的影响，并监测控制信号的幅值。在此步骤中，可以假设扰动和设定值均为零。（15分）

reference input $=0$

$\Rightarrow r=0$

$u=-Kx+F\cdot 0$
$=-Kx$

2) 假设能够测量全部四个状态变量，采用LQR方法设计状态反馈控制器，对系统进行仿真，分析阶跃响应特性，并展示初始状态非零且外部输入为零时的全部状态响应。重点探讨Q和R系数对系统性能的影响，并实时监测控制信号的幅值变化。在此过程中，需同时考虑扰动

and set point can be assumed to be zero. (15 points)

3) Assume you can only measure the two outputs. Design a state observer, simulate the resultant observer-based LQR control system, monitor the state estimation error, investigate effects of observer poles on state estimation error and closed-loop control performance. In this step, both the disturbance and set point can be assumed to be zero. (15 points)

4) Design a decoupling controller with closed-loop stability and simulate the step response of the resultant control system to verify decoupling performance with stability. In this question, the disturbance can be assumed to be zero. Is the decoupled system internally stable? Please provide both the step (transient) response with zero initial states and the initial response with respect to x_0 of the decoupled system to support your conclusion. (20 points)

5) In an application, the operating set point for the two outputs is

$$y_{sp} = [0.4, 0.8]^T.$$

Assume that you only have two sensors to measure the output. Design a controller such that the plant (the diesel engine system) can operate around the set point as close as possible at steady state even when step disturbances are present at the plant input. Plot out both the control and output signals. In your simulation, you may assume the step disturbance of magnitude $w = [0.3, 0.2]^T$ takes effect from time $t_d = 10s$ afterwards. (20 points)

6) To make things more interesting, suppose we intend to regulate the four state variables directly instead of the two outputs. Our target is to maintain the states x around a given set point $x_{sp} = [0, 0.5, -0.4, 0.3]^T$ at steady state. Is it possible? In this question, you may assume all the state variables can be measured and there are no disturbances. (10 points)

   (a) If your answer is YES, please detail your control system design strategy to ensure x to be x_{sp} at steady state and demonstrate its effectiveness through simulation.

   (b) If your answer is NO, explain why. In such a case, we may only want to keep the state variables at steady state close enough to the set point x_{sp}. However, in practice, we usually place different emphasis on the exactness of the four state variables. To address our purpose quantitively, we aim to minimize the following objective function

$$J(x_s) = \frac{1}{2}(x_s - x_{sp})^T W (x_s - x_{sp}), \tag{4}$$

   where $W = diag(a+1, b+1, c+1, d+1)$ is a diagonal weight matrix and x_s is the state vector at steady state. Here, a, b, c, d are still the last four digits in your matriculation number, as defined above. Please detail your control system design strategy to minimize the objective $J(x_s)$ at steady state and demonstrate its effectiveness through simulation.

Note that there are no unique answers to all the above design questions. For the tasks in our

并假设设定点为零。（15 points）

3) 假设你只能测量两个输出量，设计一个状态观测器，仿真基于观测器的LQR控制系统，监测状态估计误差，研究观测器极点对状态估计误差和闭环控制性能的影响。在此步骤中，可以假设扰动和设定值均为零。（15分）

4) 设计一个具有闭环稳定性的解耦控制器，并通过仿真验证该控制系统在解耦性能与稳定性的综合表现。本题假设扰动为零。解耦后的系统是否具备内部稳定性？请分别提供初始状态为零时的阶跃响应（瞬态响应）以及初始响应的对比分析。
用解耦系统x_0来支持你的结论。（20分）

5) 在应用中，两个输出的设定值为

$$y_{sp}=[0.4,0.8]^T。$$

假设你仅有两个传感器来测量输出量。设计一个控制器，使得被控对象（柴油机系统）即使在输入端存在阶跃扰动的情况下，也能在稳态下尽可能接近设定值运行。绘制控制信号和输出信号的波形图。在仿真过程中，可以假设阶跃扰动的幅值w=[0.3,0.2]^{T}从t $_d$= 10 s后开始作用。（20分）

6) 为增加趣味性，假设我们打算直接调节四个状态变量，而非仅控制两个输出。我们的目标是在稳态下保持状态变量x以x_{sp}=[0,0.5，−0.4,0.3]^{T}为基准点。这是否可行？在此问题中，你可以假设所有状态变量均可被测量且不存在干扰。（10分）

(a) 如果您的回答是肯定的，请详细说明您的控制系统设计策略，以确保x在稳态下为x $_{sp}$，并通过模拟证明其有效性。

(b) 若答案为否，请说明原因。此时，我们可能只需保持状态变量在稳态下接近设定值x $_{sp}$。但实际操作中，我们通常对四个状态变量的精确度重视程度不同。为量化实现目标，我们旨在最小化以下目标函数

$$J(x_s)=\frac{1}{2}(x_s-x_{sp})^T W(x_s-x_{sp}), \tag{4}$$

其中W=diag（a+1，b+1，c+1，d+1）是对角权重矩阵，x $_s$为稳态下的状态向量。这里a、b、c、d仍是你学号的最后四位数字（如上定义）。请详细阐述控制系统设计策略，以最小化稳态下的目标函数J（x $_s$），并通过仿真验证其有效性。

请注意，上述所有设计问题均无唯一答案。对于我们的任务

project, you can assume that the control input is unlimited. However, in practice all the physical actuators can only provide a limited drive capacity. You need to make your own judgement assuming you are the engineer responsible for the control system design in the real world. There are three major factors you should consider when you design and justify your controller:

- Speed --- Transient response
- Accuracy --- Steady state error
- Cost ---- Size of the control signals

Please do follow the design procedures you have learned in *linear systems* to solve all the above questions. List the necessary formulas and intermediate results in your report. If you only call the MATLAB built-in functions for control system design with no details, for example, simply use *place* to place poles or *lqr* to design the LQR regulator, you will get ZERO marks.

4 Reference

[1] *Understanding Emission Regulations*. https://www.deere.com/en_US/services_and_support/engine-information/understanding-emission-regulations/understanding-emission-regulations.page.

[2] Humke, Daniel A. *Analysis of multivariable controller designs for diesel engine air system control*. Diss. Iowa State University, 2013.

5 Format of Reports

Your report should mainly contain the plant description, control and observer design method description, your design details, simulation results, possible comparison, comments and discussion, modification and refinements.

The report should include the following and be organized in the following sequence:

- A cover paper to indicate "Assignment for EE5101/ME5401 (or your specialization code if else) Linear Systems", a title of your report at your choice, your full name, your Matriculation number, email address and date;
- An abstract of 50-100 words on a separate page;
- A contents table on a separate page;
- Section 1 Introduction
- The major materials of your report organized nicely in a few sections each with specific focus. Label your equations, tables, and figures with number and caption for reference in the text. Your figure size and figure quality should be high enough to facilitate the verification of your results.
- The last section on conclusions.

在理想情况下，控制输入可以视为无限量。但现实中所有物理执行器的驱动能力都存在限制。作为控制系统设计工程师，您需要根据实际情况做出专业判断。在控制器设计与论证过程中，需重点考量以下三大要素：

- 速度-瞬态响应
- 准确度——稳态误差
- 成本——控制信号的大小

请按照*线性系统*的设计流程来解决上述所有问题。在报告中列出必要的公式和中间结果。如果只是调用MATLAB的内置函数进行控制系统设计而没有详细说明，例如，只是简单地用*place*来放置极点或者用*lqr*来设计LQR调节器，那么你将得到零分。

4 参考

[1] *了解排放法规*。https://www.deere.com/en_US/services_and_support/e ngine-information/understanding-emission-regulations/understanding-emission-regulations.page.

[2] 丹尼尔·A·汉克。*柴油发动机空气系统控制多变量控制器设计分析*。爱荷华州立大学，2013*年*。

5 报告格式

报告应主要包括：工厂描述、控制和观测器设计方法描述、设计细节、模拟结果、可能的比较、评论和讨论、修改和改进。

报告应包括以下内容，并按以下顺序组织：

- 一份封面纸，注明“EE5101/ME5401课程作业（或如适用，请注明专业代码）线性系统”，报告标题自定，需填写全名、学号、电子邮箱及日期；
- 另页写50-100字的摘要；
- 另一页的内容表；
- 第1节引言
- 报告的主要内容应组织成几个重点部分，每个部分都有明确的焦点。请为公式、表格和图表添加编号和图注以便在正文中引用。图表的尺寸和质量应足够高，以便于验证你的结果。
- 最后一节是结论。

- A list of reference books/papers if any;
- Appendices if any each on a separate page. Your MATLAB code should be in this appendix. If you use Simulink, a screenshot of your Simulink model should be inserted at proper position in the above major materials part as figures.

Pay attention to your presentation (English writing, organization, and layout et al). Make the report formal, complete and readable. It is also advisable to write your report with a word-processing software such as Word or LaTeX.

The final point to note about your report: it is the content that matters not the length. Keep in mind that there are only TWENTY SEVEN pages in John Nash's PhD thesis, which leaded to his Nobel Prize. Therefore, you will be penalized if you put too much "copy and paste" material in your report.

6 A Note on Access and Use of MATLAB

To complete the project, you are supposed to use SIMULINK and MATLAB. The easy way is to learn how to build various block diagrams in SIMULINK first, and then try to solve the control systems design for the mini-project. An excellent *Control Tutorial for MATLAB and Simulink* can be found at http://ctms.engin.umich.edu/CTMS/index.php?aux=Home. Besides, a Matlab manual is provided in CANVAS for the first timers.

If you don't have MATLAB on your PC currently, you can access MATLAB in either of the following two ways:

1) Go to PC clusters located at the third floor of E2: http://www.eng.nus.edu.sg/eitu/pc.html.
2) Download MATLAB from NUS information technology center: every NUS student can have a license. https://nusit.nus.edu.sg/services/software_and_os/software/software-student/#install-matlab.

Hint on MATLAB/SIMULINK:

A. You can use functions such as *step*, *initial* and *lsim* to simulate the system's corresponding response. Also, all these simulations can be done with SIMULINK.
B. In some cases, it may be easier to use SIMULINK for the simulation, for example, question 5).

- 如有，应提供参考书目/论文清单；
- 附录（如有）应单独成页，MATLAB代码需包含在该附录中。若使用Simulink，需将Simulink模型的截图作为图示插入到上述主要材料部分的适当位置。

注意你的演示文稿（英文写作、组织和布局等）。使报告正式、完整且易于阅读。建议使用Word或LaTeX等文字处理软件撰写报告。

关于你的报告，最后一点需要注意：内容才是关键，而不是篇幅。请记住，约翰·纳什的博士论文只有27页，而这篇论文最终为他赢得了诺贝尔奖。因此，如果你在报告中大量使用“复制粘贴”的内容，将会受到扣分。

6 关于访问和使用MATLAB的说明

要完成这个项目，你需要使用Simulink和MATLAB。最简单的方法是先学习如何在Simulink中构建各种方框图，然后尝试解决这个小型项目中的控制系统设计。*一个优秀的MATLAB和Simulink控制教程*可以在http://ctms.engin.umich.edu/CTMS/index.php？aux=Home上找到。此外，Canvas平台还为初学者提供了Matlab使用手册。

如果您的电脑上目前没有安装MATLAB，可以通过以下两种方式访问MATLAB：

1) 前往E2楼三楼的PC集群：http://www.eng.nus.edu.sg/eitu/pc.html。
2) 从新加坡国立大学信息技术中心下载MATLAB：每位新加坡国立大学学生都可以获得一个许可证。https://nusit.nus.edu.sg/services/software_and_os/software/software-student/#install-matlab。

MATLAB/simulink提示：

A. 您可以使用*step*、*initial*和*lsim*等函数来模拟系统相应的响应。所有这些模拟都可以用simulink完成。

B. 在某些情况下，使用Simulink进行仿真可能更为便捷，例如第5题。