剑桥大学“Learning X”
“机器学习：从基础到提高”线上科研项目

学校简介 Introduction

麻省理工学院（Massachusetts Institute of Technology），位于美国马萨诸塞州波士顿都市区剑桥市，主校区依查尔斯河而建，是世界著名私立研究型大学。麻省理工学院创立于1861年，早期侧重应用科学及工程学，在第二次世界大战后，麻省理工学院倚靠美国国防科技的研发需要而迅速崛起。 在二战和冷战期间，麻省理工学院的研究人员对计算机、雷达以及惯性导航系统等科技发展作出了重要贡献。

2019-20年度位列QS世界大学排名第一、U.S. News世界大学排名第二、软科世界大学学术排名（ARWU）第四、泰晤士高等教育世界大学排名第五；2019-20 年度位列《泰晤士高等教育》世界大学声誉排名世界第二。2021年位列QS世界大学排名第一。

剑桥大学是一所世界顶尖的公立研究型大学，与牛津大学并称为牛剑，被誉为“金三角名校和“G5 超级精英大学”。 2020-21 年度位居世界大学学术排名第 3，QS 世界大学排名第 7。截止 2020 年 10 月，共有 121 位诺贝尔获奖者、15 位英国首相、11 位菲尔兹奖得主、7 位图灵奖得主曾为此校的師生、校友或研究人员。

项目背景 Program Background

项目将由来自剑桥大学计算机科学与技术的终身教授和计算机专业排名前列的麻省理工学院的博士生的指导下进行，介绍基本机器学习理论和前沿的机器学习研究。课程内容除了理论学习外，还提供以 project-based learning 为形式的项目设计和论文写作指导。学生的项目将由麻省理工学院的博士生亲自指导，过程中学生将学习编程语言（如：Python），数据处理，机器学习模型（如 CNN，LSTM）实现，从而完成从理论到实践的完整学习过程。

项目介绍 Program Description

学生将在项目中学习机器学习的理论和方法，了解并且掌握 Python 在机器学习中的应用。学生将在项目结束时，自选框架和问题，使用 Python 完成机器学习相关的课程项目，提交项目论文，进行成果展示。优秀的项目论文将在导师的指导下进行论文发表。

项目内容涉及机器学习核心理论和技能，学生将首先学习机器学习的基础理论：具体包括线性分类器的原理，数据的特征表示，逻辑回归（logistic regression）的原理，线性回归的原理和解释性，梯度下降和随机梯度下降算法，神经网络（neural network），卷积神经网络（convolutional neural network），循环神经网络（recurrent neural network），马尔可夫决策过程（Markov decision process）和强化学习（reinforcement learning）。在了解基础理论后，学生将学习前沿的机器学习模型，包括注意力模型（Transformers）, 图神经网络（graph neural networks）, 生成对抗网络（generative adversarial networks），深度强化学习

（deep reinforcement learning）,可解释机器学习（ explainable machine learning），以及最新的来自计算机领域顶级会议的论文（如： NeurIPS, ICML, AAAI）。

线上课程将使用 Canvas 在线课程平台与微信实时交流平台相结合的形式，实现专业的课程信息发布、 课程资料共享、课程进度跟踪和及时的学生答疑。

导师介绍 Instructor Introduction

剑桥大学计算机科学与技术终身教授

导师持有欧洲学习和智能系统实验室（Ellis；欧洲大型跨国人工智能研究所，目前拥有千位全球顶尖计算机工程师、数学家和其他领域科学家，旨在重构欧洲人工智能前沿研究）席位、剑桥大学大数据研究指导委员会席位。导师的研究兴趣为人工智能图神经网络建模，在国际知名学术期刊发表论文多篇，曾荣获欧盟委员会未来与新兴技术（FET；迄今欧盟规模最大、资助力度最强的科研资助项目之一）会展三等奖。

麻省理工学院博士生导师

导师是麻省理工学院的计算机科学的博士，并拥有麻省理工学院运输和计算机科学双硕士学位。在加入麻省理工学院之前，获得清华大学土木工程系学士学位，并获得清华总统奖学金。

导师的主要研究兴趣是数据驱动的运输模型，需求模型和应用机器学习。

项目大纲 Syllabus

第一部分：机器学习基础理论：

- **机器学习理论综述（Introduction to machine learning）**：理解机器学习的基本框架，包括：监督学习（分类、回归）、无监督学习（聚类，密度估计、降维）、强化学习、序列学习（sequence learning）。理解常用概念：损失函数、训练与预测规则、模型类别与参数估计。介绍最简单的线性分类器。
- **特征表示（Feature representation）**：数据的特征，不同类别的数据处理方法（离散、连续、文字数据）、数据标准化。简单的数据分析技巧（最值、异常值、绘制分布），理解数据之间的相关性。了解数据降维与数据可视化。课堂编程进行数据分析。
- **逻辑回归（Logistic regression）和梯度下降算法**：了解 Logistic regression 的原理，包括目标函数，sigmoid function，分类原理，优化目标，l1/l2 penalty。理解梯度下降算法的原理及其在 logistic regression 中的应用，了解随机梯度下降（SGD）。
- **线性回归（Linear regression）和随机梯度下降**：理解线性回归的原理、线性回归的解析解、模型的可解释性。理解几个的正则项对回归问题的影响（ridge regression，lasso regression）。使用 python 进行课堂编程，学会解释线性回归模型。
- **神经网络（Neural network）**：理解神经网络模型的原理，包括基本单元、层、激活函数、反向传播算法、梯度计算、模型训练、损失函数、模型参数调整、正则项、batch normalization。

- **卷积神经网络（Convolutional neural network）:** 理解卷积神经网络的计算，一维、二维、三维卷积，filter 的定义，padding，max pooling 操作，反向传播算法在 CNN 中的梯度计算，CNN 梯度的矩阵表示。
- **马尔可夫决策过程与强化学习（Markov decision process and reinforcement learning）：** 状态机器（state machine），马尔可夫决策过程（MDP），状态转移函数，Value function， Value iteration，Q-learning，Bellman equation，Temporal difference updating。
- **循环神经网络（Recurrent neural network）：** Text prediction，RNN 的基本框架和计算原理，反向传播算法在 RNN 中的梯度计算，长短期记忆网络（LSTM）介绍。

第二部分：机器学习理论前沿：

- **生成对抗网络（generative adversarial networks，GAN）：** GAN 的原理，生成器(Generator) 判别器(Discriminator)，GAN 的训练方法，GAN 在图像生成中的应用。
- **注意力模型与 Transformers**：Encoder-Decoder 框架，Attention Model，注意力机制的原理，Soft/Hard Attention Model，注意力模型的解释性，计算方法和原理。Multi-head self-attention and transformer, encoder and decoder for transform, transformer for image processing。
- **图神经网络（Graph neural network）：** 各类图神经网络的原理，包括：图卷积网络（Graph Convolution Networks，GCN）、 图注意力网络（Graph Attention Networks）、图自编码器（ Graph Autoencoders）、图生成网络（ Graph Generative Networks） 和图时空网络（Graph Spatial-temporal Networks）。图神经网络的应用。
- **深度强化学习（Deep Reinforcement Learning）：** Deep Q-learning，Policy gradient, Actor-critic algorithm，Asynchronous Advantage Actor-Critic (A3C)。

第三部分：辅导课：

- **Python 的安装使用与环境配置:** Python 和 Anaconda 的关系，软件安装，python 库的安装，jupyter notebook 的安装与介绍，pycharm 的安装和介绍。
- **如何撰写学术论文：** 学术论文写作原则，如何选择期刊，影响因子的计算，期刊多种评价指标，如何寻找期刊排名和索引，学术论文的框架，如何进行文献综述，如何查找关联文献。如何使用 overleaf（latex）进行写作。
- **GitHub 的使用：** 如何使用 GitHub 进行代码版本管理，如何使用 GitHub 与他人合作编程。
- **使用 Python 构建机器学习模型：** 使用 python 进行数据处理，数据可视化（pandas 和 matplotlab 的使用），构建就按单的逻辑回归，线性回归模型（sklearn），学会解释线性模型的结果。
- **使用 Python 构建深度神经网络（NN, CNN，LSTM）:** pytorch 与 tensorflow 的使用，构建简单的神经网络，构建卷积神经网络，构建长短期记忆网络。
- **使用 Python 建立强化学习模型：** 使用 python 实现 Q-learning 算法，在二维路径寻找游戏中训练智能体，可视化强化学习模型的结果。

课程作业（Homework）：

- 每周会由导师根据课程内容布置课程作业。
- 作业主要目的为帮助学术理解课堂所学的概念，每次作业 3-4 小题，包括计算题、问答、综述等，预计完成时间为两小时。

课程项目（Group project）：

- 以小组（每组 3-4 人）为单位进行课程项目，构建机器学习模型。
- 第一周：组队报名
- 第二周：提交项目计划（一页纸）
- 第三到五周：文献综述、数据处理、编程完成课程项目，准备需要的写作材料（如：绘图、表，方法论公式）、制作 PPT 或海报。
- 第六周：课堂口头展示、海报
- 第七周：课程论文写作（不超过 8 页）与提交。

课程评分标准（Grading policy）：

- 签到（10%）：按时参加每次课程和辅导课。
- 课程作业（40%）
- 课程项目（50%）：其中项目计划 10%，口头或海报展示 20%，课程论文 20%
- 额外奖励（Bonus, 10%）:上课积极回答问题与互动，课后提问等。

项目成果

- **一篇由学生独立完成的英文学术论文**（优秀的论文可在导师的指导下进行论文发表）。
- **推荐信**：由剑桥大学教授与麻省理工学院导师亲笔签名的私人学术推荐信；提高保研和留学申请的软实力。
- **结业证书**：包含个人名字和教授签名
- **成绩单**：包含个人名字、详细的课程各部分评分、课程介绍等。
- **优秀小组奖状**：授予课程项目最出色的小组，包含个人名字和教授签名。

项目报名

- **时间**：每年 1 月、2 月或者 7 月、8 月（具体时间待定）
- **费用**：9980 元/学生
- **专业定制**：40 人/班
- **专业要求**：计算机科学、人工智能、数据科学、电子与计算机工程等专业，软件工程、自动化等相关专业或者希望掌握强化学习的学生；对人工智能、大数据以及交叉学科和方向感兴趣的学生；掌握微积分、线性代数，有一定的概率论、优化和编程基础。
- **报名步骤**
    - 第一步：扫码在线填写报名信息

- 第二步：缴纳项目费用，签署项目协议
- 第三步：等待项目组开课通知

- **联系方式**
  - 李老师手机号码：17186457932
  - 李老师 QQ 号：1814958113

往期项目概况：

线上课程项目使用基于美国大学教务平台，**实现专业的课程信息发布、课程资料共享、课程进度跟踪、作业批改和及时的学生答疑**。每次课前，授课老师都会把需要用到的课程 PPT，课程注释（Lecture notes），参考文献，示例代码上传到教务平台，供学生下载预习。每节课后，学生可通过教务平台发布问题，授课老师可在平台上浏览问题并回答。

除了教务平台外，Learning X 课程管理团队也会组建微信群，群内有专业的课程助教和负责部分授课的 MIT 博士生，随时解答同学疑问。

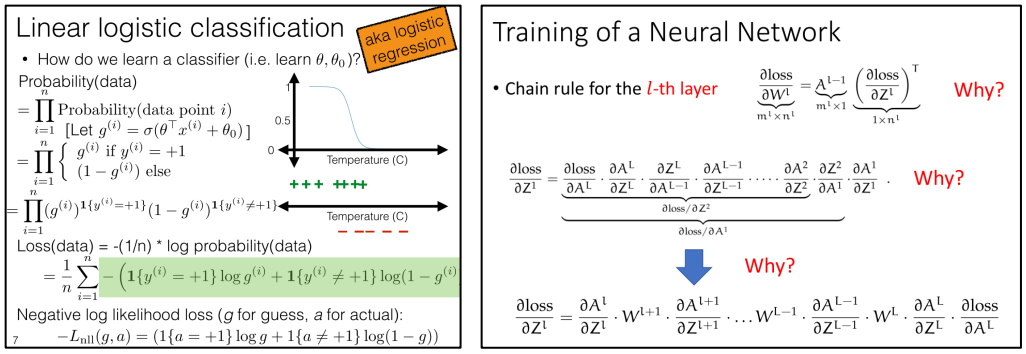


图 1：课程基础理论部分课件展示

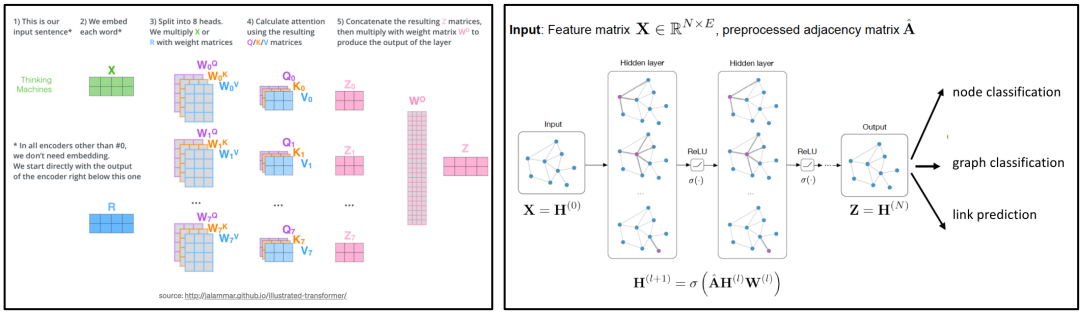


图 2：课程前沿探索部分课件展示

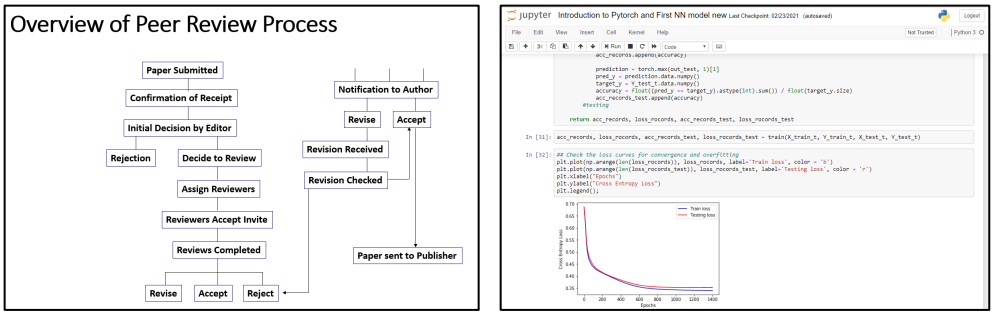


图 3：辅导课部分课件展示

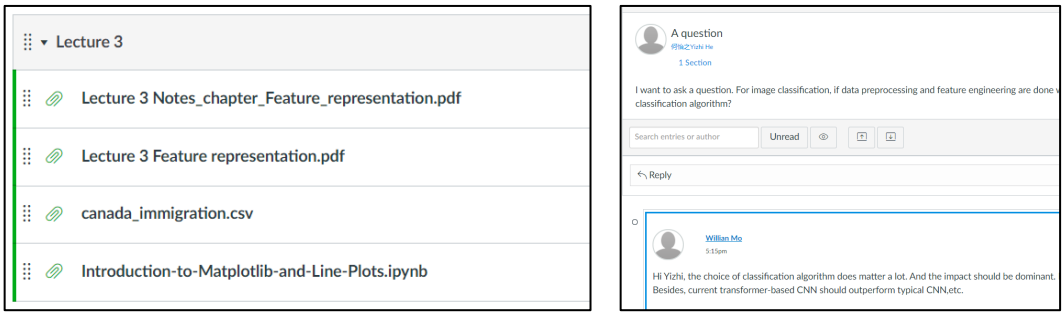


图 4：教育平台课程管理展示

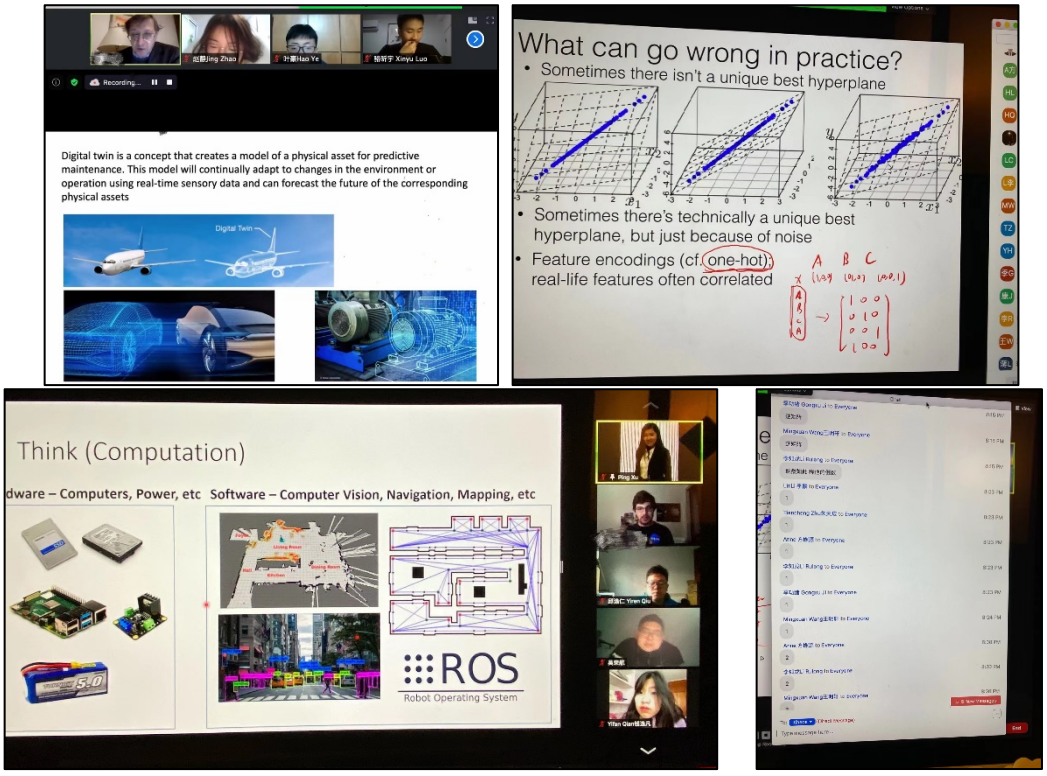


图 4：授课过程展示

2. What is the end goal of an agent?
Agents are software programs that make intelligent decisions. They are basically reinforcement learners. The ultimate goal of proxy is to maximize the expectation of this long-term return for each state.

3. What are the main differences between supervised learning and RL?
Supervised learning: provide data, predict tags. For example, predict the pictures of animals, cats and dogs, and predict the label as cat or dog.
RL: Compared with supervised learning, reinforcement learning has lower cost but higher accuracy. It uses the data with and without class labels to generate appropriate classification functions. It uses unlabeled data, but reinforcement learning algorithm to learn whether closer to the target, I understand as incentive and penalty function. Similar to life, girlfriends constantly adjust straight boyfriend into a warm man.

4. What are the benefits of combining deep learning and RL?
In traditional reinforcement learning, when the state and action space are discrete and the dimension is not high, q-table can be used to store the Q value of each state action pair. However, the more complex task which is closer to the actual situation often has a large state space and continuous action space. In this case, using q-table is not realistic. At the same time, the realization of end-to-end control is also required to be able to process high-dimensional data input, such as image, sound and so on. Deep learning can just cope with high-dimensional input. If the two can be combined, the agent will have the ability of understanding deep learning and decision-making ability of reinforcement learning at the same time.

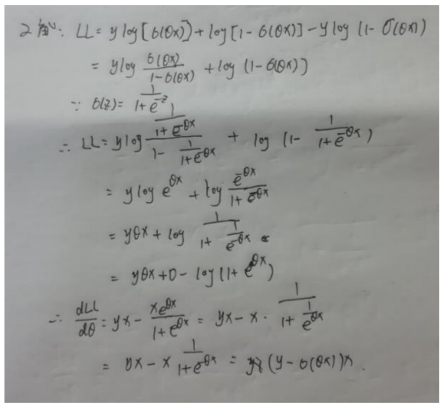
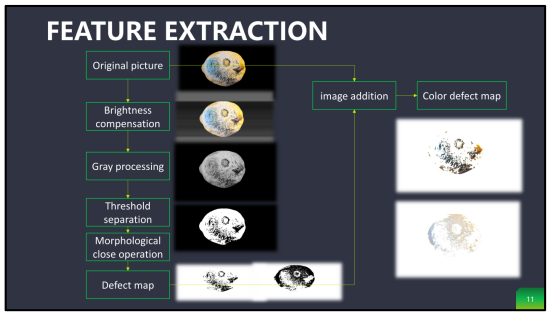
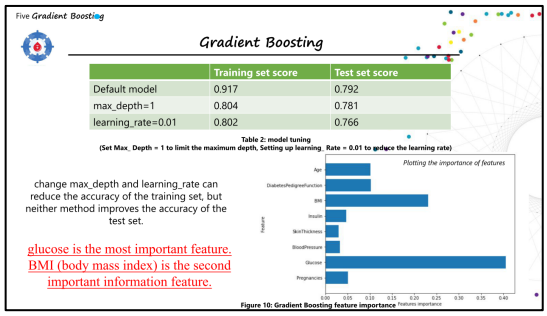
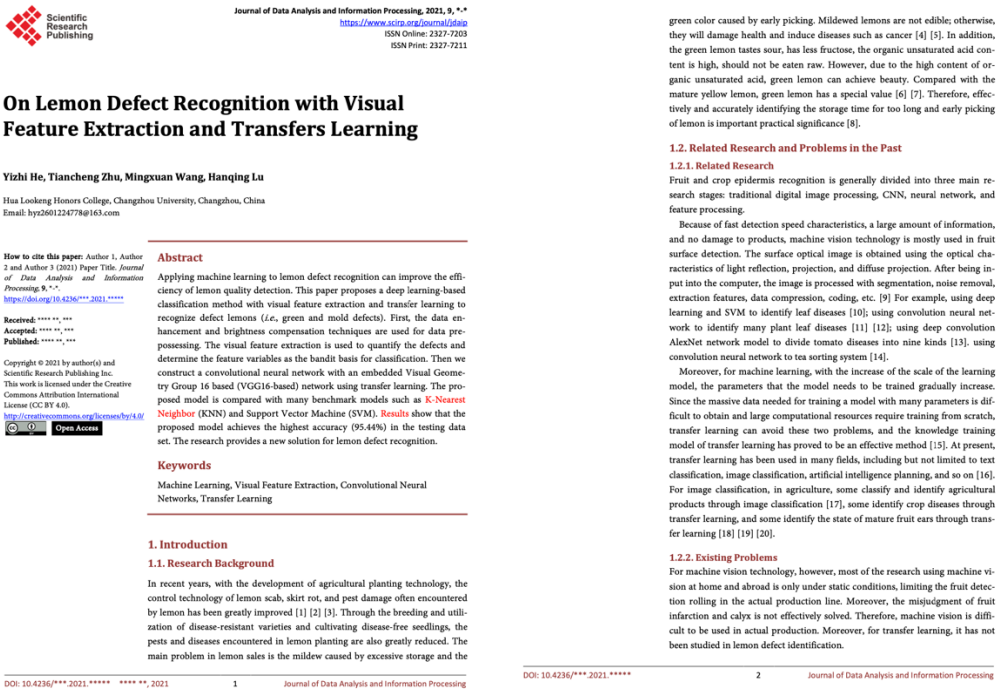


图 6：部分作业展示







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On Lemon Defect Recognition with Visual Feature Extraction and Transfers Learning

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Abstract

Applying machine learning to lemon defect recognition can improve the efficiency of lemon quality detection. This paper proposes a deep learning-based classification method with visual feature extraction and transfer learning to recognize defect lemons (*i.e.*, green and mold defects). First, the data enhancement and brightness compensation techniques are used for data preprocessing. The visual feature extraction is used to quantify the defects and determine the feature variables as the bandit basis for classification. Then we construct a convolutional neural network with an embedded Visual Geometry Group 16 based (VGG16-based) network using transfer learning. The proposed model is compared with many benchmark models such as K-Nearest Neighbor (KNN) and Support Vector Machine (SVM). Results show that the proposed model achieves the highest accuracy (95.44%) in the testing data set. The research provides a new solution for lemon defect recognition.

Keywords

Machine Learning, Visual Feature Extraction, Convolutional Neural Networks, Transfer Learning

1. Introduction

1.1. Research Background

In recent years, with the development of agricultural planting technology, the control technology of lemon scab, skirt rot, and pest damage often encountered by lemon has been greatly improved [1] [2] [3]. Through the breeding and utilization of disease-resistant varieties and cultivating disease-free seedlings, the pests and diseases encountered in lemon planting are also greatly reduced. The main problem in lemon sales is the mildew caused by excessive storage and the

green color caused by early picking. Mildewed lemons are not edible; otherwise, they will damage health and induce diseases such as cancer [4] [5]. In addition, the green lemon tastes sour, has less fructose, the organic unsaturated acid content is high, should not be eaten raw. However, due to the high content of organic unsaturated acid, green lemon can achieve beauty. Compared with the mature yellow lemon, green lemon has a special value [6] [7]. Therefore, effectively and accurately identifying the storage time for too long and early picking of lemon is important practical significance [8].

1.2. Related Research and Problems in the Past

1.2.1. Related Research

Fruit and crop epidermis recognition is generally divided into three main research stages: traditional digital image processing, CNN, neural network, and feature processing.

Because of fast detection speed characteristics, a large amount of information, and no damage to products, machine vision technology is mostly used in fruit surface detection. The surface optical image is obtained using the optical characteristics of light reflection, projection, and diffuse projection. After being input into the computer, the image is processed with segmentation, noise removal, extraction features, data compression, coding, etc. [9] For example, using deep learning and SVM to identify leaf diseases [10]; using convolution neural network to identify many plant leaf diseases [11] [12]; using deep convolution AlexNet network model to divide tomato diseases into nine kinds [13]. using convolution neural network to tea sorting system [14].

Moreover, for machine learning, with the increase of the scale of the learning model, the parameters that the model needs to be trained gradually increase. Since the massive data needed for training a model with many parameters is difficult to obtain and large computational resources require training from scratch, transfer learning can avoid these two problems, and the knowledge training model of transfer learning has proved to be an effective method [15]. At present, transfer learning has been used in many fields, including but not limited to text classification, image classification, artificial intelligence planning, and so on [16]. For image classification, in agriculture, some classify and identify agricultural products through image classification [17], some identify crop diseases through transfer learning, and some identify the state of mature fruit ears through transfer learning [18] [19] [20].

1.2.2. Existing Problems

For machine vision technology, however, most of the research using machine vision at home and abroad is only under static conditions, limiting the fruit detection rolling in the actual production line. Moreover, the misjudgment of fruit infarction and calyx is not effectively solved. Therefore, machine vision is difficult to be used in actual production. Moreover, for transfer learning, it has not been studied in lemon defect identification.

图 8：论文发表展示

- **学员感悟和课程建议：**

在项目结束后，我们邀请学生为我们的项目做出评价和提出建议，共有 20 名同学填写了反馈，**我们将部分学生评价都列在下表（我们附上了学生的姓名和院校，可供未来合作院校查验评价的真实性和与学生沟通项目的感悟）。**未来的 Learning X 机器学习项目也会依据此做出调整，不断提高项目质量，为学生提供更好的教学资源。

表 2：部分学生评价

在 2021 年的寒假，我进行了假期的线上科研项目，收获颇丰，感慨良多！在历经长达一个半月的学习之后，了解到了很多复杂而有趣的知识，例如深度学习等等。这使得我既了解了知识海洋的浩瀚，也明白了世界的广大。我作为一个几乎没接触过科研项目的小白，感受到了科研的魅力，也感受到了科研的严谨，自此，让我对科研工作者产生了浓浓的敬佩。在这次项目中，老师们时刻保持认真负责的态度，在春节依旧坚持上课，非常感动，感谢老师!!! In the winter vacation of 2021, I carried out the online scientific research project of the holiday, and I got a lot of harvest and a lot of emotion! After a month and a half of learning, I learned a lot of complex and interesting knowledge, such as deep learning and so on. This enables me to understand not only the vastness of the ocean of knowledge, but also the vastness of the world. As a little Bai who has hardly been in touch with scientific research projects, I feel the charm of scientific research and the preciseness of scientific research. Since then, I have a strong admiration for scientific researchers. In this project, teachers always maintain a serious and responsible attitude, in the Spring Festival still insist on class, very moved, thank you!!! **苏科大电气 1911 方姝源**
时间过得真快啊，不知不觉中，这次的学习就结束了，但是我们以后的路还很长；通过这次学习，我学习到了机器学习方面的知识，对我今后在这方面的学习有很大的帮助，以前我对这方面的知识很排斥，经过这次学习，我改变了态度，对这方面知识产生了一些兴趣；在本次课程中各位老师都很尽心负责；很荣幸参加这次项目，虽然我们组最后的表现不行，但是依旧感谢各位老师和同学们。 How time flies, imperceptibly, this study is over, but we have a long way to go; Through this study, I learned the knowledge of machine learning, which will be of great help to my future study in this field. I used to reject this knowledge, but after this study, I changed my attitude and developed some interest in this knowledge. In this course, all the teachers are very responsible; It's a great honor to participate in this project. Although our team did not perform well in the end, I still want to thank all the teachers and students. **常州大学国际交流学院 李乃权**
对于这次项目在整体上我个人认为是很成功的。毕竟学生来自于不同的大学，不同的专业，学习的步频也不一样，在对于机器学习与数据科学的造诣上也各有深浅，故而综合考虑下来项目完满结项是非常不容易的。下面提出一些改进方面的参考意见：主要是课件的提前到位吧。因为语言并不精通，一堂课下来的效率就十分依赖于课前预习，如果能够在课前早早获得这次课程的大纲，应该会有更加好的结果。其次我觉得就是老师和学生可以有更多的互动，而不是只是关心于听没听懂。再次我觉得在课后，学生的笔记应该也纳入评分标准。 I personally think this project is very successful on the whole. After all, students come from different universities, different majors, learning steps are not the same, in machine learning and data science attainments are also deep, so it is very difficult to consider the completion of the project. Some suggestions for improvement are provided below: It is mainly the advance acquisition of classroom content documents, because the language is not proficient, the efficiency of a class is very dependent on pre-class preparation, if you can get the outline of this course early before class, there should be better results. Secondly, I think teachers and students can interact more, not

just listen and understand. Again, I think after class, students' notes should also be included in the scoring criteria.

常州大学 华罗庚学院 华院 192 王明轩

时光飞逝，转眼间为期近 40 天的线上课程已经结束，回想起刚听课时的一头雾水，与最后 做完项目时的一点小小的满足感，真是感慨万分。在学习过程中，我收获颇丰，项目课程的优点太多，我就不一一赘述，当然许多浅尝辄止的地方，在未来学习中我也会继续深入学习。 以下是我个人的一些建议。 每次教学录屏的保存时间希望可以延迟一些，或者直接以文件形式发送给学生。有时候学到后面的内容，还想回顾复习前面的内容时，录屏已过期。 希望每一次教授的录屏上，附带有中文翻译的字幕、这样更加易于理解。

Time flies. In a twinkling of an eye, the nearly 50-day online course has ended. It's very emotional to recall the confusion when I first attended the class and the little satisfaction when I finished the project. In the process of learning, I have gained a lot. There are too many advantages of the project course, so I will not elaborate on them one by one. Of course, I will continue to learn a lot in the future. Here are some of my personal suggestions. It is hoped that the saving time of each teaching recording screen can be delayed or sent to students directly in the form of files. Sometimes when you learn the following content and want to review the previous content, the recording screen has expired. I hope that every time Professor's recording screen is attached with Chinese subtitles, so that it is easier to understand.

常州大学 软件工程 李麟

在这次项目学习中，我深入了解并对运用了机器学习。教授通过大量例子生动形象 地给我们介绍了机器学习的基本组成，还有与之相关的前沿性研究，使我得到很多启发。莫 老师详细的讲解了几种较为成熟的机器学习原理，介绍代码如何使用，网络参数如何调节。 每次上课都令我受益匪浅，需要在课下花费很多时间理解课上内容并学会运用。如果课上有 能更多的讲解代码和展示不同情况下的运行结果将会更好。

In this project learning, I deeply understand and use machine learning. Professor vividly introduced the basic components of machine learning and related cutting-edge research through a large number of examples, which inspired me a lot. Mr. Mo explained several mature machine learning principles in detail, and introduced how to use the code and how to adjust the network parameters. Every class has benefited me a lot. I need to spend a lot of time after class to understand the content and learn how to use it. It would be better if the class had more code and showed the results of the operation in different situations.

朱天成 常州大学 电子信息工程