附件

2021 年度十项适用农机化技术推荐书

推荐单位	广东省农业技术推广中心		
联 系 人	姚俊豪	办公电话	020-37380838
手机号码	13580439456	电子邮箱	16895852@qq.com
名　　称	无人驾驶水田中耕机械除草技术		

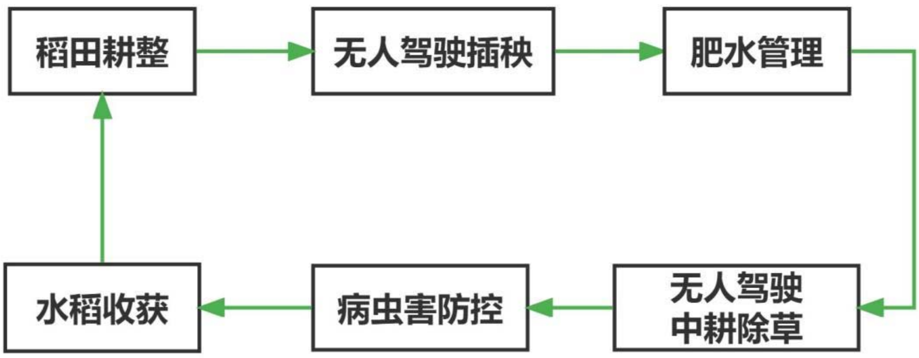
概述

一、适用区域

广泛适用于水稻种植区域。

二、技术模式

按照“稻田耕整-无人驾驶插秧-肥水管理-无人驾驶中耕除草-病虫害防控-水稻收获”的技术模式，试验示范推广了无人驾驶水田中耕机械除草技术。在稻田耕整后，采用无人驾驶插秧机进行水稻插秧，合理进行肥水管理，待除草期时除草机按照插秧路线进行水田中耕除草作业，完成杂草防控。通过这种方式作业可以有效降低伤苗率，提高除草效果。



三、解决的主要农业生产问题

1. 无人驾驶水田中耕机械除草技术可以去除水稻行间、株间杂草，还能疏松土壤，增加水稻根系含氧量，并有效解决了化学除草带来的农村面源污染问题。

2. 采用作物行株间除草一体的 3ZSC-190W 型无人驾驶水稻中耕除草机，不仅可以代替人工驾驶农机，减少农民劳动强度，还能提高作业效率，有效解决了水稻生产效率低、雇工成本高、劳动力短缺的问题。

3. 日本的研究机构和农机生产企业已经开发了一系列的水田除草机，但价格昂贵，而我们自主研发的水稻中耕机械除草装备造价只是同类进口设备的 1/3 左

右，且性能稳定可靠，解决了水稻生产中除草装备购置成本高的问题。

四、推广情况、应用规模及经济社会效益（或推广应用情况和效益）

2019 至 2021 年，该技术分别在肇庆市、江门市、鹤山市和恩平市水稻种植合作社和家庭农场进行大面积推广示范，共完成示范推广面积 37650 亩。根据除草机的田间试验调查统计，使用无人驾驶水田中耕机械除草技术，能减少田间喷除草剂一次，每亩可节省成本 35 元，同时实现平均增产 8 公斤/亩，按照江门市稻谷平均收购价为 3.2 元/公斤，实现增收 25.6 元/亩。按照平均每亩节支增收 60 元计算，实现经济效益为 225.60 万元。

附件：

主要技术简介及特征照片

华南农业大学齐龙教授团队研发了无人驾驶水田中耕机械除草技术，并研制了 3ZSC-190W 型无人驾驶水稻中耕除草机，不仅可以去除水稻行间、株间杂草，还能疏松土壤，增加水稻根系含氧量，有效解决化学除草带来的农村面源污染问题。

3ZSC-190W 无人驾驶水稻中耕除草机除草作业

3ZSC-190W 型无人驾驶水稻中耕除草机是一台集“北斗”卫星导航定位、机具自动控制、作物行株间除草于一体的高效型中耕除草机，主要由动力系统、行-株间除草装置、自动导航驾驶系统组成；自动导航驾驶系统采用我国自主知识产权的“北斗”导航技术，搭配控制器对农机液压系统进行自动控制，使除草机可以按照设定的路线自动行驶除草，并在车载显示器上显示相关图形化信息，作业误差可控制在 5cm 以内，能有效减少重复除草作业。除草机一次作业 7 行，采用平衡机构和仿形机构实时紧贴地面作业，保持恒定作业深度，提高作业效率。通过

	广东省质量监督机械检验站检测，该机作业效率为0.57hm^2/h，除草率为82.4%，伤苗率为2.1%，能有效降低伤苗率，提高除草效果，降低对农机驾驶员的劳动需求。

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单</td><td>（包括特征照片、技术模式流程图、试验示范文件、技术报告和公开发表的文章等。图片要清晰自然，JPG、JPEG、TIF、BMP 格式均可，不低于 24 位色，大小不低于 1MB。可另附页。）
见附件：
1.3ZSC-190W 型无人驾驶水稻中耕除草机田间作业图片 3 张;
2.3ZSC-190W 型无人驾驶水稻中耕除草机第三方机构检测报告;
3.除草机示范推广应用证明（2019-2021）;
4.发表论文。</td></tr>
<tr><td colspan="2">声明：本单位保证推荐材料真实有效，不存在任何违反《中华人民共和国保守国家秘密法》和《科学技术保密规定》等相关法律法规的情形。如有材料虚假或违纪行为，愿意承担相应责任并接受相应处理。如产生争议，保证积极配合调查处理工作。

推荐单位（盖章）

2022 年 2 月 22 日</td></tr>
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№: WJ2021203

检验报告

产品名称：无人驾驶水田中耕除草机

型号规格：3ZSC-190W

受检单位：华南农业大学

检验类别：委托检验

报告日期：2021年08月26日

广东省质量监督机械检验站

地 址：广州市天河北路663号省机械研究所　　电 话：020-38732907　38732156

传 真：020-38732371　　邮 编：510635

邮 箱：gmtc@vip.163.com　　网 址：www.gmtc.com.cn　www.gmi.org.cn

注意事项

1、报告无检验单位公章和检验专用章无效；

2、复制报告未重新加盖检验单位公章和检验专用章无效；

3、本检验报告非主检人、审核人和批准人亲笔签名无效；

4、报告涂改无效；

5、对检验报告有异议，应于收到报告之日起十五日内向检验单位提出，逾期不予受理；

6、检验检测数据、结果仅证明样品所检验检测项目的符合性情况。

7、客户提供样品来源信息，实验室不负责其真实性。

广东省质量监督机械检验站
检验报告

№:WJ2021203

产品名称 (型号 规格 商标 等级)	无人驾驶水田中耕除草机 3ZSC-190W	生产日期	2020 年 07 月
		编号或批号	——
		抽(送)样单号	WJ2021203
委托单位	华南农业大学	检验类别	委托检验
受检单位	华南农业大学	样品数量	1 台
生产单位（标称）	华南农业大学	抽样基数	——
抽样地点	——	检验地点	国营沙浦农场
抽(送)样方式	委托单位提供样品	抽样日期	——
抽(送)样者	——	检验日期	2021 年 08 月 23 日
检验依据	1. 《无人驾驶水田中耕除草机 技术参数》（委托单位提供） 2. GB/T 14253-2008 《轻工机械通用技术条件》		
检验结论	本次检验共 3 项，所检项目均符合检验依据要求。 检验报告专用章 签发日期：2021 年 08 月 26 日		
备注	判定说明：“P”—表示符合；“F”—表示不符合；“N”—表示不适用或者无法判定。		

批 准：2021.08.26　　审 核：　　主 检：

广东省质量监督机械检验站
检验报告

一、 产品描述及说明

1、 产品用途

该产品适用于水田中耕除草。能有效代替除草剂的施用，减少对环境的污染，避免土壤的板结，尤其适用于有机水稻的田间除草。

2、 产品组成

3ZSC-190W 型无人驾驶水田中耕除草机主要由北斗自动导航驾驶系统、动力系统、行-株间同步除草装置、多级仿形机构等组成。

3、 产品结构特点

（1）该产品采用无人驾驶技术进行水田中耕除草作业，可有效减少除草机的伤苗率并提高除草率、机具工作效率，降低对农机驾驶员的劳动需求；

（2）该产品具有一次作业可同步去除作物行间、株间杂草的功能；

（3）除草机采用横向调节装置，可适用不同水稻种植行距的除草要求；

（4）该产品运用多级仿形机构，使行间和株间的除草装置都具有独立的仿形能力，在复杂的水田环境下可以根据土壤的起伏变化自行调节中耕除草深度。

4. 主要技术参数

序 号	项 目	单 位	数 值	备注
1	作业行数	——	7 行	
2	作业幅宽	cm	190	
3	行距	cm	20～30	
4	株距	cm	11～25	
5	除草深度调节	cm	1～6	

二、检验结果汇总

序号	检验项目	条款	评定	备注
1	除草率	《无人驾驶水田中耕除草机　技术参数》GB/T 14253-2008	P	
2	伤苗率	《无人驾驶水田中耕除草机　技术参数》GB/T 14253-2008	P	
3	作业效率	《无人驾驶水田中耕除草机　技术参数》GB/T 14253-2008	P	

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广 东 省 质 量 监 督 机 械 检 验 站
检 验 报 告

三、检验结果

序号	检验项目	单位	检验依据要求	检验结果	判定	备注
1	除草率	——	≥80%	82.4%	P	
2	伤苗率	——	≤5%	2.1%	P	
3	作业效率	hm^2/h	≥0.5	0.57	P	

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四、 检验有关信息

1、样品状况

在用状态。

2、检验环境

环境温度：30 ℃ ～ 35 ℃；

相对湿度：71 % ～ 75 % 。

3、本次试验所使用的主要仪器、设备一览表

序号	仪器名称	型号规格	测量范围	技术特征	检定日期	设备编号
1	数显温湿度表	SHTC02	温度：0～50℃ 湿度：（10%～99%）RH	温度：±0.5℃ 湿度：±3%	2021.04.24	NT005
2	电子秒表	SW8019	/	日差 U=0.05 s/d 时间间隔 U=0.01s	2021.04.06	J007
3	钢卷尺	7.5m	(0～7.5)m	II 级 / U=0.3mm k=2	2021.04.03	L018
4	激光测距仪	D5	0.05～200 m	±1.0mm 倾角精度±0.3°	2021.04.24	L094

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五、样品照片

————————————————————

六、其他相关信息

非认可项目	——
意见与解释	——
抽样程序的说明	——
采用非标准方法的描述	——
偏离补充例外情况	——
检验结果不确定度说明	——
分包项目及分包方	——
备注	如适用时填写，不适用划“——”

机 构 简 介

广东省质量监督机械检验站是经广东省质量技术监督局授权批准，设立在广东省机械研究所内，具有特定专业资格和法律地位的第三方检测机构。经过近 30 多年的发展，已成为在国内享有很高知名度的省级专业检测机构，致力服务于机械产品（国家法定特种设备除外）质量检验与产品质量鉴定。

本机构技术力量雄厚、人才素质高。拥有从美国进口的三坐标测量仪等尖端仪器设备 500 多台；是省级计量认证合格单位（CMA）、省级授权质量监督检验机构（CAL）、中国合格评定国家认可委员会认可实验室（CNAS），是中国质量认证中心（CQC）签约的机械产品 CE 认证实验室，是广东省等高级人民法院司法委托专业质量鉴定机构。

GMI

广东省质量监督机械检验站

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应 用 证 明

2019 年，在华南农业大学工程学院的指导下，开平市联光农产品种植专业合作社在开平市龙胜镇胜桥村建立水稻机械除草基地，使用由华南农业大学工程学院研制的水田智能机械除草机开展田间机械化除草示范，种植品种为美香占 2 号、粤禾丝苗、象牙香占,共完成示范面积 950 亩。

田间示范过程中，水田智能机械除草机除草率达到了 83.2%，平均田间伤苗率为 4.7%，达到了较好的除草效果。同时，使用机械除草机可以有效减少使用除草剂一次，每亩可以节约成本 38 元。经过机械除草后，田间泥土经过了一个中耕的过程，水稻根系更加发达，提高了肥料利用率，能有效提高产量。经过实收测产，每亩可提高产量约 8 公斤。

其中美香占 2 号共完成示范面积 350 亩，节支共 1.33 万元，实收产量比施用除草剂田块增加 8 公斤每亩，按照每公斤水稻收购价格 2.7 元计算，增收达到 0.756 万元，节支增收共达到 2.086 万元。

粤禾丝苗共完成示范面积 200 亩，节支共 0.76 万元，实收产量比施用除草剂田块增加 10 公斤每亩，按照每公斤水稻收购价格 2.7 元计算，增收达到 0.54 万元，共完成节支增收 1.3 万元。

象牙香占共完成示范面积 400 亩，节支共 1.52 万元，实收产量比施用除草剂田块增加 6 公斤每亩，按照每公斤水稻收购价格 3.4 元计算，增收达到 0.816 万元，共完成节支增收 2.336 万元。

开平市联光农产品种植专业合作社

2019 年 12 月 13 日

应 用 证 明

2019 年，江门市农业科学研究所联合华南农业大学一起，在我台山市西南农民农机专业合作社建立水稻机械除草基地，使用由华南农业大学工程学院研制的水田智能机械除草机开展田间机械化除草示范，种植品种为象牙香占、莉香占以及粤禾丝苗，全年共完成示范面积 1300 亩。

田间示范过程中，水田智能机械除草机除草率达到了 85%，伤苗率为 4.2%，达到了较好的除草效果。同时，使用机械除草可以有效减少使用除草剂一次，每亩可以节约成本 38 元。经过机械除草后，田间泥土经过了一个中耕的过程，有利于田间根系的生长，更好的吸收肥料，能有效提高产量。经过实收测产，平均每亩可提高产量约 10 公斤。

附表　　2019 年水稻机械除草效益

品种	象牙香占	莉香占	粤禾丝苗	合计
示范面积（亩）	750	550	200	1500
节支（万元）	2.85	2.09	0.76	5.7
平均产量（公斤/亩）	372	386	483	/
增产（公斤/亩）	8	9	12	
收购价格（元/公斤）	3.4	3.3	2.7	
增收（万元）	2.04	1.683	0.648	4.371
节支增收（万元）	4.89	3.773	1.408	10.071

台山市西南农民农机专业合作社

2019 年 12 月 15 日

应 用 证 明

2019 年，华南农业大学工程学院联合江门市农业科学研究所在我合作社建立水稻机械除草基地，使用由华南农业大学工程学院研制的水田智能机械除草机开展田间机械化除草示范。

2019 年早造在恩平市良西镇长隆新村开展水稻机械中耕除草，试验品种为华航 31 号和象牙香占，共完成华航 31 号 200 亩和象牙香占 300 亩的田间机械中耕除草试验示范。经过田间试验示范，水田智能除草机田间除草率达到了 82.5%，平均伤苗率为 4.2%。

晚造在恩平市恩城镇石青村委会潭冲村开展机械中耕除草试验，试验品种为象牙香占，共完成 400 亩的田间机械中耕除草试验示范。田间调查结果得出，除草率为 81%，平均伤苗率为 4.8%。

使用机械除草，能减少田间喷除草剂一次，每亩节省成本 40 元，同时，经过田间机械中耕除草，相当于进行水稻田间中耕一次，疏松田间土壤，增加土壤含氧量，使根系更发达，可以有效增产 12 公斤每亩，按照每公斤稻谷收购价 2.6 元计算，完成增收 35 元每亩。共完成节支增收 75 元/亩，全年 900 亩共完成节支增收 67500 元。

恩平市鸿燕水稻专业合作社

2019 年 12 月 10 日

应 用 证 明

2019 年，华南农业大学工程学院联合江门市农业科学研究所在我合作社建立水稻机械除草基地，使用由华南农业大学工程学院研制的水田智能机械除草机开展田间机械化除草示范，示范品种为象牙香占、华航 48 号、粤禾丝苗。经过田间示范，水田智能除草机机械除草率达到了 80%，对田间水稻苗的伤及率能控制在 5%的范围内。

水稻智能机械除草机应用效益：

1、除草率高，效果好，能减少田间喷除草剂一次，每亩节省成本 30 元；

2、经过田间机械除草，相当于进行水稻田间中耕一次，疏松田间土壤，增加土壤含氧量，使根系更发达，可以有效增产 8-12 公斤每亩。

附表　　2019 年水稻机械除草效益情况

品种	粤禾丝苗	象牙香占	华航 48 号	合计
示范面积（亩）	300	700	400	1400
节支（万元）	0.9	2.1	1.2	4.2
平均产量（公斤/亩）	485	362	425	/
增产（公斤/亩）	10	8	9	/
收购价格（元/公斤）	2.7	3.4	2.7	
增收（万元）	0.81	1.904	0.972	3.686
节支增收（万元）	1.71	4.004	2.172	7.886

鹤山市址山镇合兴农机专业合作社

2019 年 12 月 12 日

应 用 证 明

2019 年，华南农业大学工程学院联合江门市农业科学研究所，在我合作社在新会区三江镇新江六队建立水稻机械除草基地，使用由华南农业大学工程学院研制的水田智能机械除草机开展田间机械化除草示范，种植品种为银湖香占、象牙香占，全年共完成 900 亩的水稻田间中耕除草。

田间示范过程中，水田智能除草机田间除草率为 81%，伤苗率为 4%，达到了良好的除草效果。同时，使用机械除草机可以有效减少使用除草剂一次，每亩可以节约成本 35 元。经过机械除草后，田间泥土经过了一个中耕的过程，有利于根系生长，提高田间土壤含氧量，促进化肥吸收。经过实收测产，平均每亩可提高产量约 6 公斤。

其中银湖香占共完成示范面积 400 亩，节支共 1.4 万元，实收产量比施用除草剂田块增加 7 公斤每亩，按照每公斤水稻收购价格 3.2 元计算，增收达到 0.896 万元，共完成节支增收 2.296 万元。

象牙香占完成示范面积 500 亩，节支共 1.75 万元，实收产量比施用除草剂田块每亩增加 6 公斤，按照每公斤水稻收购价格 3.4 元计算，增收达到 1.02 万元，共完成节支增收 2.77 万元。

江门市新会区三江镇利农农业机械化专业合作社

2019 年 12 月 15 日

应用证明

2020年，华南农业大学工程学院联合江门市农业科学研究所在我合作社建立水稻机械除草基地，使用由华南农业大学工程学院研制的水田智能机械除草机开展田间机械化除草示范，示范品种为莉香占、珍桂矮、象牙香占。经过田间示范，水田智能除草机机械除草率达到了85%，对田间水稻苗的伤及率能控制在2%的范围内。

水稻智能机械除草机应用效益：

1、除草率高，效果好，能减少田间喷除草剂一次，每亩节省成本30元；

2、经过田间机械除草，相当于进行水稻田间中耕一次，疏松田间土壤，增加土壤含氧量，使根系更发达，可以有效增产8-12公斤每亩。

附表　　2020年水稻机械除草效益情况

品种	莉香占	象牙香占	珍桂矮	合计
示范面积（亩）	400	800	500	1700
节支（万元）	1.2	2.4	1.5	5.1
平均产量（公斤/亩）	485	362	425	/
增产（公斤/亩）	10	8	9	/
收购价格（元/公斤）	2.7	3.4	2.7	
增收（万元）	1.08	2.176	1.215	4.48
节支增收（万元）	2.28	4.576	2.715	9.57

鹤山市雅瑶镇金穗康水稻种植专业合作社

2020年12月19日

应用证明

2020年，华南农业大学工程学院联合江门市农业科学研究所在我合作社建立水稻机械除草基地，使用由华南农业大学工程学院研制的水田智能机械除草机开展田间机械化除草示范。

2020年早造在恩平市良西镇长隆新村开展水稻机械中耕除草，试验品种为华航52号和象牙香占，共完成华航52号400亩和美香占2号500亩的田间机械中耕除草试验示范。经过田间试验示范，水田智能除草机田间除草率达到了85.1%，平均伤苗率为2.2%。

晚造在恩平市恩城镇石青村委会潭冲村开展机械中耕除草试验，试验品种为象牙香占，共完成600亩的田间机械中耕除草试验示范。田间调查结果得出，除草率为86%，平均伤苗率为2.5%。

使用机械除草，能减少田间喷除草剂一次，每亩节省成本40元，同时，经过田间机械中耕除草，相当于进行水稻田间中耕一次，疏松田间土壤，增加土壤含氧量，使根系更发达，可以有效增产12公斤每亩，按照每公斤稻谷收购价2.6元计算，完成增收35元每亩。共完成节支增收75元/亩，全年1500亩共完成节支增收112500元。

恩平市鸿燕水稻专业合作社

2020年12月6日

应用证明

2020年，在华南农业大学工程学院的指导下，开平市联光农产品种植专业合作社在开平市龙胜镇胜桥村建立水稻机械除草基地，使用由华南农业大学工程学院研制的水田智能机械除草机开展田间机械化除草示范，种植品种为美香占2号、粤禾丝苗、象牙香占，共完成示范面积1550亩。

田间示范过程中，水田智能机械除草机除草率达到了85.2%，平均田间伤苗率为1.5%，达到了较好的除草效果。同时，使用机械除草机可以有效减少使用除草剂一次，每亩可以节约成本38元。经过机械除草后，田间泥土经过了一个中耕的过程，水稻根系更加发达，提高了肥料利用率，能有效提高产量。经过实收测产，每亩可提高产量约8公斤。

其中美香占2号共完成示范面积550亩，节支共2.09万元，实收产量比施用除草剂田块增加8公斤每亩，按照每公斤水稻收购价格2.7元计算，增收达到1.19万元，节支增收共达到3.28万元。

粤禾丝苗共完成示范面积400亩，节支共1.52万元，实收产量比施用除草剂田块增加10公斤每亩，按照每公斤水稻收购价格2.7元计算，增收达到1.08万元，共完成节支增收2.6万元。

象牙香占共完成示范面积600亩，节支共2.28万元，实收产量比施用除草剂田块增加6公斤每亩，按照每公斤水稻收购价格3.4元计算，增收达到1.22万元，共完成节支增收3.5万元。

开平市联光农产品种植专业合作社

2020年12月11日

应用证明

2020年，华南农业大学工程学院联合江门市农业科学研究所在我合作社建立水稻机械除草基地，使用由华南农业大学工程学院研制的水田智能机械除草机开展田间机械化除草示范，示范品种为莉香占、珍桂矮、象牙香占。经过田间示范，水田智能除草机机械除草率达到了85%，对田间水稻苗的伤及率能控制在2%的范围内。

水稻智能机械除草机应用效益：

1、除草率高，效果好，能减少田间喷除草剂一次，每亩节省成本30元；

2、经过田间机械除草，相当于进行水稻田间中耕一次，疏松田间土壤，增加土壤含氧量，使根系更发达，可以有效增产8-12公斤每亩。

附表　2020年水稻机械除草效益情况

品种	莉香占	象牙香占	珍桂矮	合计
示范面积（亩）	400	800	500	1700
节支（万元）	1.2	2.4	1.5	5.1
平均产量（公斤/亩）	485	362	425	/
增产（公斤/亩）	10	8	9	/
收购价格（元/公斤）	2.7	3.4	2.7	
增收（万元）	1.08	2.176	1.215	4.48
节支增收（万元）	2.28	4.576	2.715	9.57

鹤山市址山镇合兴农机专业合作社

2020年12月19日

应用证明

2020年，江门市农业科学研究所联合华南农业大学一起，在我台山市西南农民农机专业合作社建立水稻机械除草基地，使用由华南农业大学工程学院研制的水田智能机械除草机开展田间机械化除草示范，种植品种为象牙香占、莉香占以及粤禾丝苗，全年共完成示范面积1900亩。

田间示范过程中，水田智能机械除草机除草率达到了 85.6%，伤苗率为 1.8%，达到了较好的除草效果。同时，使用机械除草可以有效减少使用除草剂一次，每亩可以节约成本38元。经过机械除草后，田间泥土经过了一个中耕的过程，有利于田间根系的生长，更好的吸收肥料，能有效提高产量。经过实收测产，平均每亩可提高产量约10公斤。

附表　　2020年水稻机械除草效益

品种	象牙香占	莉香占	粤禾丝苗	合计
示范面积（亩）	950	700	250	1900
节支（万元）	3.61	2.66	0.95	7.22
平均产量（公斤/亩）	372	386	483	/
增产（公斤/亩）	8	9	12	
收购价格（元/公斤）	3.4	3.3	2.7	
增收（万元）	2.584	2.079	0.81	5.473
节支增收（万元）	6.194	4.739	1.76	12.693

台山市西南农民农机专业合作社

2020年12月16日

应用证明

2020年，华南农业大学工程学院联合江门市农业科学研究所，在我合作社在新会区三江镇新江六队建立水稻机械除草基地，使用由华南农业大学工程学院研制的水田智能机械除草机开展田间机械化除草示范，种植品种为银湖香占、象牙香占，全年共完成900亩的水稻田间中耕除草。

田间示范过程中，水田智能除草机田间除草率为86.2%，伤苗率为1.7%，达到了良好的除草效果。同时，使用机械除草机可以有效减少使用除草剂一次，每亩可以节约成本35元。经过机械除草后，田间泥土经过了一个中耕的过程，有利于根系生长，提高田间土壤含氧量，促进化肥吸收。经过实收测产，平均每亩可提高产量约6公斤。

其中银湖香占共完成示范面积520亩，节支共1.4万元，实收产量比施用除草剂田块增加7公斤每亩，按照每公斤水稻收购价格3.2元计算，增收达到1.1648万元，共完成节支增收25648万元。

象牙香占完成示范面积650亩，节支共1.75万元，实收产量比施用除草剂田块每亩增加6公斤，按照每公斤水稻收购价格3.4元计算，增收达到1.326万元，共完成节支增收3.076万元。

江门市新会区三江镇利农农业机械化专业合作社

2020年12月15日

应 用 证 明

2021 年，华南农业大学工程学院联合江门市农业科学研究所在我合作社建立水稻机械除草基地，使用由华南农业大学工程学院研制的 3ZSC-190W 型无人驾驶水稻中耕除草机开展田间机械化除草示范，示范品种为莉香占、美香占 2 号、象牙香占。经过田间示范，无人驾驶水稻中耕除草机除草率达到了 85%，对田间水稻苗的伤及率能控制在 2%的范围内。无人驾驶水稻中耕除草机应用效益：

1、除草率高，效果好，能减少田间喷除草剂一次，每亩节省成本 30 元；

2、经过田间机械除草，相当于进行水稻田间中耕一次，疏松田间土壤，增加土壤含氧量，使根系更发达，可以有效增产 8-12 公斤每亩。

附表　　2021 年水稻机械除草效益情况

品种	莉香占	象牙香占	美香占 2 号	合计
示范面积（亩）	500	300	200	1000
节支（万元）	1.50	0.90	0.60	3.0
平均产量（公斤/亩）	395	345	425	/
增产（公斤/亩）	10	8	12	/
收购价格（元/公斤）	3.6	3.8	3.4	
增收（万元）	1.80	0.91	0.82	3.53
节支增收（万元）	3.30	1.81	1.42	6.53

鹤山市址山镇合兴农机专业合作社

2020 年 12 月 19 日

应 用 证 明

2021 年，在华南农业大学工程学院和江门市农科所的指导下，开平市苍城镇天丰水稻病虫害防治技术专业合作社在开平市苍城镇六合村建立水稻机械除草基地，使用由华南农业大学工程学院研制的 3ZSC-190W 型无人驾驶水稻中耕除草机开展田间机械化除草示范，种植品种为莉香占、19 香、象牙香占，共完成示范面积 2550 亩。

田间示范过程中，水田智能机械除草机除草率达到了 85.6%，平均田间伤苗率为 1.7%，达到了较好的除草效果。同时，使用机械除草机可以有效减少使用除草剂一次，每亩可以节约成本 38 元。经过机械除草后，田间泥土经过了一个中耕的过程，水稻根系更加发达，提高了肥料利用率，能有效提高产量。经过实收测产，平均每亩可提高产量约 8 公斤。

其中莉香占共完成示范面积 1000 亩，节支共 3.8 万元，实收产量比施用除草剂田块增加 8 公斤每亩，按照每公斤水稻收购价格 3.6 元计算，增收达到 2.88 万元，节支增收共达到 6.68 万元。

19 香共完成示范面积 850 亩，节支共 3.23 万元，实收产量比施用除草剂田块增加 9 公斤每亩，按照每公斤水稻收购价格 3.4 元计算，增收达到 2.6 万元，共完成节支增收 5.83 万元。

象牙香占共完成示范面积 700 亩，节支共 2.66 万元，实收产量比施用除草剂田块增加 6 公斤每亩，按照每公斤水稻收购价格 3.6 元计算，增收达到 1.51 万元，共完成节支增收 4.17 万元。

开平市苍城镇天丰水稻病虫害防治技术专业合作社

2021 年 12 月 8 日

应 用 证 明

2021 年，华南农业大学工程学院联合江门市农业科学研究所，在我合作社在新会区三江镇新江六队建立水稻机械除草基地，使用由华南农业大学工程学院研制的 3ZSC-190W 型无人驾驶水稻中耕除草机开展田间机械化除草示范，种植品种为莉香占和 19 香，全年共完成 1850 亩的水稻田间中耕除草。

田间示范过程中，水田智能除草机田间除草率为 86.4%，伤苗率为 2.6%，达到了良好的除草效果。同时，使用机械除草机可以有效减少使用除草剂一次，每亩可以节约成本 35 元。经过机械除草后，田间泥土经过了一个中耕的过程，有利于根系生长，提高田间土壤含氧量，促进化肥吸收。经过实收测产，平均每亩可提高产量约 6 公斤。

其中莉香占共完成示范面积 1000 亩，节支共 3.5 万元，实收产量比施用除草剂田块增加 7 公斤每亩，按照每公斤水稻收购价格 3.4 元计算，增收达到 2.38 万元，共完成节支增收 5.88 万元。

19 香完成示范面积 850 亩，节支共 2.98 万元，实收产量比施用除草剂田块每亩增加 6 公斤，按照每公斤水稻收购价格 3.4 元计算，增收达到 1.73 万元，共完成节支增收 4.71 万元。

江门市新会区三江镇利农农业机械化专业合作社

2021 年 12 月 5 日

江门市新会区三江镇利农农业机械化专业合作社

应 用 证 明

2021 年，在华南农业大学工程学院和江门市农科所的指导下，开平市永晖农机专业合作社联合社在开平市水口镇黎村建立水稻机械除草基地，使用由华南农业大学工程学院研制的 3ZSC-190W 型无人驾驶水稻中耕除草机开展田间机械化除草示范，种植品种为莉香占、19 香、象牙香占,共完成示范面积 1050 亩。

田间示范过程中，水田智能机械除草机除草率达到了 85.4%，平均田间伤苗率为 2.0%，达到了较好的除草效果。同时，使用机械除草机可以有效减少使用除草剂一次，每亩可以节约成本 36 元。经过机械除草后，田间泥土经过了一个中耕的过程，水稻根系更加发达，提高了肥料利用率，能有效提高产量。经过实收测产，平均每亩可提高产量约 7 公斤。

其中莉香占共完成示范面积 500 亩，节支共 1.8 万元，实收产量比施用除草剂田块增加 6 公斤每亩，按照每公斤水稻收购价格 3.6 元计算，增收达到 2.88 万元，节支增收共达到 0.43 万元。

19 香共完成示范面积 350 亩，节支共 1.26 万元，实收产量比施用除草剂田块增加 9 公斤每亩，按照每公斤水稻收购价格 3.4 元计算，增收达到 1.07 万元，共完成节支增收 2.33 万元。

象牙香占共完成示范面积 200 亩，节支共 0.72 万元，实收产量比施用除草剂田块增加 6 公斤每亩，按照每公斤水稻收购价格 3.9 元计算，增收达到 0.47 万元，共完成节支增收 1.19 万元。

开平市永晖农机专业合作社联合社

2021 年 12 月 15 日

应 用 证 明

2021 年，江门市农业科学研究所联合华南农业大学一起，在我台山市都斛镇胜裕家庭农场建立水稻机械除草基地，使用由华南农业大学工程学院研制的 3ZSC-190W 型无人驾驶水稻中耕除草机开展田间机械化除草示范，种植品种为象牙香占、莉香占以及 19 香，全年共完成示范面积 1500 亩。

田间示范过程中，水田智能机械除草机除草率达到了 84.5%，伤苗率为 2.0%，达到了较好的除草效果。同时，使用机械除草可以有效减少使用除草剂一次，每亩可以节约成本 35 元。经过机械除草后，田间泥土经过了一个中耕的过程，有利于田间根系的生长，更好的吸收肥料，能有效提高产量。经过实收测产，平均每亩可提高产量约 10 公斤。

附表　　2021 年水稻机械除草效益

品种	象牙香占	莉香占	19 香	合计
示范面积（亩）	600	500	400	1500
节支（万元）	2.1	1.75	1.4	5.25
平均产量（公斤/亩）	345	403	415	/
增产（公斤/亩）	8	10	12	
收购价格（元/公斤）	3.6	3.5	3.4	/
增收（万元）	1.73	1.75	1.63	5.11
节支增收（万元）	3.83	3.50	3.03	10.36

台山市都斛镇胜裕家庭农场

2021 年 12 月 5 日

应 用 证 明

2021 年，华南农业大学工程学院联合江门市农业科学研究所在我合作社建立水稻机械除草基地，使用由华南农业大学工程学院研制的 3ZSC-190W 型无人驾驶水稻中耕除草机开展田间机械化除草示范。

2021 年早晚两造分别在恩平市良西镇长隆新村和恩城街道石青村委会潭冲村开展水稻机械中耕除草试验示范，试验品种为莉香占、19 香和美香占 2 号，完成莉香占 700 亩（其中早造 300 亩，晚造 400 亩）、19 香 500 亩（其中早造 300 亩，晚造 200 亩）和美香占 2 号 300 亩（其中早造 200 亩，晚造 100 亩）的田间机械中耕除草试验示范。经过田间试验示范，无人驾驶水稻中耕除草机田间除草率达到了 84.1%，平均伤苗率为 2.6%。

使用机械除草，能减少田间喷除草剂一次，每亩节省成本 40 元，同时，经过田间机械中耕除草，相当于进行水稻田间中耕一次，疏松田间土壤，增加土壤含氧量，使根系更发达，可以有效增产 13 公斤每亩，按照每公斤稻谷收购价 3.6 元计算，完成增收 46.8 元每亩。共完成节支增收 86.8 元/亩，全年 1500 亩共完成节支增收 130200 元。

恩平市鸿燕水稻专业合作社

2021 年 12 月 4 日

应用证明

2021 年，江门市农业科学研究所联合华南农业大学一起，在我台山市西南农民农机专业合作社建立水稻机械除草基地，使用由华南农业大学工程学院研制的 3ZSC-190W 型无人驾驶水稻中耕除草机开展田间机械化除草示范，种植品种为象牙香占、莉香占以及南晶香占，全年共完成示范面积 2800 亩。

田间示范过程中，水田智能机械除草机除草率达到了 84.3%，伤苗率为 1.9%，达到了较好的除草效果。同时，使用机械除草可以有效减少使用除草剂一次，每亩可以节约成本 38 元。经过机械除草后，田间泥土经过了一个中耕的过程，有利于田间根系的生长，更好的吸收肥料，能有效提高产量。经过实收测产，平均每亩可提高产量约 11 公斤。

附表　　2021 年水稻机械除草效益

品种	象牙香占	莉香占	南晶香占	合计
示范面积（亩）	1250	1000	550	2800
节支（万元）	4.75	3.80	2.09	10.64
平均产量（公斤/亩）	355	405	425	/
增产（公斤/亩）	9	10	14	
收购价格（元/公斤）	3.6	3.5	3.4	/
增收（万元）	4.05	3.50	2.62	10.17
节支增收（万元）	8.80	7.30	4.71	20.81

台山市西南农民农机专业合作社

2021 年 12 月 3 日

应 用 证 明

2021 年，华南农业大学工程学院联合江门市农业科学研究所在我合作社建立水稻机械除草基地，使用由华南农业大学工程学院研制的 3ZSC-190W 型无人驾驶水稻中耕除草机开展田间机械化除草示范，示范品种为莉香占、美香占 2 号。经过田间示范，无人驾驶水稻中耕除草机除草率达到了 85%，对田间水稻苗的伤及率能控制在 2%的范围内。无人驾驶水稻中耕除草机应用效益：

1、除草率高，效果好，能减少田间喷除草剂一次，每亩节省成本 33 元；

2、经过田间机械除草，相当于进行水稻田间中耕一次，疏松田间土壤，增加土壤含氧量，使根系更发达，可以有效增产 8 公斤每亩。

附表　　2021 年水稻机械除草效益情况

品种	莉香占	美香占 2 号	合计
示范面积（亩）	600	300	900
节支（万元）	1.98	0.99	2.97
平均产量（公斤/亩）	405	435	/
增产（公斤/亩）	8	8	/
收购价格（元/公斤）	3.6	3.2	
增收（万元）	1.73	0.77	2.50
节支增收（万元）	3.71	1.76	5.47

鹤山市雅瑶镇金穗康水稻种植专业合作社

2020 年 12 月 19 日

应 用 证 明

2021 年，华南农业大学工程学院联合江门市农业科学研究所在我合作社建立水稻机械除草基地，使用由华南农业大学工程学院研制的 3ZSC-190W 型无人驾驶水稻中耕除草机开展田间机械化除草示范。

2021 年早晚两造分别在恩平市沙湖镇乌石村开展水稻机械中耕除草试验示范，试验品种为象牙香占和美香占 2 号，完成象牙香占 500 亩（其中早造 300 亩，晚造 200 亩）和美香占 2 号 400 亩（其中早造 300 亩，晚造 100 亩）的田间机械中耕除草试验示范。经过田间试验示范，无人驾驶水稻中耕除草机田间除草率达到了 84.3%，平均伤苗率为 2.5%。

使用机械除草，能减少田间喷除草剂一次，每亩节省成本 38 元，同时，经过田间机械中耕除草，相当于进行水稻田间中耕一次，疏松田间土壤，增加土壤含氧量，使根系更发达，可以有效增产 10 公斤每亩，按照每公斤稻谷收购价 3.6 元计算，完成增收 36 元每亩。共完成节支增收 72 元/亩，全年 900 亩共完成节支增收 64800 元。

广东恩洲丰穗农业专业合作社联合社

2021 年 12 月 8 日

应 用 证 明

2021 年，华南农业大学工程学院联合江门市农业科学研究所，在我合作社在新会区双水镇木江村建立水稻机械除草基地，使用由华南农业大学工程学院研制的 3ZSC-190W 型无人驾驶水稻中耕除草机开展田间机械化除草示范，种植品种为莉香占、南晶香占和 19 香，全年共完成 1900 亩的水稻田间中耕除草。

田间示范过程中，水田智能除草机田间除草率为 86.5%，伤苗率为 2.5%，达到了良好的除草效果。同时，使用机械除草机可以有效减少使用除草剂一次，每亩可以节约成本 36 元。经过机械除草后，田间泥土经过了一个中耕的过程，有利于根系生长，提高田间土壤含氧量，促进化肥吸收。经过实收测产，平均每亩可提高产量约 6 公斤。

其中莉香占共完成示范面积 800 亩，节支共 2.88 万元，实收产量比施用除草剂田块增加 6 公斤每亩，按照每公斤水稻收购价格 3.6 元计算，增收达到 1.73 万元，共完成节支增收 4.61 万元。

南晶香占完成示范面积 600 亩，节支共 2.16 万元，实收产量比施用除草剂田块每亩增加 8 公斤，按照每公斤水稻收购价格 3.4 元计算，增收达到 1.63 万元，共完成节支增收 3.79 万元

19 香完成示范面积 500 亩，节支共 1.8 万元，实收产量比施用除草剂田块每亩增加 7 公斤，按照每公斤水稻收购价格 3.4 元计算，增收达到 1.19 万元，共完成节支增收 2.99 万元。

新会区双水镇文发农业种植场

2021 年 12 月 15 日

应 用 证 明

2021 年，华南农业大学工程学院联合肇庆市农业科学研究所在我合作社建立水稻机械除草基地，使用由华南农业大学工程学院研制的 3ZSC-190W 型无人驾驶水稻中耕除草机开展田间机械化除草示范，示范品种为华航 52 号，示范面积 1000 亩。经过田间示范，无人驾驶水稻中耕除草机除草率达到了 84.2%，对田间水稻苗的伤及率能控制在 0-2.3%的范围内。无人驾驶水稻中耕除草机应用效益：

1、除草率高，效果好，能减少田间喷除草剂一次，每亩节省成本 40 元；

2、经过田间机械除草，相当于对水稻田进行一次中耕，疏松田间土壤，增加土壤通气性、促进土壤好气微生物活动和养分有效化，促进根系生长发育，平均有效增产 14.57 公斤每亩。

附表　　2021 年水稻机械除草效益情况

品种	华航 52 号
示范面积（亩）	1000
节支（万元）	4.00
平均产量（公斤/亩）	510.20
增产（公斤/亩）	14.57
收购价格（元/公斤）	2.4
增收（万元）	3.50
节支增收（万元）	7.50

肇庆市高要区禄步镇飞翔农业机械化专业合作社

2021 年 12 月 2 日

应 用 证 明

2021 年华南农业大学工程学院联合肇庆市农业科学研究所与我公司合作，在怀集县梁村镇基地设立水稻机械中耕除草示范点，使用由华南农业大学工程学院研制的 3ZSC-190W 型无人驾驶水稻中耕除草机开展田间机械化除草示范。试验品种为优质稻 19 香、莉香占和南晶香占，共完成 19 香 1000 亩、莉香占 1500 亩和南晶香占 1500 亩的田间机械中耕除草试验示范。经过田间试验示范，无人驾驶水稻中耕除草机田间除草率达到了 85.1%，平均伤苗率为 2.0%。

使用机械除草，能减少田间喷除草剂一次，每亩节省成本 35 元，同时，经过田间机械中耕除草，相当于进行水稻田间中耕一次，疏松田间土壤，增加土壤含氧量，促进好气微生物活动、，使根系更发达，可以有效增产 7-13 公斤每亩。

附表　　2021 年水稻机械除草效益情况

品种	19 香	莉香占	南晶香占	合计
示范面积（亩）	1500	1500	1000	4000
节支（万元）	5.25	5.25	3.50	14.00
平均产量（公斤/亩）	469	490	395	/
增产（公斤/亩）	9	13	7	/
收购价格（元/公斤）	3.6	2.7	2.7	/
增收（万元）	4.86	5.27	1.89	12.02
节支增收（万元）	10.11	10.52	5.39	26.02

广东新辉园农业发展有限公司

2021 年 12 月 3 日

应 用 证 明

2021 年，华南农业大学工程学院联合肇庆市农业科学研究所在我公司基地设立水稻机械除草示范基地，使用由华南农业大学工程学院研制的 3ZSC-190W 型无人驾驶水稻中耕除草机开展田间机械化除草示范，示范品种为丝苗米品种 19 香、美香占 2 号。经过田间示范，无人驾驶水稻中耕除草机除草率达到了 83.5%-85%，对田间水稻苗的伤及率能控制在 3.4%的范围内。无人驾驶水稻中耕除草机应用效益：

1、除草率高，效果好，能减少田间喷除草剂一次，每亩节省成本 40 元；

2、经过田间机械除草，相当于进行水稻田间中耕一次，疏松田间土壤，增加土壤含氧量，使根系更发达，可以有效增产 8-11 公斤每亩。

附表　　2021 年水稻机械除草效益情况

品种	19 香	美香占 2 号	合计
示范面积（亩）	1300	700	2000
节支（万元）	4.20	2.80	7.00
平均产量（公斤/亩）	497.9	395.3	/
增产（公斤/亩）	11	8	/
收购价格（元/公斤）	3.60	3.20	/
增收（万元）	5.15	1.79	6.94
节支增收（万元）	9.35	4.59	13.94

四会禾源农业科技有限公司

2021 年 12 月 10 日

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Bending diagnosis of rice seedling lines and guidance line extraction of automatic weeding equipment in paddy field

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ABSTRACT

Mechanical weeding is an efficient weeding method, which is of considerable significance to the paddy field ecosystem. However, traditional mechanical weeding methods can cause seedling damages due to the bending phenomenon of the seedling lines. Introducing computer vision and control technology to traditional mechanical weeding methods can help the system diagnose the bending phenomenon and avoid crushing the seedlings. In this paper, we propose a deep-learning-based method of seedling line bending diagnosis and guidance line extraction. To prove the proposed method effective in the mechanical weeding system, we choose the Faster Region-based Convolutional Network (R-CNN) and Single Shot MultiBox Detector (SSD) as the representative models of the single-phase method and the two-phase method. With a novel dataset of rice seedling images established, we compare and analyze the confidence and real-time performance of the trained models. The experimental results show that the Faster R-CNN model is better in terms of accuracy, yet the SSD model has more advantages in the speed. Comprehensively considering the system requiring and model performances, the SSD model is a better choice in the automatic rice avoidance system.

1. Introduction

During the rice growing process, weeding is of great importance to improve the yield and quality of rice. Although the use of chemical herbicides helps, the damage to the environment is enormous. The demand for environment-friendly, labor-saving and yield-increasing weeding methods is growing. Mechanical weeding suits that demand well, though it has problems regarding labor costs and rice injuries.

In practical paddy fields, different degrees of misalignment of seedling rows exist in either mechanical or manual transplanting. Consequently, the weeding machine without feedback could inflict rice injury, for it is unable to adjust the weeding wheels automatically according to the bending. Thus, it is significant for the weeding machine to avoid seedlings automatically. In 2011, Ma's group studied and summarized the development of domestic and foreign mechanical weeding machines, especially the development of intelligent weeding robots in the United States and Japan. They proposed that the development of mechanical weeding technology should be the one that includes bionics, multi-technology integration, and intelligence, especially computer vision [1].

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CRediT authorship contribution statement

Fuchun Liu: Conceptualization, Methodology. **Yang Yang:** Data curation, Writing - original draft. **Yiming Zeng:** Investigation, Software. **Zeyong Liu:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Automatic Detection of Plant Rows for a Transplanter in Paddy Field Using Faster R-CNN

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ABSTRACT Uniform plant row spacing in a paddy field is a critical requirement for rice seedling transplanting, as it affects subsequent field management and the crop yield. However, current transplanters are not able to meet this requirement due to the lack of accurate navigation systems. In this study, a plant row detection algorithm was developed to serve as a navigation system of a rice transplanter. The algorithm was based on the convolutional neural network (CNN) to identify and locate rice seedlings from field images. The agglomerative hierarchical clustering (AHC) was used to group rice seedlings into seedling rows which were then used to determine the navigation parameters. The accuracies of the navigation parameters were evaluated using test images. Results showed that the CNN-based algorithm successfully detected rice seedlings from field images and generated a reference line which was used to determine navigation parameters (lateral distance and travel angle). Compared with mean absolute errors (MAE) test results, the CNN-based algorithm resulted in a deviation of 8.5 mm for the lateral distance and 0.50° for the travel angle, over the six intra-row seedling spacings tested. Relative to the test results, the CNN-based algorithm had 62% lower error for the lateral distance and 57% lower error for the travel angle when compared to a classical algorithm. These results demonstrated that the proposed algorithm had reasonably good accuracy and can be used for the rice transplanter navigation in real-time.

INDEX TERMS Agglomerative hierarchical clustering, convolutional neural network, image, navigation, rice, seedling, transplanting.

I. INTRODUCTION

Rice is the staple food for more than half of the global population. Transplanting rice seedlings is one of the most popular methods of rice production. A critical requirement for transplanting is to have straight plant rows and uniform row spacings in rice fields. Uniform seedling row spacing is favorable to increased rice yields and minimize plant damage in the subsequent field operations, such as weeding, fertilization, spraying, and harvest. Compared to manually driving transplanters, automatic transplanters have the potential to achieve more uniform plant row spacings. However, it is challenging to navigate a transplanter to autonomously maintain a desired plant row spacing. This study addressed this challenge by developing an algorithm for automatic detection of rice seedlings for real-time navigation.

The navigation technology based on GPS or computer vision has been primarily used for agricultural automatic vehicles. Two-dimensional LiDAR was used to detect corn plant rows [1], [2]. The main advantage was the short distance target location but the shape of the plants was not considered. Moreover, this method may not be suitable for

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Deep localization model for intra-row crop detection in paddy field

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ABSTRACT

Automated and precise rice plant localization is crucial for the mechanization of rice production, which can facilitate targeted spraying, site-specific fertilization, and mechanized weeding etc. Existing approaches adopted thus far have mainly focused on inter-row weed detection or rice seedling row detection. Nevertheless, techniques for intra-row individual rice plant positioning continue to face major challenges induced by the specific paddy field environments or complex morphology of rice plant. This paper proposed a new deep localization network for intra-row rice detection at the single plant level in a paddy field. This method designed a two-stage model. The module in stage 1 identified potential locations containing rice plants in the entire image. The module in stage 2 predicted the confidence of rice plant identification and refined the corresponding box bounds. The two-stage processing modules shared a deep backbone network for learning full-image convolutional features and are combined into a unified framework to facilitate an end-to-end training. In addition, we constructed a rice plant detection dataset and proposed a task-oriented evaluation method for performance verification of the algorithm. Experiment results showed the proposed deep model achieved a high localization accuracy of 93.22% and a high testing speed of 15 fps, verifying the effectiveness and efficiency of the method. Using this method, we can develop techniques for finer-level agriculture production, such as spraying and weed control, to achieve healthy and economical rice yields.

1. Introduction

Rice is one of the most important staple crops for large populations worldwide. However, there remains a severe shortage of rice, mainly because of pests that reduce the yield and low-level mechanization that contributes toward low efficiency of the rice production process. Therefore, it is increasingly demanded for new tools and methods to meet the objectives of improving the management and productivity of the rice sector and as well reducing adverse environmental effects (Huang et al., 2015). Such technologies include targeted spraying and site-specific fertilization (Carballido et al., 2013; Midtiby et al., 2011), mechanized weeding (Gobor et al., 2013; Tillett et al., 2008; Griepentrog et al., 2006), and agricultural machinery navigation (Choi et al., 2015; Rasmussen et al., 2012; Astrand and Baerveldt, 2002; Perez-Ruiz et al., 2013). To enhance the feasibility and effectiveness of these tools, it is necessary to acquire the location information of individual crop plants accurately.

Existing rice localization research work can be roughly categorized into two classes: non-vision-based and machine-vision based methods. Herein, non-visual approaches for detecting individual crop plants include global positioning system (GPS) (Pérez-Ruiz et al., 2012; Nørremark et al., 2012; Nørremark et al., 2008) and various approaches based on proximity sensors (Bontsema et al., 1991; Cordill and Grift, 2011). The advantage of these methods is that their accuracy and precision are independent of the visual appearance of the crop, or shadows. However, these non-vision-based methods are vulnerable to interruption from other objects or crop flourishing conditions and are unreliable in the presence of weeds. Therefore, machine vision using camera sensors is adopted as an important alternative means for detecting crop and acquiring their positional information.

Thus far, some investigations have attempted to develop camera-based methods for fast and accurate crop location identification with varying levels of success (Müter et al., 2014; Nan et al., 2015; Hague and Tillett, 2001; Nishiwaki et al., 2001; Zhang et al., 2012; Hu et al., 2013; Astrand, 2005; Aitkenhead et al., 2003). Müter et al. (2014) used a wavelet transformation and simple threshold method in HSL color space to segment a plant from the background. Nan et al. (2015) proposed a modified excess green feature based on thresholding to segment a plant from the background in RGB color space. These techniques share a common method for the segmentation of vegetation from the

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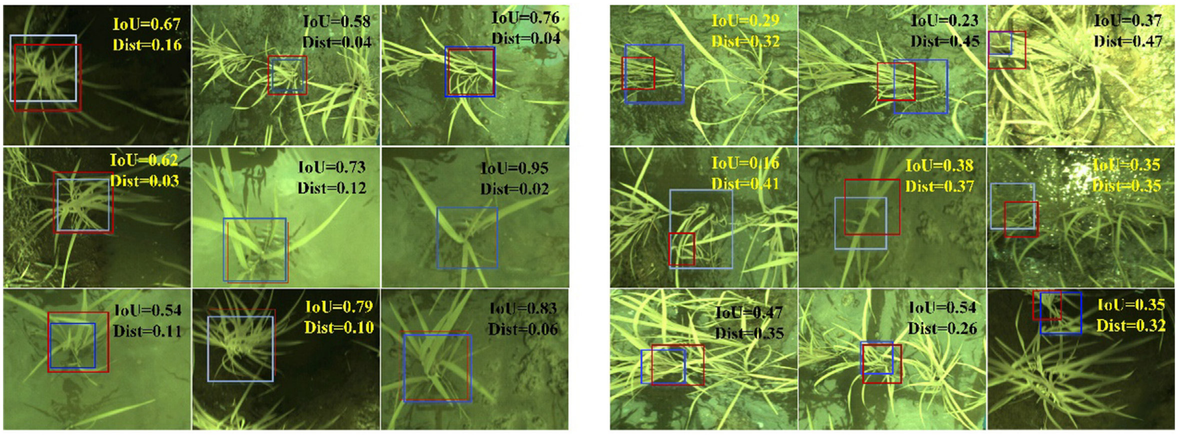

(a) (b)

Fig. 11. Detection of samples with proposed decision rule: (a) True detections; (b) False detections.

Table 5
Performance of different rice plant detection methods.

Method	Recall (%)	Precision (%)	AP (%)	Time (s/image)
HOG + SVM	60.39	34.18	35.73	5.1105
YOLO	94.07	70.48	90.20	**0.0458**
The Proposed (Ours)	**94.86**	**83.88**	**93.22**	0.0654

detection method with two consecutive coarse-to-fine processes, i.e., from candidate proposal to refined detection, for improved positioning performance. The proposed method is equipped with a deep multi-scale backbone design of ResNet-FPN for more discriminative representations of rice plants, thus handling the challenges induced by the associated specific paddy field environments or complex morphological characteristics of canopy or stems. Owing to the unavailability of a public rice plant detection dataset, we constructed a large rice plant knowledge dataset called FieldRiDet, containing more than 8000 images and 27,000 rice plant instances, which is expected to be useful to the agricultural community in the future. In addition, we presented a rice plant position-specific evaluation method that can provide more reasonable goal-oriented evaluations by comprehensively considering the center distance between the estimated and true squares and the estimated IoU ratio with regard to the ground truth.

Experiment delivered on FieldRiDet shows a significant improvement in the intra-row rice positioning problem at the single plant level. The results confirmed the superiority of the proposed algorithm over state-of-the-art methods. Specifically, the proposed method was shown to achieve a high AP value of 93.22% and a frame rate of 15fps. Thus, it was a practical rice plant localization method in terms of both accuracy and speed which may be great conducive to (i) identify a stem-base-centered square region at single plant level that corresponded to the protected area for the weeding machinery to reduce crop damage; (ii) determine the work space for the target sprayer or fertilizer to increase the cultivation accuracy; and (iii) form a work line for robot navigation to enhance the agricultural productivity.

CRediT authorship contribution statement

Shuangping Huang: Conceptualization, Methodology, Writing - original draft. **Sihang Wu:** Software, Writing - original draft, Visualization, Investigation, Validation. **Chao Sun:** Data curation, Visualization, Investigation, Validation. **Xu Ma:** Supervision. **Yu Jiang:** Validation. **Long Qi:** Writing - review & editing, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Visual detection of rice rows based on Bayesian decision theory and robust regression least squares method

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Abstract: Paddy field management is complicated and labor intensive. Correct row detection is important to automatically track rice rows. In this study, a novel method was proposed for accurate rice row recognition in paddy field transplanted by machine before the disappearance of row information. Firstly, Bayesian decision theory based on the minimum error was used to classify the period of collected images into three periods (T1: 0-7 d; T2: 7-28 d; T3: 28-45 d), and resulting in the correct recognition rate was 97.03%. Moreover, secondary clustering of feature points was proposed, which can solve some problems such as row breaking and tilting. Then, the robust regression least squares method (RRLSM) for linear fitting was proposed to fit rice rows to effectively eliminate interference by outliers. Finally, a credibility analysis of connected region markers was proposed to evaluate the accuracy of fitting lines. When the threshold of credibility was set at 40%, the correct recognition rate of fitting lines was 96.32%. The result showed that the method can effectively solve the problems caused by the presence of duckweed, high-density inter-row weeds, broken rows, tilting (±60°), wind and overlap.

Keywords: rice rows detection, Bayesian decision theory, clustering, RRLSM, credibility analysis, automatic tracking

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1 Introduction

Rice is one of the most important cereal crops worldwide and is predominantly grown in the Asian monsoon region. Rice farming occupies 31 million hm^2 in China, accounting for 20% of global production and representing a total rice yield of 208.56 million t in 2016[1]. With the rapid development of mechanized rice production, the total mechanization level for rice has reached 79.2%, among which tillage, cultivation and harvest mechanization levels are 99.31%, 44.45%, and 87.11%, respectively[2]. In recent years, intelligent rice farming machinery has been developing, like the Global Navigation Satellite System (GNSS) based unmanned transplanter and unmanned combine harvester are becoming increasingly popular. However, paddy field management remains complicated and labor intensive and the mechanization level for this link is only 16.84%[2]. Currently, weed control, fertilization, and pest control processes for paddy fields mainly adopt human-operated high-clearance machines, which have a low degree of automation. A human operator is typically required to concentrate on not driving over the rice rows; however, this is a quite difficult and tiring task (Figure 1a). Conversely, high-clearance paddy management machines navigated by machine vision technology can automatically track rice rows, thereby significantly reducing the labor intensity and minimizing the damage to crop rows caused by tractor operation[3-7]. Correct row detection is crucial to automatic tracking, but machine vision-aided rice rows recognition technology faces the following challenges.

(1) The paddy field environment is complicated by different water depths in different fields, severe inverted image and mirror effects, difficulties to tell color feature between rice and weeds, duckweeds, cyanobacteria, and the presence of natural wind leading to the overlap of adjacent rice rows and unclear row information. At present, the researchers choosing different color spaces and color features for processing images can effectively reduce the influence of light intensity changes and weeds on image segmentation[8,9]. Moreover, Zhang[7] proposed the smallest univalue segment assimilating nucleus (SUSAN) corner and improved sequential clustering algorithm, which can detect the rice row under the noise of cyanobacteria. Kaizu and Imou[10] developed a dual-spectral camera system that could reduce water surface noise and clearly detect seedling rows. Furthermore, the appearance of weeds and crops can be differentiated by leaf shape and texture features as well[11-14].

(2) Due to the unevenness of the bottom layer of paddy fields, paddy field machines and implements are forced to change position frequently[15-16], which would lead to row breaking, tilting, and overlap. With the parallel and equidistant characteristics of crop rows, horizontal strip scanning can be used to search for feature points and fill the feature points into broken row space[17,18]. For some dry-land crops such as wheat, corn, and soybean, the horizontal strip scanning method can successfully detect crop rows in field with high-density weeds or even under varying circumstances like having different values of soil hardness, light intensity, and camera yaw; however, the method is hardly able to detect rows with uneven row spacing caused by the unevenness of the bottom layer of paddy fields during the mechanized

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(4) Results of crop row recognition before the closing stage

Under different natural environments, 1200 paddy field images were collected from fields planted by machine, and the number of images collected for each time period was *T*1=400, *T*2=550, and *T*3=250. When taking the credibility no less than 40% as a judgment basis, the average correct recognition rate was 96.32%, and the recognition rates of *T*1, *T*2 and *T*3 were 98.75%, 99.00% and 91.20%, respectively. The main reason for the obvious decrease of recognition rates of *T*3 was that the adjacent rice rows crossed seriously in the later period, very close to the closing stage. As shown in Figure 10, under different circumstances such as uneven planting, bent rows, the presence of inter-row weeds, the overlap caused by wind, and the inclination angle of rice less than 60° caused by camera lateral offset, the rice row all can be detected correctly. Hence, the rice row recognition method proposed in this paper can meet the requirements of rice row recognition and location for fields planted by machine in the complex paddy field environment.

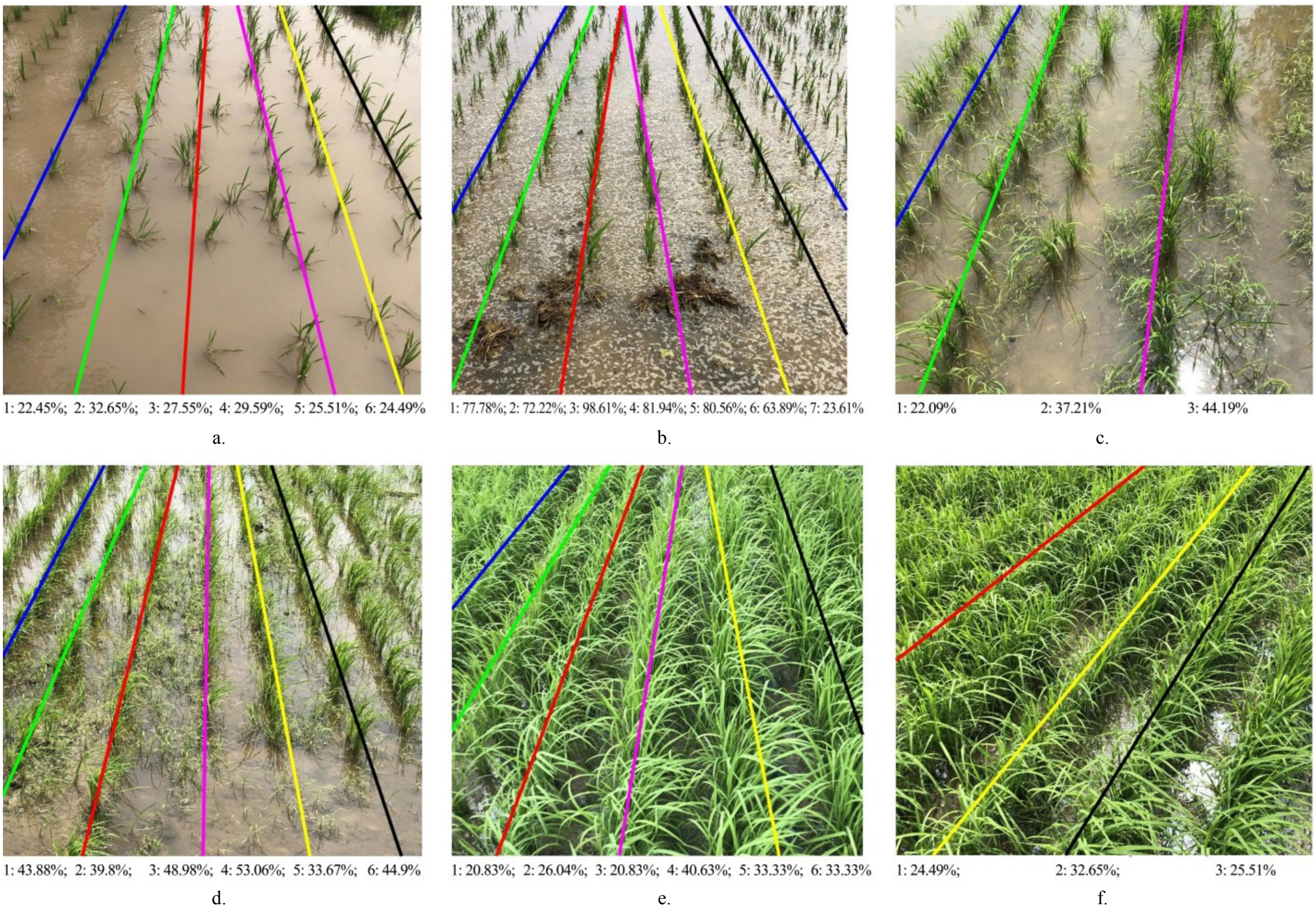

Figure 10 Overall rice row detection results for complex conditions (a) Uneven planting, (b) bent rows, (c) and (d) the presence of inter-row weeds, (e) the effect of wind, and (f) camera lateral offset

4 Conclusions

In this study, a novel method for accurate crop-row detection in paddy fields before the closing stage was proposed. The proposed method consists of four main processes: rice growth period classification, feature point extraction, crop row detection and credibility analysis. Firstly, the Bayesian decision theory based on the minimum error ratio was used to divide the rice images into three time periods, and different linear morphological operations were performed on images to enhance the rice row information. Then, the vertical projection method was combined with horizontal strip division to identify the feature points of the crops. Next, secondary clustering of feature points based on the shortest distance method was proposed, which effectively improved the number of correct cluster points, and the rice rows with tilting angle (within ±60°) could also be clustered. The RRLSM effectively eliminated the impact of outliers and accurately fitted the rice row. Finally, credibility analysis of connected region markers was proposed to assist the selection of the optimal precision fitting lines from the lines with different precision. The performance of the proposed method was tested using a set of images, and this experiment results showed that the correct recognition rate of images was 96.32%. However, the average computational time from reading one image (1754×1494 pixels) to credibility analysis was about 0.8 s. The optimization of processing time will be paid more attention in the future.

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sensors

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Article

A Tactile Method for Rice Plant Recognition Based on Machine Learning

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Abstract: Accurate and real-time recognition of rice plants is the premise underlying the implementation of precise weed control. However, achieving desired results in paddy fields using the traditional visual method is difficult due to the occlusion of rice leaves and the interference of weeds. The objective of this study was to develop a novel rice plant recognition sensor based on a tactile method which acquires tactile information through physical touch. The tactile sensor would be mounted on the paddy field weeder to provide identification information for the actuator. First, a flexible gasbag filled with air was developed, where vibration features produced by tactile and sliding feedback were acquired when this apparatus touched rice plants or weeds, allowing the subtle vibration data with identification features to be reflected through the voltage value of an air-pressured sensor mounted inside the gasbag. Second, voltage data were preprocessed by three algorithms to optimize recognition features, including dimensional feature, dimensionless feature, and fractal dimension. The three types of features were used to train and test a neural network classifier. To maximize classification accuracy, an optimum set of features (b (variance), f (kurtosis), h (waveform factor), l (box dimension), and m (Hurst exponent)) were selected using a genetic algorithm. Finally, the feature-optimized classifier was trained, and the actual performances of the sensor at different contact positions were tested. Experimental results showed that the recognition rates of the end, middle, and root of the sensor were 90.67%, 98%, and 96% respectively. A tactile-based method with intelligence could produce high accuracy for rice plant recognition, as demonstrated in this study.

Keywords: rice; weeds; recognition; tactile; ANN

1. Introduction

Rice is one of the major global food crops and feeds over 65% of Chinese people [1]. One of the basic questions impeding the growth of crops concerns the competition of rice plants from weeds in farmland. Weeds in rice fields compete with rice for water, nutrients, and sunlight, resulting in a detrimental impact on rice yield and quality if not properly controlled [2].

Different operations have been attempted to control weeds, with chemical and mechanical weeding being widely used in rice fields nowadays. Conventional chemical weeding sprays herbicides uniformly to cover the total field, regardless of the presence of weeds or not, resulting in high herbicide costs. Overuse of herbicides in agriculture causes catastrophic environmental pollution problems, especially in China [3]. Another widely adopted weeding method is mechanical weeding, which is much more efficient but generally unsatisfactory in terms of weed control performance, causing differences in the bending of rice rows, leading to contact between weeding hoes and rice plants and potentially causing rice plant damage [4–6].

In this case, precise identification of rice plants is conducive to control weed growth, because it provides necessary information for subsequent decision-making and implementation procedures.

that, in the process of feature selection using genetic algorithm, some features may not be selected, which reduces the accuracy of selecting the best features to some extent. Therefore, more features selection methods need to be carried out to optimize features. More recognition models such as decision tree and support vector machine should be compared, and the best recognition model can be used by comparing the recognition results. In future studies, the parameters that can better reflect the tactile signal characteristics should be introduced to further improve the recognition accuracy of sensor. In addition, appropriate transplanting periods should be selected according to the agronomy of rice plant growth (bending strength of the stem). The sensor should be waterproofed in the future to facilitate field measurement.

5. Conclusions

In this study, a rice plant recognition sensor was developed using a tactile method and machine learning algorithm. Tactile information was acquired from voltage signals of an air-pressure sensor in a gasbag which touched rice plants. During data processing, three algorithms were used to extract 13 features of tactile voltage signals, and an optimum set of features (variance, kurtosis, waveform factor, box dimension, and hurst exponent) was selected using a genetic algorithm. A rice plant and weed classifier was built using a BP neural network. The rice recognition rates for the three testing sets were 95.3%, 95.1%, and 94.9%.

Based on the proposed classifier, an experiment with three case was designed according to the different positions of the gasbag touching the rice plants and weeds. The best recognition performance was achieved by the middle of gasbag touching the rice plants, with the recognition rate being as high as 98%. The second-best recognition performance was achieved by the root of gasbag touching the rice plants, at 96%. When the end of the gasbag touched the rice plants, the recognition rate was the lowest that was observed in the experiment, at 90.67%. The dataset in this paper were obtained from a single rice variety, so the data of the corresponding varieties need to be obtained to train the classifier for the recognition of other rice varieties. The experiment proved that tactile-based recognition of rice plants is a promising method.

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Intra-row weed density evaluation in rice field using tactile method

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ABSTRACT

Accurate evaluation of weed density is crucial for effective utilization of herbicides, improvement of rice quality, and reduction of herbicide dosages. The application of visual methods is disadvantageous because intra-row weeds are blocked by the canopies of adjacent rice plants. Therefore, an innovative tactile sensing method is proposed. A flexible gasbag filled with special microstructures distributed over its surface was developed. The tactile data of weed density were generated through contact between the microstructures and weeds, and the data were measured using the voltage value of a barometric sensor mounted inside the gasbag. The tactile time series was processed using fractal theory and Hilbert–Huang transform (HHT), and the discriminating features of the weed density were acquired. The discriminating features were input into a neural network to train a weed density classifier to evaluate the weed density. The results of the feasibility experiment demonstrated that the evaluation accuracies for high-density, medium-density, and low-density weeds were 95.4%, 91.8%, and 87.9%, respectively, with an average accuracy of 91.7%. The field validation test demonstrated that the visual-based method had an average classification accuracy of 64.17%, whereas the proposed method had an average accuracy of 77.04%, experimentally demonstrating superior accuracy over the image-based method.

1. Introduction

Intra-row weeds have favorable conditions for growth while competing with rice plants for water, nutrients, and sunlight in a rice field ecosystem compared with that of inter-row weeds because they grow closer to rice plants. Presently, chemical weeding is the main method used for weeding. However, uniformly spraying pesticides over large areas for chemical weeding often leads to problems such as chemical damage to rice, soil and water pollution, and pesticide residues. Accurate evaluation of intra-row weed density to effectively spray pesticides on demand can reduce the amount of chemical herbicide used. The pesticide spraying system can adaptively control the pesticide dose according to the inter-row weed density using it as the input information for the pesticide spraying controller. Therefore, it is crucial to develop a technique that can effectively evaluate the intra-row weed density in crop fields.

Weed perception and grade classification are the main techniques used for weed density evaluation. Several researchers have conducted studies on weed perception (Dadashzadeh et al., 2020; Tshewang et al., 2016; Feyaerts and Van Gool, 2001; Alonso-Ayuso et al., 2018). Jin et al. (2012) proposed an image segmentation algorithm to distinguish between grass weeds and rice crops based on different color features. Tang et al. (2016) used Gabor wavelet to extract texture features and designed a three-layer back propagation (BP) neural network to identify weeds in a field. A few studies in this field have researched the recognition of crops based on their morphological features. Wu et al. (2009a, b) developed a weed identification method for a cornfield. The images acquired from the cornfield were processed and the morphological features of the target object were used as the input vector to a support vector machine (SVM), and the correct recognition accuracy was 98.3%.

The abovementioned methods for weed detection are based on the effective expression and accurate extraction of crop colors, textures, and morphological features. However, the physical appearance of weeds drastically change with each growing stage. Additionally, in a rice field ecosystem, the image processing performance is severely affected by complex paddy backgrounds due to the presence of cyanobacteria or green algae, variable lighting conditions in the field, and occlusion or overlapping of rice and weed leaves (Montalvo et al., 2012; Bakker et al., 2008; Jiang et al., 2015). Hence, these methods are ineffective for weed perception, and innovative perceptual methods are required for paddy field environments.

Tactile perception identifies an object through contact sensing,

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types of weeds should be considered to expand the training samples to improve the universality of the method.

(iii) The weed density was divided according to the number of weeds in the weed statistical area. However, the specific conditions of the spraying equipment and chemical efficacy were not considered. The accuracy of weed density division should be further verified.

(iv) Tactile signal acquisition depends upon manual segmentation. In the future, multi-sensor method will be incorporated to investigate continuous real-time signal acquisition. Additionally, the excitation response time of the model in the actual operation will be studied.

CRediT authorship contribution statement

Xueshen Chen: Conceptualization, Methodology, Writing – review & editing, Visualization, Project administration. **Yuanyang Mao:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Yuesong Xiong:** Conceptualization, Data curation, Visualization, Methodology, Validation. **Long Qi:** Funding acquisition, Resources, Supervision, Project administration. **Yu Jiang:** Funding acquisition, Resources, Supervision, Project administration. **Xu Ma:** Resources, Supervision, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Research Article

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Overexpression of *EiKCS* confers paraquat-resistance in rice (*Oryza sativa* L.) by promoting the polyamine pathway

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Abstract

BACKGROUND: Paraquat is used widely as one of the bipyridine herbicides, which generates reactive oxygen species to cause cell death. With a growing number of paraquat-resistant weeds, the mechanism of paraquat-resistance in plants remains unclear. This research verified the functions of a previously confirmed putative paraquat-resistant gene, *EiKCS*, from paraquat-resistant goosegrass by genetic engineering in a single overexpressing line in rice.

RESULTS: Overexpression of *EiKCS* improved paraquat resistance in transgenic rice (KCSox). Pre-applied (12 h) exogenous spermidine (1.5 mmol L^{-1}), alleviated the injury of paraquat in rice. Paraquat induced injury in KCSox was 19.57%, which was lower than 32.22% injury it induced in wild-type (WT) rice. The paraquat-resistant mechanism was through the increased activity of antioxidant enzymes and the overproduction of endogenous polyamines. The spermine content in KCSox was more than 30 μg mL^{-1}, while that in WT rice was less than 5 μg mL^{-1}. Quantitative proteomics showed that β-ketoacyl-coenzyme A (CoA) synthase (51.81 folds) encoded by the transgenic *EiKCS* gene promoted the synthesis of the proteins involved with the polyamine pathway. The synthesized putrescine was promoted by the arginine decarboxylase (ADC) pathway. The spermidine synthase I (1.10-fold) and three eceriferum cofactors (CERs) were responsive to the paraquat stress. We validated putrescine ($C_{18}H_{20}N_2O_2$) spermidine ($C_{28}H_{31}N_3O_3$), and spermine ($C_{38}H_{42}N_4O_4$) in this study.

CONCLUSION: *EiKCS* encoding β-ketoacyl-CoA synthase from goosegrass has been shown as an ideal candidate gene for engineering genetically modified organism (GMO) crops, as its overexpression does not only bring paraquat-resistance, but also have potential benefits without decreasing yield and rice grain quality.

Supporting information may be found in the online version of this article.

Keywords: paraquat resistance; polyamines; goosegrass (*Eleusine indica* L.); GMO crops; rice (*Oryza sativa* L.)

1 INTRODUCTION

Paraquat (1,1′-dimethyl-4,4′-bipyridinium dichloride) is a photosystem I (PSI) inhibitor used in agriculture and gardening worldwide, because it rapidly kills weeds and green plants.[1] In green plants, paraquat interrupts normal electron flow through PSI by excepting electrons instead of ferredoxin. This turns paraquat^{2-} into a free radical, which, in turn, disrupts cell membranes.[2] This action of paraquat results in the production of toxic reactive oxygen species (ROS), including hydrogen peroxide (H_2O_2), hypochlorous acid (HClO), and free radicals O^{2-} which facilitate the toxic action of paraquat.[3] In addition to its control efficacy of weeds, paraquat is also one of the most widely used herbicides in bipyridine herbicides for its timely inactivation upon reaching the soil.[4]

It has been reported that over 30 species of weeds have developed resistance to paraquat due to the repeated applications of commercial paraquat for decades worldwide (http://www.weedscience.org). A dominant (or semi-dominant) single gene was identified to underlie the resistance to paraquat, which was also identified to be involved in vacuolar sequestration.[5–7] Goosegrass (*Eleusine indica* L.) is one of the most serious invasive weeds in crop fields in many countries due to its paraquat-resistance.[8–10] Polyamines have been identified to be associated with the

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mutants.[44] These results may explain that polyamines metabolized paraquat based on their chemistry homology and interacted with the ROS generated by paraquat.

This study provides the latest results from manipulating the polyamine biosynthetic pathway in cereals using genetic engineering since it was reported 20 years ago.[45] Molecular formulae of the dominant benzoylated polyamines in rice were further derived in this study based on other previous reports.[28] The overexpression of the *EiKCS* gene, which significantly increased endogenous polyamines in rice, can be used to improve paraquat resistance in crops and shows great potential in medical and industrial applications.

In human medicine, it is known that polyamines treat cancer by the designing of anticancer agents, and polyamine-regulated genes are worth being identified in links of carcinogenesis or apoptosis.[46] The spermine and spermidine in tumor cells can inhibit cellular apoptosis.[47] The polyamines are synthesized from arginine and proline metabolism, and the polyamine pathway is a potential target for cancer chemoprevention.[48,49] The gene of ODC in the polyamine pathway making polyamine synthesis associated with cancer polyamine function for the therapeutic intervention.[50,51] We propose that *EiKCS* in plants related to polyamine synthesis may be of medicinal value. For example, the ectopic expression of a *KCS* gene from *Cardamine graeca* in *Brassica* oilseeds produces more nervonic acid oils that are beneficial for human and animal health.[52]

In addition, this study demonstrated that the polyamine metabolic pathway was associated with the enhanced paraquat-resistance in the KCSox rice, providing new evidence for the interaction of the polyamine metabolic pathway with other metabolic routes.[27] The polyamine synthetic pathway in plants showed that putrescine was synthesized via ODC or ADC.[29] In *Arabidopsis thaliana*, the lack of an *ODC* gene in its genome causes the absence of ODC.[28] In this study, both ADC and OCD were found, but putrescine is mainly synthesized through the ADC pathway in the KCSox rice under paraquat stress.

Moreover, significant expression variations of 15 proteins involved with polyamine metabolism were detected under paraquat stress. And the folds of the expression changes were much higher than those detected by the same quantitative proteomic methods in a previous study.[53] The increased expression of the proteins well explained the accumulation of polyamines, especially the Q9SMB1. And the lack of spermine metabolism protein could infer that spermine accumulation in rice was the main response to paraquat stress. The transient increase of MDA content in the KCSox rice could infer that MDA forming was related to fatty acid degradation affected by the *KCS* gene. Also, we discovered an association between the EiKCS protein and three CER cofactors in rice, which expanded the understanding of the function of CERs in VLCEAs extension in other species.[54–57]

By now, 21 *KCS* genes have been identified in the *Arabidopsis* genome, but their substrates are still unknown. It is well recognized that the same kind of KCSs can catalyze the acyl extension of VLCEAs with different chain lengths, and different KCSs can catalyze substrate of the same structure.[58] *WSL1* encodes *β*-ketoacyl CoA synthetase (KCS) in rice, and the content of VLCEAs C20-C24 decreased significantly in leaf and sheath of the *wsl1* mutant.[59] Osgl1-1/WSL2 was found to be homologous to CER3 in *Arabidopsis* and GL1 in maize.[38] Another *KCS* gene, *WSL4*, was found in rice, whose defective mutation leads to loss of wax crystals, while overexpression leads to increased wax content.[60,61] Meanwhile, the gene encoding KCS in FAE1 mutation was identified in *Brassica napus* L., which caused accumulation of both C20 and C22 fatty acids.[62] A *HvKCS6* gene homologous to *AtCER6* (*AtKCS6/AtCUT1*) was identified in a barley mutant, which changed sensitivity responding to water limitation.[63] And 33 genes in barley from the *KCS* gene family were identified in an annotation map of the KEGG metabolic pathway, which had up-regulated or down-regulated trends under drought stress.[64,65]

Although the paraquat-tolerant KCSox rice showed similar effects on proteins involved in photosynthesis and light-harvesting processes with a mesosulfuron-methyl resistant *Alopecurus aequalis*,[40] no significant decline was observed in the yield and quality of the KCSox rice (Tables S6 and S7). The 1000-grain weight and grain filling rate were not affected by water limitation as a drought treatment in the field. All these traits give the *EiKCS* gene a niche as a candidate gene for engineering GMO crops. Its overexpression provides crops with enhanced paraquat resistance and other potential benefits without decreasing yield and quality.

5 CONCLUSIONS

We successfully cloned *EiKCS* gene from the paraquat-resistant goosegrass and transformed it into rice plants. Its overexpression and characterization demonstrated that *EiKCS* conferred paraquat-resistance in rice. This study provided useful insight for further functional studies of genes in GMO that show resistance to non-selective herbicides.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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Active Disturbance Rejection Control Design for the Hydraulic Actuator on Weeding Machine

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Abstract: A weeding machine can sometimes cause plant damage while working in the paddy field due to the seedling line bending phenomenon. Thus, we introduce a computer-vision-based automatic seedling avoidance system for the weeding machine, with a hydraulic cylinder actuator driving the weeding wheels according to the guidance information. This paper aims to study and design a Linear Active Disturbance Rejection Control (LADRC) controller for the hydraulic system. The proportional directional valve has a large input dead zone, decreasing the controller's performance and causing oscillation of the system output near the setpoint. We designed a nonlinear dead zone compensation module and proposed a residual dead zone compensation method, taking advantage of the Extended State Observer (ESO). A well-behaved hydraulic position servo system was designed and tested in Simulink simulation and on an experimental platform based on the compensation method. The results show that the system performance meets the requirement with approximately no overshoot, response time within 0.7 s, and steady-state error within 0.7 mm on the experimental platform.

Key Words: weeding machine, hydraulic system, dead zone compensation, LADRC

1 Introduction

Weeds can cause severe losses in the paddy field ecosystem during crop production. With the development of agricultural technology, weeding has become an essential part of modern agriculture. Therefore, how to efficiently weed and save the labor required for weeding to improve economic benefit has become a valuable and study-worthy problem.

Mechanical weeding is an essential substitute for the chemical weeding method with efficiency and less pollution[1]. However, its development is restricted for the mechanical weeding parts can cause plant damage[2].

In a paddy field, there is always misalignment of the seedling rows. The entire seedling rows could be C-shaped, regardless of using a transplanter or not, and manually driving the weeding machine can easily cause seedling damages. As a result, it is necessary to design an automatic correction system for the weeding wheels. We call it alignment control by real-time controlling the weeding wheels along the direction perpendicular to the row of rice seedlings within a proper range.

Researchers have been studying the seedling avoidance issue. Nakamura's team investigated the plant damage of their rice field weeding robots[3]. Romeo et al. designed a crop-background image segmentation system based on image histogram analysis[4]. Pérez et al. developed a GPS-based weeding system with alignment control[5], composed of a path control system for weeding components and a real-time dynamic differential global satellite positioning system (RTK-GPS). Kanagasingham et al. attempted to integrate GNSS, compass, and machine vision into a rice field weeding robot to achieve fully autonomous navigation for the weeding operation[6]. Sori et al. used capacitive touch sensors to detect the rice plants and an azimuth sensor for turning detection on their weeding robot[7]. Guerrero et al. proposed a vision system based on geometry for crop rows and weeds detection in maize fields[8]. Bah et al. proposed a crop row detection algorithm named CRowNet for crop row detection, introducing Deep Learning into the visual navigation method for the seedling avoidance issue[9].

However, lots of research on the seedling avoidance problem of weeding machines is carried out from the perspective of agronomy and mechanics but less work from that of control.

Fig.1 shows one typical appearance of a weeding machine with an automatic weedling avoidance system. The weeding wheels are usually heavy and need a hydraulic system to drive them. Since the purpose of introducing a hydraulic system is to move the weeding wheels to avoid rice seedlings, the solenoid valve is not the best choice due to its low precision. Instead, the proportional directional valve is a better option with higher precision than the solenoid valve and a lower price than the servo valve.

The complicated working environment must be considered to design a hydraulic displacement servo system. For example, the reference signal dithering due to the camera shaking, system parameter changes caused by long-term mechanical wear, and soil resistance during weeding operations can decrease the system performance. Thus, we need a control algorithm with better robustness. When it is difficult to build an accurate mathematical model of the hydraulic system with nonlinear characteristics, the Active Disturbance Rejection Control (ADRC) algorithm can suit our application just fine.

Mr. Han proposed ADRC in the 1990s[10], and its main idea is the "total disturbance." The total disturbance includes the disturbance signal and the so-called "internal disturbance," which includes the object's unmodeled nonlinear characteristics and high-frequency dynamic characteristics.

However, there are quite a few parameters introduced by

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基于触觉感知的水稻行弯度测量装置设计与试验

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摘要： 为解决水田环境下稻行弯度信息提取问题，提出一种触觉感知方法。根据除草期内水稻与杂草的生理高度及力学差异，基于弯曲传感器设计了一种稻株定位的感知梁。通过力学分析，建立了感知梁与稻株接触作用的力学模型，结合稻株抗弯强度，确定了感知梁抗弯刚度的设计原则。在此基础上，构建感知梁标定试验装置，获得了装置偏距与感知梁电压差的映射关系。基于多传感器技术，通过采集4根感知梁的电压(形变)变化特征，计算出稻行弯度。为检验测量装置的精度及稳定性，进行了田间试验，行进速度试验表明：行进速度的提高不利于测量结果的稳定性，在行进速度为1.5 m/s时，平均误差为5.90 mm，最大误差为8.30 mm；稻穴株数试验表明：测量误差与稻穴株数有一定的相关性，稻穴株数为6株以上的测量误差最小，平均误差为2.56 mm，4～5株的平均误差较大，为4.36 mm，1～3株测量的平均误差最大，为6.17 mm；水层厚度试验表明：测量误差与水层厚度没有明显相关性，误差均能控制在14 mm范围内。该装置测量结果可满足避苗机械除草等精准控制的要求。

关键词： 水稻；除草；触觉感知；识别

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Design and Experiment of Tactile Sensing Device for Measuring Rice Curvature

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Abstract: In order to solve the technical problem of extracting rice row curvature information in paddy field environment, a tactile sensing method was proposed. According to the mechanical difference and the physiological height of rice and weeds during the weeding period, a kind of tactile beam which was based on bending sensor was designed. Though the mechanical analysis, a dynamic model of the contact between tactile beam and rice seedlings was established. Combined with the bending strength of rice seedling, the principle of the bending rigidity of the tactile beam was determined. Through building the tactile beam calibration test bench, the functional relationship between the device offset and the pressure difference of tactile beam was obtained. On this basis, based on multi-sensor technology, according to the voltage characteristics generated by the four tactile beams, the calculation method of rice seedling bending was proposed. In order to verify the measurement accuracy and the stability of the device, several field experiments were carried out. The test of speed of travel showed that the acceleration of travel speed was harmful to the stability. At the speed of 1.5 m/s, the average relative error was 5.90 mm and the maximum error was 8.30 mm. The test of rice hole number indicated that the measurement error became lowest when the number of rice hole was more than 6 and the average error was 2.56 mm. The average error was 6.17 mm when the number of rice hole was between 1 and 3. The average error was 4.36 mm when the number of rice hole was between 4 and 5. The test of water layer thickness indicated that there was no significant correlation between measurement errors and water layer thickness and the lateral offset of neighboring rice seedlings can be controlled within 14 mm. The

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基于线性自抗扰的稻田除草对行控制系统设计与试验

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摘 要：为降低水稻机械除草的行间伤苗率，该文基于线性自抗扰技术开展水稻田间除草对行控制系统研究。在苗带信息获取的基础上，针对水田作业环境设计了一种基于线性自抗扰的对行液压控制系统。采用内、外滑梁结构，实现对行执行机构对除草部件作业路径的避苗调控。应用Amesim与Matlab联合仿真方法，构建了对行液压控制系统仿真平台，分别对线性自抗扰算法和PID算法进行了控制器设计及仿真比较，仿真结果表明：在加入扰动情况下，线性自抗扰控制系统达到期望的对行调控时间比PID减少0.1s，且抗干扰性及鲁棒性均优于PID控制算法。田间试验结果表明：行进速度和作业深度对伤苗率影响显著，最优作业参数组合为行进速度0.5 m/s，调节间距60 cm，作业深度20 cm，此时伤苗率为3.6%；性能比较试验表明：有对行控制系统的平均伤苗率为3.9%，没有对行系统控制的伤苗率为18.6%。该系控制统满足机械除草对行控制的要求，可为水田作业环境下的精准控制问题提供借鉴。

关键词：农业机械；自动化；水稻；机械除草；对行控制；线性自抗扰
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0 引 言

杂草是造成水稻产量下降和品质降低的主要原因之一[1-4]。施用除草剂是一种高效的除草方式，但除草剂的大量应用造成了杂草抗药性、作物药害、环境污染等问题[5-8]。机械除草作为一种绿色除草方式，符合国家提出的质量兴农、绿色兴农的发展方向。然而，在实际作业中，苗带变化引起行的除草部件伤苗问题严重制约了机械除草技术的发展。因此，根据苗带信息，实现对行控制是机械除草亟需解决的问题。

对行是指控制机具实时沿作物的行方向运动，使除草部件相对作物行的横向偏差控制在不会伤害作物的范围内[9-10]。国内外学者进行了相关研究，Romeo等[11]设计了一种基于图像直方图分析的作物-背景图像分割系统，该系统通过直方图判别图像的对比度和饱和度完成苗带提取，可实现苗带引导的对行控制。Pérez等[12]研制了一种基于GPS的避苗除草系统，由除草部件路径控制系统和实时动态差分全球卫星定位系统（RTK -GPS）组成，实现自动对行。国外采用机器视觉或GPS的对行控制技术主要用于旱田，针对水田的对行控制技术少有报道。在国内，因水稻种植面积广泛，致力于对行控制的研究相对较多。针对GPS导航技术的应用主要针对旱田的种植作业[13-14]，对于除草等管理作业，特别是水田管理作业一般采用机器视觉技术。由于水田作业环境的特殊性，无法获得准确的转向数学模型，因此，采用模糊控制最为常见，文献［15-16］基于模糊控制算法实现了应用于农机的自适应自动驾驶算法，但该方法涉及的参数较多，累积误差较大。近年来，为了弱化参数影响，有学者针对水田环境采用纯追踪或改进纯追踪算法[17-20]取得了较好的效果，李革等[21]用基于速度、路径弯度等线性调整前视距离的改进纯追踪方法在插秧机平台上进行了水田试验，试验结果显示作业段平均误差为0.058 m，最大跟踪误差为0.135 m，该控制算法明显提高了跟踪控制精度。但水田环境机具作业航向不稳，水田拖拉机与除草部件相距较远，通过导航方式实现对行跟踪控制，存在除草部件调节相对机身运动具有一定的滞后性，在纠偏期间除草部件对稻苗不可避免造成损伤。因此，有学者采用建模方法或PID等经典算法直接控制除草部件，实现除草部件避苗控制。陈勇等[22]和郭伟斌等[23]进行了除草机器人机械臂的控制研究，通过建模、求逆解，实现了除草机械臂的控制。胡炼等[24-25]采用双阈值死区控制算法实现了除草部件的主动避苗。上述控制方法根据除草部件与作物的相对位置，控制除草部件的作业路径，均能达到避苗作业效果，但采用建模及控制算法的应用局限在旱田环境，水田作业环境复

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水稻机械除草避苗控制系统设计与试验

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摘 要:为使除草部件的作业路径能避开稻苗,降低机械除草的伤苗率,设计了一种机器视觉与液压伺服控制技术相结合的避苗控制系统。采用垂直俯拍方式,提取了稻苗冠层边界的形心图像坐标位置,通过小孔成像模型转换,获得稻苗地面坐标位置及除草部件中心与苗行中心线的距离。建立了平行四杆纠偏机构的液压控制系统模型,获得纠偏调控量与液压推杆的映射关系。基于PID控制算法,建立了比例阀液压系统数学模型,应用Matlab/Simulink仿真表明:模型的稳态响应时间约为0.28 s,静差约为0.07 mm。进行了台架试验,结果表明:图像处理系统提取苗行中心线误差不超过3 cm;正交试验结果表明:避苗控制系统中伤苗率的影响因素主次顺序为:行进速度、移栽天数、稻苗间距,当行进速度为0.8 m/s、移栽天数为10 d、稻苗株距为12 cm时,伤苗率为2.48%。

关键词:农业工程与信息技术;水稻;机械除草;避苗控制;PID算法;仿真分析

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Design and test of control system for rice mechanical weeding and seedling-avoiding control

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Abstract: To enable the weeding component to avoid the seedling on the operation path and reduce the seedling injury rate of machinery weeding, an automatic seedling avoidance control system based on machine vision and hydraulic servo control is proposed in this paper. First, by the way of overshoot, the centroid image coordinate position of the seedling canopy is extracted. Second, through pinhole imaging principle conversion, the seedling ground coordinate position and the distance between the weeding component and the center line of rice row are obtained. Third, a hydraulic control systems model of parallel four connecting rods of organizations is built, and the mapping relations between deviation control and hydraulic stem is acquired. Finally, based on PID algorithm, a proportional valve hydraulic system mathematical model is built. The Matlab/Simulink simulation shows that the model has a steady-state response time of 0.28 s and a

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高效型水田行-株间同步机械除草装置设计与试验

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摘　要: 为了有效去除水稻行间、株间杂草，提高机械除草的作业效率，研制了一种高效型水田行-株间同步机械除草装置。该装置与水田插秧机底盘配套，分别配备株间和行间除草部件，可同时对株间、行间杂草及土壤进行剪切、翻耕，并采用二级仿形机构配合除草部件完成作业。田间试验结果表明: 影响除草率和伤苗率的主次顺序均为前进速度>除草轮类型; 随着机具前进速度增加，除草率和伤苗率均先降后升。综合试验结果表明: 伞状除草轮(A)平均除草率最高，在 0.7m/s 和 1.0m/s 前进速度下，株间平均除草率为 74.6%，整机平均除草率为 83.6%，平均伤苗率为 1.6%，符合水稻田机械除草作业的技术指标。

关键词: 水稻; 水田除草装置; 机械除草; 高效

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0　引言

稻田杂草是制约水稻产量和品质的主要因素。化学除草是稻田杂草防控的主要方式，我国稻田化学除草面积约占种植面积的 90%以上，而长期、高频的施药会造成杂草抗药性[1]、作物药害[2]及环境污染[3]等诸多负面问题。机械除草是一种环境友好型的除草方式，可以有效缓解当前化学除草弊端，符合国家提出的质量兴农、绿色兴农的农业产业发展方向。

我国的水田除草机械特别是水田株间除草机械研究尚处在理论和试验研究阶段。东北农业大学研究人员[4-6]设计了一种株间除草装置，华南农业大学齐龙等[7]发明了一种株间机械弹性触觉除草器等，但尚未在生产中广泛应用。日本的研究机构和农机生产企业已经开发了一系列的水田除草机，如日本美善株式会社研发的水田除草机[8]、日本和同产业研发的步进式水稻中耕除草机[9]及日本三菱农机公司[10]生产的水田除草机等，均在生产中得到了较好的应用，但价格昂贵。稻米是我国主要的粮食作物，长期依赖日本的水稻生产机械也会影响我国农业生产的战略安全，因此迫切需要提高我国水稻机械除草关键技术和装备的自主研发水平。

由于水田环境的复杂性和水稻密植的农艺特点，水稻生产中采用机械除草方式存在伤苗率高、除草率低、适应性差等问题。水稻种植的株距较小(机械化移栽株距: 10~17cm)，株间杂草不易去除，多次作业又会增加伤苗率，因此株间机械除草技术是水田机械除草的“瓶颈”问题。鉴于水稻机械除草的重要性，针对水稻机械除草技术中的难点，提出了一种可同步去除行-株间杂草的水田机械除草技术，并研制了一种高效的水田机械除草装置，以解决现阶段机械除草效率低、伤苗率高的问题。

1　整机结构设计

1.1　整机结构与工作原理

研制的高效型水田行株间同步机械除草装置主要由乘坐式插秧机底盘、挂接装置、机架、四杆仿形机构、株间除草轮及行间除草轮等部件组成，如图 1 所示。为探究除草机不同除草部件的作业效果，设计可同时去除行-株间杂草的试验装置(3 行)，工作宽幅为 0.9m。工作前，根据水田杂草高度调节株间除草轮的安装高度，位置太高会导致杂草清除不彻底，太深会导致稻苗根系受损; 根据稻苗生长大小调节株间除草轮横向位置，防止机具伤苗。除草作业时，除草装置以一定的速度前进，株间除草轮触土后绕轴滚动旋转，深入土壤表面下约 1~5cm 来去除作物株间内的杂草; 行间除草轮沿水平方向进行绕轴滚动，通过螺

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水稻机械除草技术装备研究现状及智能化发展趋势

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摘要: 稻田生态系统中的杂草是造成水稻产量下降和品质降低的主要原因之一，施用化学除草剂会带来作物药害、杂草抗药性和环境污染等诸多负面问题，机械除草作为一种环境友好型的绿色除草方式，可以有效地替代化学除草，缓解施用除草剂带来的危害。本文针对水稻株间机械除草的技术难点，从苗草根系差异特点的角度对水稻株间机械除草装置研究现状进行了系统介绍，归纳了水稻机械除草新技术的类型和特点，总结了几种新型水稻机械除草装备的特色和优点。提出具有高精度杂草定位功能的智能除草技术将是未来水田机械除草技术发展的必然趋势。

关键词: 农业机械; 水稻; 株间除草; 智能除草; 研究现状; 发展趋势
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Present status and intelligent development prospects of mechanical weeding technology and equipment for rice

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Abstract: Weed is one of the main causes for decline of rice yield and quality. The application of chemical herbicide has brought many negative problems, such as crop toxicity, weed resistance and environmental pollution, etc. Mechanical weeding, as an environmentally-friendly weeding method, can effectively replace chemical weeding and alleviate the harm caused by herbicide. Aiming at the technical difficulties of mechanical weeding among rice plants, the research status of mechanical weeding devices among plants were systematically introduced from the perspective of root difference characteristics of weed seedlings. The types and characteristics of new mechanical weeding technology were introduced, and the unique features and advantages of several new mechanical weeding equipments for rice were summarized. It is pointed out that intelligent weeding technology with high precision and high weed localization function will be the inevitable development trend of mechanical weeding technology for rice in future.

Key words: agricultural machinery; rice; intra-row weeding; intelligent weeding; research status; development trend

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气动式水稻株间机械除草装置研制

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摘要:【目的】针对水稻株间机械除草自动化程度低、难度大的问题，在机器视觉识别定位技术研究的基础上，研制一种气动式水稻株间机械除草装置。【方法】采用机械设计理论、离散元动力学仿真方法结合田间试验，研制出气动式水稻株间机械除草装置。首先对气动式株间除草机构的结构进行设计，运用运动学方程计算并确定机构的几何参数，通过Pro/E 运动学仿真验证机构的可行性；然后对除草刀齿与水田土壤的相互作用过程进行仿真，并对仿真结果进行验证试验；最后进行田间试验验证整机工作性能，并利用三因素五水平二次旋转正交试验对影响除草率与伤苗率的工作参数进行分析。【结果】气动式水稻株间除草机构连杆长 35.00 mm，摆杆长 72.24 mm，除草部件到回转中心水平距离为 84 mm，垂直距离为 191 mm。离散元动力学仿真分析表明，倾角为 10°的弯齿刀除草刀齿与土壤的接触阻力较小，阻力平均值为 3.12 N，且对土壤的扰动程度较大，受影响的面积达 149.69 cm^2。田间试验中，在机具前进速度 0.25 m/s、气缸伸缩速度 0.45 m/s 和除草深度 2.5 cm 的工作参数下，平均除草率为 83.91%、伤苗率为 3.63%。【结论】该机具满足除草率大于 80%、伤苗率小于 4% 的设计要求，能够满足水稻株间避苗除草的作业要求。

关键词: 水稻田; 株间除草; 离散元; 动力学仿真; 农业机械
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Design and experiment of pneumatic paddy intra-row weeding device

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Abstract: 【Objective】In order to solve the problem of low automation and high difficulty of mechanical intra-row weeding in paddy field, a pneumatic paddy intra-row weeding device was developed based on the recognition and positioning technology of machine vision.【Method】The mechanism of pneumatic intra-row weeding device was designed by applying the principle of mechanical design, discrete element dynamics (DEM) simulation method and field test. Firstly, the structure of pneumatic intra-row weeding device was designed, and the geometric parameters of the mechanism were calculated using the kinematic equations. The feasibility of the

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80%苯·吡·西草净WP防治水稻移栽田一年生杂草试验

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摘 要：[目的]为明确80%苯·吡·西草净WP在华南地区稻移栽田中杂草的防除效果、最佳使用剂量和安全性进行研究。[方法]2017—2018年采用大田药效试验，与华南地区3种常规单剂对比，试验采用毒土法，并定期进行田间药效调查。[结果]80%苯·吡·西草净WP在双季稻移栽田杂草2叶期，用推荐剂量480～600g a.i./hm²进行处理，能有效防除一年生杂草。[结论]80%苯·吡·西草净WP在推荐剂量的使用范围内对水稻安全，且高剂量对水稻无影响，是一种理想的水田除草剂，适合在华南地区推广使用。

关键词：苯·吡·西草净；水稻；安全性

水稻移栽技术是保证我国水稻产量与质量，提高农民经济收入和促进我国农业健康发展的一项重要栽培技术[1]。水稻的移栽技术可以有效提高水稻单位面积产量，同时便于集中管理防治病害，并且缩短生育期，因此华南地区作为双季稻主产区，十分适于使用水稻移栽技术。随着除草剂品种单一化以及抗性杂草等新问题不断出现，即便是在移栽稻田，草害问题仍旧突出，并且愈发严重。所以，水稻移栽田的草害防控是提高该地区水稻产量质量的关键工作。目前，除草剂的发展应用进入了新的发展阶段，除草剂混配制剂的研发已成为一种发展趋势，可以减少施药次数、克服杂草抗性、降低药剂毒害和节省除草成本等[2]。

1 材料和方法

1.1 试验对象

研究对象为华南地区水稻移栽田，试验于2017年下半年、2018年上半年在广东省肇庆市封开县渔涝镇农作物病虫测报站进行。前茬作物为水稻，水稻品种为华航31号，栽培方式为移栽。晚稻移栽时间为2017年8月5日、2018年3月26日。试验于同一田块，杂草均为稗草（Echinochloa crusgalli （L.） Beauv）、莎草（Cyperus rotundus L.）、千金子（Leptochloachinensis （L.） Nees）和部分阔叶草等。

1.2 试验方法

1.2.1 试验设计

试验药剂为80%苯·吡·西草净WP（56：4：20），由辽宁三征化学有限公司提供。3种对照药剂分别为50%苯噻酰草胺WP，由哈尔滨富利生化有限公司提供；20%吡嘧磺隆WP，由连云港市金囤农化有限公司提供；25%西草净WP，由吉林金秋农药有限责任公司提供。

试验共设8个处理，80%苯·吡·西草净WP 480、540、600、1080 g a.i./hm²，50%苯噻酰草胺WP 288 g a.i./hm²，20%吡嘧磺隆WP 24 g a.i./hm²，25%西草净WP 656.25 g a.i./hm²，空白对照（喷施等量清水）。每个处理4次重复，随机区组排列，小区面积5m×6m。

1.2.2 施药时期及天气情况

试验均在在水稻移栽后7d以后，杂草萌发至2叶期施药。2017年施药为8月12日上午9：00～12：00，喷药期间天气多云，气温24℃～33℃，药后24h内无降水；2018年施药时间为4月2日上午9：00～12：00，喷药期间天气多云见晴，气温24℃～32℃，微风，风速1.1m/s，药后24h内无降水。试验地为砂壤土，pH为5.46，有机质含量16.5g/kg。施药方式为毒土法，拌湿润细沙或土撒施处理。空白对照区撒施等量细沙或土。

1.3 调查内容和方法

1.3.1 防效调查

药后0d（覆盖度和基数调查）、15d（株数调查）、30d（株数调查）、45d（株数和鲜重调查）、齐穗后（安全性调查）共5次调查，每个小区随机选择4个点，每点0.25m2方块进行抽样调查。根据调查数据，按照公式（1）计算

$$E=\frac{C-T}{C}\times 100 \quad (1)$$

式中：E为防治效果（%）；C为空白对照区杂草株数或鲜

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