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# Optimization and experimental validation of reinforcing fibers winding pattern for carbon/carbon composite crucible preform

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## Abstract

In order to address the problem of transition slip between the cylindrical segment and the ellipsoidal head segment of the carbon/carbon composite crucible preform with asymmetrical structure during the winding process, a winding pattern combining geodesic and non-geodesic is presented innovatively. Firstly, the formulae for the winding angle and the winding central rotation angle of the crucible cylindrical segment and the ellipsoidal head segment are established, and the fourth-order Runge-Kutta numerical method is employed for parametrical design. The two-tangent point winding path is determined by analyzing the effect of the cylindrical segment's winding pitch, different ellipsoidal head segment heights, and slip coefficient on the winding angle. Secondly, the needle disk winding method is proposed to address the slight winding angle at the open end of the cylinder, making it easier to hang the yarn. Finally, the experiment on dry yarn winding of 3k carbon fiber (linear density: 198 g/km) is carried out. The results indicate that the relative error rate between the actual winding angle and the theoretical design angle

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*Review*

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# C/C soft-hard mixed preform multi-units compression compaction viscoelastic rebound technique and optimization

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## Abstract

To address the issue of non-uniform fiber volume fraction between layers in the compression compaction process of C/C soft-hard mixed preforms, a multi-unit variable duration cyclic compression compaction process based on the inter-laminar fiber compression viscoelastic deformation behavior is proposed. This process aims to gradually eliminate the rebound characteristics of inter-laminar fibers and reduce the error of inter-laminar fiber volume fraction. The mapping relationships between the number of units, holding duration, and compaction times with the rebound height of inter-laminar fibers are established using data fitting. The compression compaction process is determined using the Box Behnken response surface design method, and digital devices are utilized for preform compaction experiments. The micro-morphology of the preform is observed using an optical microscope, and the density of inter-laminar fibers

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# 单边双针双线摆动缝合轨迹设计及实验验证

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**摘要**：针对单边双针双线缝合头插刺机构无法缝制3 mm以上厚度预制体的问题，提出一种不对称的8字形运动轨迹并对插刺机构的运动轨迹进行了设计。首先，基于单边双针双线缝合工艺对插刺机构运动学进行分析，确定摆动插刺机构各构件的尺寸；其次，在ADAMS中构建机构模型并进行轨迹分析；最后，通过实验样机进行缝合实验。实验结果表明，设计的缝合机构可将实际缝合厚度不足3 mm提高到8 mm，并在缝合过程中形成稳定线环，验证了不对称8字形缝合工艺及摆动插刺机构的可靠性。

**关键词**：单边双针双线缝合；轨迹设计；摆动插刺机构设计；实验验证
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## Design and Experimental Verification of Unilateral Double-needle Double-thread Oscillating Stitching Trajectories

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**Abstract**: Due to a thickness of more than 3 mm could not be sewed using the single-sided double-needle double-thread stitching head insertion mechanism, an asymmetrical 8-shaped motion trajectory was proposed and the motion trajectory of the needle insertion mechanisms was designed. Firstly, the dimensions of various components of the oscillating insertion mechanisms were determined based on the kinematic analysis of the single-sided double-needle double-thread stitching processes. Then, a mechanism model was constructed in ADAMS and a trajectory analysis was performed. Finally, stitching experiments were conducted using the prototype. The results show that the designed stitching mechanisms may increase the actual stitching thickness from less than 3 mm to 8 mm and form a stable loop during the stitching processes, confirming the reliability of the asymmetric 8-shaped stitching technique and the oscillating insertion mechanisms.

**Key words**: single-sided double-needle double-thread stitching; trajectory design; design of oscillating needle insertion mechanism; experimental verification

## 0 引言

随着复合材料制造技术的发展，生产企业对复合材料制件形状提出了更高的要求，传统的双边缝合技术难以缝制尺寸大且曲率复杂的预制件，而单边缝合工艺很好地解决了这个问题[1-2]。单边缝合技术的主要特点是只在材料一侧进行缝合且一次性完成缝合，从而降低了生产成本、减小了复合材料的质量[3-4]。复合材料的密度小、强度高、耐磨性好、抗冲击性强，同时还具有优异的耐腐蚀性和耐高温性能[5-6]，这些特性使得单边缝合复合材料在航空航天、汽车、船舶、建筑等领域得到广泛应用[7-9]。

单边缝合技术主要有以下四种缝合方式：Tufting(簇绒)缝合、OSS(单边双针单线)缝合、Blind(盲缝)缝合、ITA(单边双针双线)缝合[10-12]。目前国内先后对Tufting(簇绒)缝合[13]、OSS(单边)缝合[14-15]、Blind(盲缝)缝合[16]开展了研究工作，然而对基于单边双针双线缝合工艺的缝合装置研制尚未见公开报道。

单边双针双线缝合工艺最初由德国亚琛工业大学ITA纺织研究中心提出并对其装备进行研制，其样机验证了单边双针双线缝合工艺的可行性，同时相比其他缝合工艺，单边双针双线缝合工艺拥有更高效的缝合速度(可达1400针/min)、

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# 基于多维度建模的碳/碳软硬混编预制体孔隙分析与单胞模型

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**摘 要** 为探究碳/碳软硬混编预制体在压实过程初始和最终密实2个阶段中孔隙分布及变化,解决成型后孔隙率无法预测的问题。基于碳/碳软硬混编预制体成型工艺构建一种三维四向孔隙模型,在无压缩载荷和施加压缩载荷2种工况下,从单胞模型的 *xoy* 平面和 *xoz* 平面2个维度、4个方向观测孔隙;从介观和微观2个尺度研究载荷下纤维形态与截面形状变化对单胞孔隙的影响,建立了纤维尺寸截面变化与孔隙率映射关系,提出影响孔隙率的尺寸系数,使预制体最终孔隙率具有可设计性;通过单胞孔隙模型计算得到预制体在压实阶段最小孔隙率。利用万能拉伸试验机对不同尺寸的预制体进行压实致密实验,得到不同尺寸预制体所受压缩载荷与高度变化曲线,揭示了预制体高度与孔隙率的关系并得到压实致密阶段最小孔隙率。实验结果表明最小孔隙率与理论模型误差小于3%,验证了软硬混编单胞孔隙模型表征预制体孔隙率的正确性。

**关键词** 碳/碳软硬混编预制体; 多维度; 单胞孔隙模型; 压实致密; 孔隙率

**中图分类号**: TB 332 **文献标志码**: A

三维四向碳/碳预制体采用碳棒与碳纤维软硬混编成型工艺,碳棒垂直于水平面按正六边形等距密排排列,纤维在碳棒间三向叠层铺放,叠层纤维间、纤维与碳棒间均有孔隙,预制体经过加压致密,孔隙率减小,纤维体积分数增加。孔隙率决定预制体纤维体积含量,从而影响预制体成型密度,最终影响复合材料力学与热力学性能。

目前,国内外学者对复合材料孔隙与纤维体积分数已有相关研究,并提出了相应的经验公式和理论模型,主要采用实验数据拟合法、弹性梁法和有限元法。Gutowski 等[1]基于科泽尼-卡尔曼方程式建立了应力与复合材料纤维体积分数的关系,并通过实验数据拟合的方法获得经验常数;Trevino 等[2]采用对数函数拟合压力与复合材料孔隙率的关系,指出了压缩系数随着织物类型变化取不同常数;胡培利等[3]通过实验的方法测量并记录压实过程中压实位移、压实载荷及构件回弹量与成型工艺参数之间的作用规律,揭示了纤维体积分数与压缩应力的关系。Chen 等[4-5]建立单层织物与多层织物压实模型,采用梁弯曲理论分析压实过程中纤维形态的变化;Kelly[6]建立了由 $n$ 个 Maxwell 模型串联的纤维压缩模型,该模型揭示了压缩应力与体积分数的关系。Green 等[7-8]建立三维正交复合材料有限元模型,进一步分析了压缩过程中纤维形态变化;刘云志等[9]根据三向正交结构复合材料预制体工艺重复性与对称性的特点,通过建立柔性导向三维正交结构预制体纤维体积分数单元模型,在碳纤维平直状态下推导出织物单元体各向纤维体积含量预测公式。

分析发现目前对孔隙率的研究主要有以下局限性:现有研究多针对两向对称性织物的孔隙,对多向铺放三维织物的孔隙形成鲜见报道;尽管部分学者建立了压缩应力与预制体的孔隙的关系,但并未分析纤维形态与截面形状变化对预制体孔隙的影响;当前研究对软硬混编预制体的孔隙分布和载荷下孔隙变化规律缺少全面系统地分析,且未建立三维四向孔隙模型,从而无法使预制体孔隙率具有可设计性。

本文基于三维四向碳/碳软硬混编预制体成型

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# 三维四向碳/碳预制件微孔板压实致密关键技术

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**摘 要** 为解决手工编织三维四向碳/碳复合材料预制件层间致密不一致的问题,基于预制件成型技术,建立碳纤维铺放高度与纤维体积含量映射关系,设计等距密排微孔板并提出适用于微孔板的加工工艺;同时为保证预制件压实致密过程中纤维流动性好,采用纤维压缩理论,对等距密排微孔板结构进行优化以降低预制件孔隙率。基于位移-压力双闭环控制策略,研制数字化压实装置,实现预制件密度在线动态调控与无损压纱,保证层间密度一致。为验证压实致密关键技术可行性,进行等距密排微孔板压实实验并对预制件进行形貌观测,结果显示采用优化后等距密排微孔板压实的预制件均匀性更好,较优化前等距密排微孔板压实的预制件孔隙率降低50%。

**关键词** 预制件; 压实致密; 等距密排微孔板; 数字化压实装置; 孔隙率
**中图分类号**:TS 103.3 **文献标志码**:A

# Key technology for compaction and densification of micro-porous plates made from 3-D four-directional carbon/carbon preforms

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**Abstract** Aiming at the inconsistent density between layers of hand-woven 3-D four-directional carbon/carbon composite preforms, the mapping relationship between carbon fiber laying height and fiber volume content were established based on the prefabricated parts forming technology. Equal distance and density micro-porous plates were designed, and processing technique suitable for micro-porous plates was established to ensure uniform density of the preforms. In order to ensure good fiber fluidity during the compaction and densification process of the preforms, the fiber compression theory was applied and the optimization of the structure for equal-distance and density micro-porous plates was carried to reduce the porosity of the preform. Based on the control strategy of displacements-pressure double closed loop, a digital compaction device was developed for on-line dynamic control of the preform density and nondestructive compaction to ensure the uniform density between the preform layers. Compaction experiments of equal-distance and density micro-porous plates were carried out to verify the feasibility of the key technology of compaction and densification process and the preforms were examined with an industrial microscope. The results show that the uniformity of preforms compacted by the optimized equal-distance and density micro-porous plates is better, with the preform porosity reduced by 50% compared to the non-optimized preforms.

**Keywords** preform; compaction density; equal-distance and density micro-porous plates; digital compaction device; porosity

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# 碳纤维增强碳/碳坩埚预制体柔性缠绕成形系统设计与实验研究

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**摘要**:为解决目前手工增强缠绕碳/碳坩埚预制体无法保证产品一致性及生产效率低下的问题,设计了一种碳纤维增强坩埚预制体柔性缠绕成形系统。基于非测地线法提出了适用于一端平面封头一端椭球封头特殊回转体结构坩埚芯模的线型设计流程,介绍了计算机辅助线型设计的各个模块及实现方法,并对设计线型进行了仿真;根据缠绕特性设计了四自由度专用缠绕机运动机构,基于可编程控制器和触摸屏设计了四自由度缠绕机控制系统,并进行了碳纤维增强缠绕实验。实验结果表明:缠绕机运行稳定,纤维可连续稳定地缠绕在芯模表面,所设计的系统可实现碳纤维增强碳/碳坩埚预制体的自动化缠绕。

**关键词**:碳/碳预制体;碳纤维增强缠绕;非测地线;线型轨迹;控制系统
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## Design and Experimental Study of a Flexible Winding Forming System for Carbon Fiber Reinforced Carbon/Carbon Crucible Preform

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**Abstract**: In order to solve the problems of product consistency and low production efficiency caused by manually reinforced carbon/carbon crucible preforms, a flexible winding forming system of carbon fiber reinforced crucible preform was proposed. The line type design process of crucible core die for special rotary body structure with one end plane head and one end ellipsoid head was presented based on the non-geodesic method. Each module and implementation method of computer aided line type design were introduced, and the design line type was simulated. A special winding machine with four degrees of freedom was designed according to the winding characteristics. The control system of four-axis winding machine was designed based on programmable controller and touch screen, and the winding tests were carried out. It is indicated that the winding machine runs stably and the fiber may be wound continuously and stably on the surfaces of the core die, and the system may realize automatic winding of carbon fiber reinforced carbon/carbon crucible preforms.

**Key words**: carbon/carbon preform; carbon fiber reinforced winding; non-geodesic; line type trajectory; control system

## 0 引言

碳/碳复合材料具有低密度、高模量、高强度、抗腐蚀、低膨胀系数、高抗热振性和高尺寸稳定性等优异特性[1-2]。随着近年来太阳能光伏发电的迅速发展,对直拉法单晶硅炉热场部件碳/碳坩埚的尺寸和寿命要求越来越高[3-4]。碳/碳坩埚由高强度碳纤维增强碳基体复合材料制备而成,但通过针刺技术成形的碳/碳坩埚预制体存在Z向连续纤维不足和周向力学性能较弱的缺点,进行增强缠绕可较好地弥补该缺点,提高制品力学性能,延长产品使用寿命[5-7]。

近年来,国内外学者对缠绕成形方法及设备进行了大量研究。邹财勇等[8]针对运载火箭中锥形零部件的缠绕技术和设备进行了研究,描述了缠绕工艺及原理,并进行了机构设计及控制系统

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# 基于运动合成的旋转变速运动建模及其驱动机构演变

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**摘 要** 为满足织机开口运动停—升—停的工艺特性及其动力学性能,提出一种基于运动合成的旋转变速运动规律构造方法。从组合机构角度提出旋转变速运动驱动机构及其演变,建立不同驱动机构的相对运动传递函数模型。采用目标优化法对旋转变速机构尺寸参数进行设计,在相同的中心距半径和转子臂初始位置的情况下建立优化函数并进行求解。仿真结果表明:偏移系数是影响旋转变速运动的关键参数,且变速运动静止时间、相对位移和速度峰值随偏移系数增加而减小;传递函数是影响旋转变速机构运动特性的重要参数,当偏移系数为 0.414 7 时,随传动比的减小,转子臂相对位移减小,同时影响旋转变速机构凸轮特性,传动比大于 0.9 后不能满足旋转变速机构约束条件;用导杆滑块机构和铰接四杆机构对齿轮机构进行代换,可近似实现变速规律相对运动的传递,其传动误差分别为 0.010、0.003 rad;通过减小中心距对铰接四杆机构重新优化可以提高旋转变速机构传动性能,满足高速运动需求。

**关键词** 运动合成; 旋转变速运动; 驱动变速机构; 偏移系数; 目标优化; 织机开口

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旋转式多臂机是目前最先进的开口装置,旋转变速机构作为旋转式多臂机的核心部件之一,其作用是将输入的匀速旋转运动转变为变速旋转运动输出。

国内外学者对旋转变速机构的研究主要集中在旋转变速机构构型、运动特性及变速运动规律的构造等方面。对于机构构型和运动特性,Staubli 公司提出固定凸轮-齿轮、固定凸轮-连杆和固定凸轮-滑块 3 种构型旋转变速机构[1],Hasçelik[2]、沈毅等[3]、周国庆等[4]基于这 3 种构型提出旋转变速机构设计理论和实验方法,研究旋转变速机构运动学和动力学模型并进行仿真分析。在变速运动规律方面,Eren 等[5]对比了简谐与摆线函数速度和加速度峰值与综框运动特性关系,周国庆等[3]利用等速摆线、简谐函数[6]组合构造变速函数,还有部分学者提出 5 次修正等速运动规律、11 次多项式[7]等来满足织机开口工艺需求。国内外学者对旋转变速机构的研究已取得一定的进展,但不同旋转变速机构演变与系统性的设计方法鲜有报道,同时,需优化变速规律以满足不同开口工艺需求。

本文基于运动合成原理提出变速运动规律的构造方法及其驱动机构之间的演变,建立不同驱动机构的相对运动传递函数模型,基于目标优化法提出多种驱动机构统一的设计模型,分析不同传递函数下的机构优化特性,为旋转变速机构的设计与分析提供理论和参考。

## 1 变速运动规律构造及模型

在织机开口过程中,取摆线函数作为变速运动规律驱动综框运动。根据运动合成原理,图 1 示出摆线函数的合成原理。在纯摆线情况下,正弦波幅是以静止线为基线,然后将其垂直量加到等速直线上。

标准摆线函数方程为

$$\varphi_4 = \beta\left[z - \frac{1}{2\pi}\sin(2\pi z)\right] \tag{1}$$

式中:$z=\varphi_1/\varphi_0$,$z\in[0,1]$,在标准摆线函数中 $\varphi_0$ 为摆线周期,$\varphi_1$ 为主轴转角,rad;$\beta$ 为幅值,rad;$\varphi_4$ 为修正摆线运动的角位移,rad。

为获得不同的曲线形状,将正弦曲线峰值的位

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# 间隔织物用钢筘运动路径规划及驱动机构设计

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**摘 要** 为满足间隔织物打纬过程中钢筘运动轨迹和动态特性等需求,基于凸轮连杆组合机构研究钢筘运动路径规划、驱动机构设计及动态特性控制方法。建立基于刚体导引的钢筘驱动机构设计模型及基于傅里叶级数的钢筘运动特性控制模型,设计并仿真验证钢筘运动路径及其运动特性。结果表明:摇杆初始角位移是决定钢筘运动路径的重要参数,设计5组不同参数的钢筘驱动机构均可实现钢筘平行打纬,最小轨迹误差率为0.02%;构建的凸轮从动运动规律可平稳控制钢筘沿其运动路径往复运动,且在钢筘运动启停阶段有50°的近似静止时间,可增加开口角和引纬角,有利于提高织机转速和满足幅宽需求;调节负向加速度峰值可获得不同惯性打纬力,为打纬机构参数化设计提供理论参考。

**关键词** 间隔织物; 钢筘; 运动路径规划; 驱动机构; 动态特性控制; 打纬机构
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间隔织物[1]是具有代表性的立体织物之一,其已逐渐应用于航空航天、医用设备、汽车用品和建筑材料等领域[2-4]。

作为织机重要组成部分,打纬机构决定了织物成形品质,常用的打纬形式有四连杆[5-6]、六连杆[7-8]和共轭凸轮[9-10]等,打纬过程中钢筘、筘座和筘座脚固结并绕摇轴往复摆动。为满足间隔织物上下表面层受力一致性,国内外学者提出不同解决办法,其中:Mountasir等[11]优化钢筘形状,以四杆机构或共轭凸轮机构驱动异形钢筘打纬;Celik等[12]优化钢筘驱动机构形式进行打纬,钢筘运动轨迹为圆弧,且前死心位置钢筘与上下表面层保持垂直,后死心位置钢筘与综框平行,满足30 mm以内间隔织物打纬。部分学者对多连杆平行打纬的构型、设计方法和运动特性进行了研究,如:韩斌斌等[13]对比不同构型的六连杆打纬机构,并通过仿真进行钢筘运动特性分析;刘薇等[14-15]提出RRR型串联RRP型六连杆打纬机构的设计方法,并分析不同机构参数对钢筘运动的影响;徐昊月等[16]基于后死心位置钢筘停留时间优化设计八连杆打纬机构。上述连杆式打纬机构的输出端均为摇杆滑块机构,钢筘只能沿导轨往复移动,其运动轨迹为直线,满足多层织物受力均匀性需求,通过优化机构尺寸参数改善打纬期间钢筘相对静止时间。Debaes等[17-18]提出共轭凸轮平行式打纬机构,打纬过程中钢筘沿水平和垂直2个方向运动,其运动路径为弧线,满足间隔织物平行打纬,且打纬时刻钢筘中下部与织物接触,增强打纬系统刚度,可实现80 mm以内间隔织物织造。

本文从间隔织物打纬工艺需求出发,基于凸轮连杆组合机构研究打纬过程中钢筘运动路径规划、钢筘驱动机构设计方法和钢筘动态特性控制,以实现钢筘运动路径和运动特性的打纬工艺,建立钢筘驱动机构设计模型及钢筘动态特性控制模型,优化设计并仿真验证钢筘运动路径及打纬机构动态特性,以满足间隔织物平行打纬需求。

## 1 间隔织物打纬工艺分析

### 1.1 间隔织物织造原理

间隔织物由2个表面层和间隔层组成,图1示出间隔织物织造原理简图。*EF*为织物—经纱水平基准面,开口时综框4、6控制的上层地经纱9形成上层梭口,综框3、5控制的下层地经纱9′形成下层梭口,综框1、2控制的接结经纱10和10′分别处于上层梭口的上方和下层梭口的下方;纬纱7、7′由剑杆同时引入上、下层梭口后,钢筘8′把纬纱打进各

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# 变速引纬规律驱动下剑带变长度非线性振动建模及其响应

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**摘 要** 为深入研究不同变速引纬规律驱动下剑带纵向振动对工艺的影响,针对变速引纬规律设计,提出基于余弦级数的引纬参数化建模方法;同时对受驱动力作用下变长度、变速运动剑带的非线性动力学研究,基于有限元法建立变长度项的剑带受迫振动模型,可知其系统质量、刚度、阻尼项均与剑带长度有关。分析不同加速度参数下引纬规律对剑带运动特性、纵向振动与工艺影响,结果表明:剑带初始加速度与负向加速度峰值是影响引纬工艺的关键参数。剑带速度与加速度峰值、进梭口时间、内应力峰值随初始加速度增加而减小;剑带握持纬纱与进梭口时振动则随负向加速度峰值增加而增加;合理调控关键参数,能协调打纬、引纬与开口等工艺时序及动态特性。

**关键词** 剑带; 纵向振动; 变速引纬; 变长度; 非线性
**中图分类号**:TS 103 **文献标志码**:A

# Modeling and response of variable longitudinal nonlinear vibration of rapier belt driven by variable speed weft insertion patterns

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**Abstract** This paper mainly studies the influence of the longitudinal vibration of the rapier belt driven by different variable-speed weft insertion patterns on the weft insertion process. For designing a variable speed weft insertion pattern, a parametric modeling method of weft insertion based on cosine series was proposed. In parallel, for the nonlinear dynamics of variable length and variable speed moving rapier belt under the action of driving force, the forced vibration model of variable length rapier belt was established based on the finite element method. The system mass, stiffness and damping terms were found to be related to the length of rapier belt. The effects of weft insertion pattern on the motion characteristics, longitudinal vibration and process of rapier belt under different acceleration parameters were analyzed. The results show that the initial acceleration and peak negative acceleration of rapier belt are the key parameters affecting the weft insertion process. The peak value of the speed and acceleration of the rapier belt, the time of entering the shed and the peak value of the internal stress would decrease with the increase of the initial acceleration. When the rapier belt holds the weft and enters the shed, the vibration increases with the increase of the peak value of negative acceleration. Reasonable regulation of key parameters can coordinate the process timing and dynamic characteristics of beat-up, weft insertion and shedding.

**Keywords** rapier belt; longitudinal vibration; variable speed weft insertion; variable length; nonlinear

剑杆织机广泛用于棉、麻、毛、丝等多种纤维材料织造,其织造速度可达 650 r/min 以上。剑带常

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# 印花面料的边缘轮廓快速提取方法

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**摘 要** 工业协作型缝纫机器人代替操作工自动完成缝合是未来发展的必然趋势,但当前的工业协作型缝纫机器人难以快速精准地定位面料边缘轮廓信息,影响缝纫效率与缝纫质量。针对印花面料提出线下使用深度学习建立面料检测模型,线上调用面料检测模型分割面料与背景并结合传统轮廓检测算法快速准确提取面料边缘轮廓的方法。首先,建立面料图像数据集,并通过卷积拆分和融合损失函数对 VGG-UNet 模型进行优化,将面料数据集输入至优化的 VGG-UNet 模型进行训练学习并构建最优面料检测模型;其次,利用最优面料检测模型分割面料与背景;然后,采用数学形态学算法对分割后的面料图像进行自适应开运算去除面料边缘的毛边;最后,利用 Canny 算子对去除毛边后的面料图像进行轮廓提取。实验结果表明,本文方法可较好去除面料毛边并快速精准提取印花面料的边缘轮廓,所提取的轮廓与面料边缘轮廓高度拟合,轮廓提取精度高于 99%,轮廓提取时间仅需 0. 216 s。本文研究可为后续机器人的轨迹规划提供快速准确的坐标信息,提高缝合质量和效率,推进无人化、自动化缝合生产线的实现。

**关键词** 印花面料; 边缘轮廓提取; 机器视觉; 深度学习; VGG-UNet 模型; 缝纫质量
**中图分类号**:TP 317. 4 **文献标志码**:A

当前服装生产中主要依靠操作工完成缝纫,工人一直重复无技术性的缝纫工作,因此使用机器人代替工人完成缝合是今后发展的必然趋势。但传统工业机器人无法满足服装行业未来全自动化、无人化的生产需要,面对多品种、小批量的个性化消费市场,使用基于轮廓提取的工业协作型缝纫机器人是未来服装生产的必然选择[1-2]。基于轮廓提取的工业协作型缝纫机器人借助视觉辅助设备提取面料边缘轮廓,并根据面料边缘轮廓信息来规划机器人的运动轨迹,从而与缝纫机配合实现面料的缝制,因此,提取的面料边缘轮廓精度直接影响缝合精度。面料在裁剪后边缘存在的大量毛边、面料的印花图案以及采集面料图像时的背景都会影响面料边缘轮廓提取精度,同时提取时间又直接影响缝合效率,因此快速准确地提取面料边缘轮廓是自动化缝合的关键所在。

当前对面料轮廓提取的研究大都为基于传统算子的面料轮廓提取方法。安立新等[3]首先通过多项式拟合获得面料的初步轮廓,并删除轮廓误差大的纹理噪声数据段,最后再利用多项式拟合生成真实轮廓;周佳等[4]利用改进的 Canny 算法检测并分割平滑处理后的服装样板,然后利用骨架提取算法来优化样板的轮廓;李东等[5]先将采集的服装图像转化为灰度图像,然后使用最大类间方差法进行二值化,再使用形态学开运算处理和孔洞填充,最后使用 Canny 算子进行边缘检测获取服装的外部轮廓。Jia 等[6]首先将面料图像转换为灰度图像,然后使用 Liu 等[7]提出的分割阈值方法对灰度图像进行二值化,最后使用轮廓跟踪提取轮廓。以上方法易受噪声影响,无法较好地实现对面料印花图案以及色彩方面的处理,且未对毛边着重考虑,易产生无法精准提取面料边缘轮廓等问题。

本文针对自动缝合时传统轮廓提取方法无法快速准确提取带有印花图案的面料边缘轮廓以及未考虑裁切面料后面料边缘产生大量毛边等问题进行研究。首先,采集印花面料图像并标注制作数据集;其次,通过卷积拆分和融合损失函数对 VGG-UNet 模型进行优化,提高模型的推理速度以及分割精度;然后,使用优化 VGG-UNet 模型训练并构建的最优面料检测模型快速精准分割印花面料与桌面背景;之后使用自适应开运

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# 精梳机分离罗拉齿轮传动机构优化

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**摘 要** 混合驱动的精梳机分离罗拉齿轮传动机构的动力学性能直接影响车速的提高,为改善传动机构的动力学性能,首先,分析现有混合驱动的精梳机分离罗拉齿轮传动机构,采用集中质量法建立传动机构的固有频率模型,并计算传动机构在不同精梳机车速下的激励频率,发现当车速为 600 钳次/min 时机构会出现共振;然后,采用导数法建立传动机构固有频率对机构中各个构件转动惯量的灵敏度模型,发现行星轮 p 的转动惯量对一阶固有频率的影响较大;最后,通过优化传动机构中 WW 型差动轮系的各个齿轮齿数以改变其转动惯量,使传动机构的一阶固有频率比原先提高了 43.44%,避免了机构在 600 钳次/min 时出现共振。

**关键词** 精梳机; 分离罗拉; 混合驱动; 齿轮传动机构
**中图分类号**:TS 112.2 **文献标志码**:A

分离罗拉是精梳机的核心构件,在精梳过程中,分离罗拉需要完成“倒转—正转—静止”的高速周期运动,因此对分离罗拉传动机构有较高的性能要求[1-2]。针对传统的多连杆机构与差动轮系相结合的分离罗拉传动机构传动链长及噪声、振动大等缺点[3-4],Li 等[5-6]提出一种基于混合驱动的精梳机分离罗拉齿轮传动机构,该机构将 2 个伺服电动机的运动合成后传递至分离罗拉以实现其高速周期运动,具有传动链短及可实现柔性输出运动的优点。随着精梳机车速的增大,混合驱动的分离罗拉齿轮传动机构的内部激励频率会随之增大,当其接近传动机构的固有频率时,机构将发生共振,导致某些构件损坏。而传动机构的参数直接决定其固有特性,进而影响内部激励频率与固有频率之间的关系,因此,为了掌握传动机构的动力学性能、避免共振,有必要研究机构参数的变化对固有特性的影响进而对传动机构进行优化设计。

对齿轮传动机构固有特性的研究是进行动力学优化的基础,近年来针对齿轮传动机构固有特性的研究较为广泛。Kahraman[7]建立了行星齿轮机构的纯扭转动力学模型。Lin 等[8]推导了行星齿轮机构灵敏度的计算公式,研究了啮合刚度和质量等参数对机构固有频率的影响。张俊等[9]建立了行星齿轮机构的刚柔耦合动力学模型,分析了内齿圈柔性对机构固有特性的影响。Qian 等[10]建立了采煤机截割传动机构弯扭耦合动力学模型,研究了机构固有频率随内啮合刚度的变化规律。Zhang 等[11]建立了两级 NGW 行星齿轮传动机构动力学模型,发现啮合刚度对行星轮扭转模式的固有频率影响较大。Zhang 等[12]建立了两级封闭差动轮系动力学模型,研究了系统的典型振动模式。李孝磊等[13]根据对纯电动汽车动力传动系统扭振固有特性及灵敏度的分析结果,对转动惯量和扭转刚度进行优化,减小了系统的整体波动。窦作成等[14]采用多步参数优化的方法调整转动惯量和刚度参数,避免了多档位行星变速传动系统的共振。综上,目前的固有特性及动力学优化研究大都集中在经典的 NGW 型行星齿轮传动机构上,而混合驱动的精梳机分离罗拉齿轮传动机构是以 WW 型差动轮系为核心部分的齿轮传动机构,上述研究无法完全适用于其动力学建模及固有特性的分析,而国内外鲜见关于混合驱动的精梳机分离罗拉齿轮传动机构固有特性及动力学优化相关方面的研究。

基于此,本文以混合驱动的精梳机分离罗拉齿轮传动机构为研究对象,采用集中质量法得到传动机构的固有频率模型,并比较不同精梳机车速下传

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# 棉精梳机分离罗拉混合驱动系统优化

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**摘 要** 为更好地解决现有分离罗拉驱动方式传动链长及难以调整分离罗拉运动规律等缺点,首先,分析精梳机分离接合工艺,提出分离罗拉运动过程中的工艺关键点,并用分段拟合的方法进行拟合,得到理想的分离罗拉运动规律;其次,在对分离罗拉混合驱动方式中的齿轮传动系统进行动力学分析的基础上优化系统中各齿轮的齿数;然后,结合运动学分析及相关要求规划伺服电动机的运动规律,计算得到伺服电动机的速度曲线;最后,通过仿真软件及实验平台进行验证。结果表明,优化后的分离罗拉混合驱动系统可以使分离罗拉按照符合工艺要求的运动规律运行并使分离罗拉的运动具有柔性,解决了现有分离罗拉驱动方式机构传动链长及分离罗拉运动规律调整困难等问题。

**关键词** 精梳机; 分离罗拉; 混合驱动; 齿轮传动系统; 动力学
**中图分类号**:TS 112.2 **文献标志码**:A

精梳机是纺纱过程中的重要设备,能够排除生条中的杂质和短纤维,进一步增加纤维的伸直度、平行度及分离度[1]。在精梳过程中,驱动系统使分离罗拉完成“倒转-正转-静止”的高速周期运动以实现对棉网的分离接合[2-3]。随着速度的不断提高,机构在运行时会产生较大的振动,造成机构稳定性与精度降低,进而影响精梳条质量。如何解决现有驱动方式传动链长、振动噪声大的缺点显得尤为重要。

分离罗拉的驱动主要有传统的多连杆或凸轮与差动轮系相结合、伺服电动机直接驱动及混合驱动的方式。任家智等[4-5]对传统驱动方式中的多连杆机构受到的惯性力进行分析,利用添加平衡配重的方法降低了机构的振动;丰田-特吕茨勒 TCO12 型精梳机采用伺服电动机代替现有的机械驱动方式[6],简化了传动链。但是上述方式还存在一些不足之处,如传统的机械驱动方式很难调整工艺参数,伺服电动机直接驱动的方式对电动机及控制系统的要求比较高,因此,一些研究将混合驱动理论应用到分离罗拉的驱动中,提出用 2 个伺服电动机作为动力源,通过齿轮传动系统进行运动合成来驱动分离罗拉的方案[7]。刘立东等[8]对比了 1 个常速电动机和 1 个伺服电动机作为动力源和 2 个伺服电动机作为动力源这 2 种方案发现,第 2 种方案对伺服电动机的要求更低。杨海鹏等[9]研究了双伺服电动机驱动分离罗拉的方案,通过优化分离罗拉运动规律以及合理分配伺服电动机的速度规律,减小了伺服电动机最大角加速度,从而降低对伺服电动机的要求。综上,以往的研究主要集中于如何降低伺服电动机的功率,为混合驱动理论在分离罗拉驱动上的应用奠定基础,但在如何优化齿轮传动系统以及如何避免刚性冲击与柔性冲击,从而使拟合的分离罗拉运动规律更为理想等方面的研究较少。

基于此,本文首先采用分段拟合的方法对分离罗拉运动曲线进行拟合,其次建立传动系统的动力学模型,并对系统中齿轮的齿数进行优化,然后规划伺服电动机的运动规律,最后通过仿真及实验验证设计的合理性,以期为分离罗拉混合驱动方式的完善提供理论指导与技术支撑。

## 1 分离罗拉驱动系统

### 1.1 分离罗拉运动分析

#### 1.1.1 分离接合工艺及位移关键点分析

精梳机中机构的运动配合关系是靠装在锡林轴上的分度盘来确定的,分度盘沿圆周分为 40 等份,

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# 面向服装面料自动缝合的缝纫工艺参数建模

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**摘 要** 为了解决缝纫中面料性能与缝纫加工工艺参数仅依靠技术工的经验完成匹配的问题,通过建立面料在缝纫过程中的多力场耦合模型智能选择缝纫加工工艺参数。以纬编织物为例,首先建立了织物单元的三维结构模型;其次分析了穿刺过程中织物组织与纱线间的抱合力对缝纫针的影响,并对面料在缝纫过程中的运动进行分析,创新性地建立了缝纫过程中基于面料力学性能的多力场耦合模型;然后建立了织物的有限元模型和缝纫针的几何模型,分析面料在缝纫过程中应力、应变的分布情况,得到面料在缝纫过程中因受外力作用而发生的形变并验证模型的正确性;最后搭建了协同自动缝纫实验平台进行实验验证数学多力场耦合模型的正确性。结果表明,该方法相比于工人凭借着经验完成缝纫可减少面料的形变和皱缩率,提高服装缝纫质量,为下一步服装面料自动缝合提供工艺参数,并为服装智能制造提供理论及技术参考。

**关键词** 织物组织; 力场耦合; 缝纫工艺; 自动缝合; 服装面料
**中图分类号**:TP 317.4 **文献标志码**:A

随着服装制造行业向自动化、智能化方向发展,缝纫加工工艺参数与服装面料性能的智能匹配限制了服装自动加工技术的发展,服装面料因其材料的柔性特性,在缝纫过程中如果对缝合机器人末端执行器的外力控制不好,很容易出现缝纫质量差的问题[1-2]。为了解决这个问题,在服装面料进行加工缝纫之前,需要使缝纫加工工艺参数与服装面料性能得到匹配,从而推动服装智能制造的发展[3-4]。

当前,面料性能与缝纫加工工艺参数相匹配的研究被视为未来提高缝纫加工质量的研究方向。Cheng等[5]对几种不同面料不同方向进行缝纫加工性能测试,通过对比得到了工艺参数对不同面料的缝纫性能有不同的影响。Choudhary等[6]提出选择与面料性能相匹配的缝纫加工工艺参数可最大限度消除或减少缝纫破损现象。传统缝合都是工人凭借经验来完成面料与缝纫针的配合,对面料的性能和缝纫过程中面料所受到的外力与缝纫质量之间的关系缺乏理论支撑,但随着服装智能制造的发展,未来将会由机器人代替人工进行缝纫[7-8]。Lee等[9]根据织物性能建立自动缝纫的服装生产流程,这种自动缝纫机对不同性能和表面粗糙度的织物进行2种类型的缝合。Koustoumpardis等[10]提出了一种智能缝纫系统,将织物的拉伸测试整合到缝纫机器人缝制站中,预测织物的拉伸性,在缝纫过程中施加合适的拉力。机器人与缝纫机配合的出料速度往往要大于喂料速度,这样在缝纫时对面料有一个速度差,以产生一个拉力拉动面料进行缝纫,因此对面料在缝纫过程中的外力以及面料性能之间的关系的研究显得尤为重要,是提升未来面料缝纫质量的关键因素。前人鲜有在面料性能与缝纫加工工艺参数之间建立桥梁,本文建立了缝纫过程中的多力场耦合,更好地使缝纫加工工艺参数与服装面料性能得到智能匹配,提升面料的缝纫质量[11-12]。

本文以织物结构较为复杂、最具弹性的纬编织物为例,对织物在缝纫过程中受到的外力和运动过程进行分析,创新性地建立了缝纫过程中基于面料力学性能的多力场耦合模型,并通过仿真和协同自动缝纫实验平台验证了多力场耦合模型的正确性。选择与面料性能相匹配的缝纫加工工艺参数,并在协同自动缝纫实验平台完成面料的缝纫,不仅实现了服装行业无人化、自动化的生产方式,还满足了未来服装行业多批量、多种类化发展的趋势,提高了面料缝纫质量。

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# Dynamic Analysis of Metamorphic Mechanisms with Impact Effects During Configuration Transformation

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**Abstract**

Metamorphic mechanisms have attracted considerable attention owing to their capability to switch their topology to adapt to different operational tasks. One feature of topological change is the re-contact of different bodies, which inevitably causes collisions affecting operation accuracy and service life. Consequently, in this study, a collision incidence matrix was introduced to describe the topology of a system involved in collisions, and a method for reducing the closed-loop system to an open-loop system was proposed. The complex movement of the metamorphic mechanism in a changing topology was classified into two different running stages of the source metamorphic mechanism. Based on the relative coordinate method, dynamic modeling of the source metamorphic mechanism considering the impact effects was conducted. Combining the classical collision theory and Newton–Euler equation, the generated impact impulse and the motion after collision were determined. Subsequently, a dynamic analytical method for the full configuration of metamorphic mechanisms was proposed to reflect the changes in the topological structure in the dynamic model. Finally, two typical metamorphic mechanisms used in packaging and spinning were considered as examples to verify the correctness and effectiveness of the proposed method, and their impact characteristics during configuration transformation were analyzed. The proposed analytical method of internal impact for a variable topology process provides effective theoretical guidance for the stability analysis of configuration transformation and structural design aimed at minimizing impacts.

**Keywords** Metamorphic mechanism, Configuration transformation, Impact dynamics, Internal impact, Variable topology

## 1 Introduction

The concept of a metamorphic mechanism was first proposed in 1998 in the study of decorative carton folds [1] and has the advantage of switching its topology structure to adapt to different working requirements compared to the traditional mechanism [2]. The metamorphic mechanism used in practical engineering transforms its working configuration by restricting the motion cycle of metamorphic joints that have specific constraints, such as position, force, or a combination of both [3, 4]. Research on metamorphic mechanisms has focused on structural design [5–7], type synthesis [8–10], and topological description [11–13]. After decades of development, metamorphic mechanisms have been widely used in industry and research applications, such as bionic metamorphic mechanisms [14, 15], extendable or foldable mechanisms [16, 17], automated laying mechanisms [18, 19], scissor-shaped mechanisms [20, 21], space metamorphic parallel mechanisms [22, 23], metamorphic manipulators [24, 25], and robot mechanisms [26–28]. The proposal of metamorphic

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# Analysis and modeling for the dynamics of the nipper mechanism considering jaw's impacts

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**Abstract**

The comber is very important in the spinning for high quality yarns, in which the nipper mechanism (NM) determines the quality of the yarn it combs. This paper is to connect topology and multi-body dynamics to reveal the principle of impact motion of the nipper mechanism. Firstly, the working process of the NM is analyzed and corresponding kinematic models of work sub-phases are derived. Subsequently, the transition from the work phase of the jaw closed to the opened is studied. The research results show that during the transformation process, the mechanism presented another work phase with multiple impacts, which is the main reason why the NM could not stably clamp the cotton clump and thus affect the quality of the yarn combed by the comber. According to the relative coordinate method, the dynamic model of the NM is set up. Combining the classical collision theory and the restitution coefficient equation, the acquisition of the impact impulse generated at the jaw and the subsequent motion of the mechanism are decided. Finally, the NM in the E62 comber is taken as an example to verify the correctness of the established dynamic model, and the influences of different input speeds, restitution coefficients, and stiffness coefficients of spring on the jaw's impact are studied. This has certain theoretical value for improving the speed and efficiency of the comber.

**Keywords**

Comber, nipper mechanism, Dynamic Modeling, impact dynamics, jaw's impact, Restitution coefficient

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## Introduction

With the rapid development of human society and the progress of science and technology, people's living standards continue to improve. The demand for high-grade textiles and special textiles is increasingly large. Without the combing process, it is difficult to meet the manufacturing requirements of yarn below 9.7tex which is used in the production of high-grade fabric and special fabric, such as medical suture thread, tire cord thread, high-speed sewing thread, and embroidery thread.[1] Therefore, the comber is the key equipment to produce yarn with high quality, in which the short fiber, neps, and impurities could be removed and cotton fibers can be straightened.[2]

Comber is mainly composed of five parts the nipper system, separating roller mechanism, feeding mechanism, top combing mechanism, and cylinder mechanism, among which the nipper system plays the most important role in the combing process with achieving complex motion including the jaw's opening-closing motion and the nippers' reciprocating swing motion. And meanwhile, the nipper mechanism (NM) in the system is the main part to produce noise and vibration.[3] Therefore, the research on it

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# 精梳机钳板机构接触碰撞动力学建模与仿真

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**摘 要** 高速、高产、优质是新一代国产棉纺精梳机的发展目标,而当前精梳机存在的主要问题之一是高速运行时钳板机构产生的冲击严重限制了精梳机转速的提升,针对该问题进行动力学研究以提升钳板机构稳定性,达到推进精梳机高速化的目的。首先,以中支点式钳板机构为研究对象,基于接触碰撞理论建立钳板在接触和分离瞬时的冲击力计算模型,结合Lagrange方程对钳板机构进行接触碰撞动力学建模。其次,运用MatLab对所建动力学模型进行数值计算仿真,结合三维虚拟样机仿真验证模型的正确性和有效性。最后,分析钳板机构工况参数和加压弹簧刚度对冲击运动和冲击接触应力的影响规律。结果表明:钳口与牵吊杆处的最大接触应力远大于稳定接触应力,且回弹量和回弹时间会随锡林轴转速的提高而增大,随加压弹簧刚度的增大而减小。

**关键词** 精梳机; 钳板机构; 接触碰撞力; Lagrange方程; 动力学
**中图分类号**:TH 112 **文献标志码**:A

高速是棉纺精梳机高效的重要指标之一,运转速度越高,精梳机单位时间内的产量就越高,但是,提高精梳机的转速,使分离罗拉、钳板及其传动机构所产生的惯性力急剧增大,精梳过程中产生的冲击、噪声越大,精梳机机件的损坏就越多[1]。

目前在生产实践过程中已发现,高速型精梳机的钳板机构在1个工作周期内的2个时刻出现较大冲击,分别为:在钳口闭合瞬时,上、下钳板闭合,有力握持须丛,钳板整体先向后再向前运动,锡林开始梳理须丛前端,排除短纤维和棉结杂质;在钳口分离瞬时,上、下钳板开启,将锡林梳理过的须丛头端送向分离罗拉。这些冲击作用不仅影响钳板开闭口定时及闭合时间,还会造成钳板最前位置走动和握持不匀,严重时甚至会导致钳板加压弹簧断裂,进而产生棉网成形不良、棉网破洞、棉网横向切断以及落棉率高等一系列产品质量问题,且2次冲击运动导致的构件之间接触碰撞使得机构铰接处的碰撞力增大,加剧机构破坏,并产生严重的噪声和振动。由此可见,该冲击作用产生的负面影响限制了精梳机转速的提升,必须对其进行深入研究。

任家智等[2]运用ADAMS软件,对精梳机钳板加压机构各连杆受力进行了动力学仿真和分析,发现铰链点的最大受力发生在钳板闭合阶段,且随着精梳机转速的提高而迅速增大;李金键等[3]建立了钳板摆轴阻力矩及驱动力矩的数学模型并结合ADAMS软件进行仿真,发现随着精梳机转速的提高,钳板机构惯性力对钳板摆轴驱动力矩的影响增大;梁灼等[4]对钳板钳持过程的动力学进行了分析,基于ANSYS软件分析了下钳板工作时的应力与应变;刘鹏展等[5]运用ADAMS软件建立了精梳机钳板机构的三维模型,并对其进行了动力学仿真,结果表明,钳板闭合时产生的瞬时冲击不仅导致钳板自身产生弹性振动,还会通过传动系统最终作用于锡林轴、钳板摆轴和张力轴,进而引发整机振动;王晓维等[6]基于钳板机构运动原理,建立了钳板开闭口时间的计算模型,得出影响开闭口定时及闭合时间的因素,确定了钳板开闭口时间与工艺参数的定量关系;赵春花等[7]建立了适用于钳板机构的非线性动力学模型,利用拉格朗日方程和非线性Newmark法,考察了剪切变形和轴向拉压非线性应变对机构动力响应的影响。

连续接触力模型[8-10]由Hertz接触模型发展而来,以局部接触变形引起碰撞力为假设基础,将物体间的接触变形量和接触变形速度作为计算参数,是一种以弹簧阻尼力元代替接触区域复杂变形的近似方法。目前,已有的连续接触力模型主要包括:Flores模型[11]、Lankarani-Nikravesh模型[12]、Zhiying-Qishao模型[13]、Hu-Guo模型[14]、Gonthier模

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# 多闭环厚板折展蜂窝机构的几何设计与性能分析

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**摘要**:基于厚板折纸理论设计出一种单闭环空间折展机构,并用螺旋理论对机构的自由度进行了分析。引入Myard类型约束和Sarrus类型约束,提出将机构自由度降低为1的2种方法,对应得到M型和S型折展蜂窝单元。将2种折展蜂窝单元的运动特征与平面镶嵌原理相结合,构造出M型和S型折展蜂窝机构。研究了设计参数对机构折展率的影响规律,并以提高折展率为目标对机构的结构进行了优化。研究结果表明,M型折展蜂窝机构完全展开后可形成单侧平整的表面;S型折展蜂窝机构的折展率更大。

**关键词**:折展机构;蜂窝结构;Myard机构;Sarrus机构;折展率
**中图分类号**:TH112
DOI:10.3969/j.issn.1004-132X.2024.07.003 **开放科学(资源服务)标识码(OSID)**:

## Geometric Design and Performance Analysis of Multi-closed-loop Deployable Honeycomb Mechanisms with Thick Panels

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**Abstract**: A new type of space mechanisms with single-closed-loop was proposed according to thick-panel origami teory, and the mobility was analyzed by using screw theory. The degree of freedom of mechanism was reduced to 1 by the introduction of Myard constraint and Sarrus constraint, and the corresponding deployable units were obtained with the names of Myard deployable honeycomb unit and Sarrus deployable honeycomb unit. M-type honeycomb mechanism and S-type honeycomb mechanism were proposed based on kinematic analysis and planar mosaic array of deployable honeycomb units. The influence regularity of various factors on folding ratio was analyzed, and the deployable honeycomb units were optimized with the rising of folding ratio index. The results show that M-type honeycomb mechanism may achieve flat surface, and S-type honeycomb mechanism may achieve higher folding ratio index.

**Key words**: deployable mechanism; honeycomb structure; Myard mechanism; Sarrus mechanism; folding ratio

## 0 引言

折展机构是指能从收拢状态展开到预定或期望的结构形式并能承受特定载荷的一类机构,具有质量小、体积小、便于储藏和运输的特点,被广泛应用于土木工程[1-2]、航空航天[3-7]、医疗[8-9]、超材料[10-11]、可展天线[12-13]等领域。折展机构通常采用模块化结构,即折展机构由若干个相同的折展模块(基本折展单元)连接而成。基本折展单元的设计是构造大尺度折展机构的基础,也是机构学领域研究的一个重点。

折纸作为一种古老的东方艺术,可将二维平面纸板折叠成三维空间结构,是一种构造基本折展单元的有效方法。折叠的纸板具有可将纸板分割成多个纸板单元的折痕,若将纸板单元抽象为构件,将折痕抽象为运动副,则纸板可等效为一个具体机构。同一纸板经不同折叠方式可形成不同机构(折纸机构)。此类机构具有可折叠、可展开的特性,其运动学模型通常是在纸板单元厚度为零且刚度无穷大的假设下建立的。对于给定的折痕,目前有多种判断刚性折叠的方法。WATANABE等[14]提出了图解和数值方法。TACHI[15]推广了在四边形网格折纸中实现刚性运动的几何条件,推导出对应运动学函数的恒等式。CAI等[16-17]提出了四元数旋转序列与对偶四元数相结合的方法,解决了圆柱形折展机构刚性可折叠性的判定问题。DAI等[18-19]从机构学角度分析了

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# 面向精梳任务的高速变胞机构冲击动力学研究*

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**摘要**：精梳机是生产高品质纱线的关键装备，高速化是其发展趋势。精梳机的钳板机构是典型的力/位组合约束变胞机构，高速运行时产生的钳口冲击力对钳板开闭口定时和须丛梳理质量影响很大，是制约精梳机转速提升的关键因素，但目前对钳板机构的冲击动力学研究还很不够，对通过优化机构参数来降低钳口冲击力还缺乏一套系统的理论和方法。以力/位组合约束精梳机钳板机构为研究对象，基于机构学和多体系统动力学理论，对钳板机构的结构组成和工作构态进行分析，建立各子构态机构的运动学和动力学模型。基于接触碰撞理论描述钳板机构构态切换时上、下钳板的接触碰撞过程，建立钳口冲击力计算模型和计及冲击力作用的钳板运动规律求解模型，并与冲量方法相结合连同虚拟样机仿真验证所建模型的有效性。为了保证充分的钳板闭合时间以提高须丛梳理质量，研究不同机构设计参数对钳口回弹量和回弹时间的影响规律，为高效能精梳机转速的进一步提升提供理论依据。

**关键词**：变胞机构；钳板机构；构态切换；接触碰撞力；动力学
**中图分类号**：TH112

# Impact Dynamics of High-speed Metamorphic Mechanism for Comber

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**Abstract**: Comber is the key equipment to produce yarn with high quality and the development tendency of this kind of machine is high speed. Nipper mechanism in comber is a typical constrained metamorphic mechanism and jaw impact force generated at the time of configuration change has a negative effect on nipper opening-closing time and combed product property. Therefore, how to effectively reduce the impact force by optimizing the parameters of nipper mechanism has become an important and chief research topic which must be solved urgently. Firstly, the structure of Nipper mechanism with geometric and force constraints is analyzed and dynamics models of each sub-configuration are established by using Lagrange equations. Secondly, it is proposed to connect metamorphosis with topology and multi-body dynamics to reveal the principle of impact motion of metamorphic mechanism at the time of changing configuration. A contact force with hysteresis damping factor is introduced as an external force to analyze the impact process between nipper knife and nipper plate during configuration change. The result obtained is compared with impact impulse method and virtual simulation to verify the effectiveness of models established. Finally, according to the study of impact dynamic modeling and optimum design of nipper mechanism, important theoretical foundation will be provided for design of comber with high efficiency and low energy consumption.

**Key words**: metamorphic mechanism; nipper mechanism; configuration change; contact force; dynamics

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RESEARCH ARTICLE

# Multi-Scale Infrared Military Target Detection Based on 3X-FPN Feature Fusion Network

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**ABSTRACT** To solve the problems of misdetection and omission of infrared military targets and poor detection effect in battlefield environments, an improved YOLOv4 algorithm is proposed to improve the accuracy of long-range target detection. First, a new 4th-scale feature extraction layer is introduced to enhance the multi-scale detection sensitivity for infrared military targets. Second, the TL intermediate layer channel is introduced to realize feature fusion across gradient connections, the 3X-FPN feature fusion network structure is proposed, and the adaptive network parameters are adopted to realize the weighted and balanced fusion of data to improve the target detection accuracy. Finally, the multi-scale detection loss function is established and optimized to improve the model stability and convergence effect. The depth separable convolution structure is adopted to realize the model's lightweight. The experimental results of vehicle class military target ablation show that the improved algorithm increases the detection accuracy by 9.85% compared with the original algorithm, reduces the model volume by 36%, and its target detection distance is up to 2000 m. The improved algorithm achieves a mean average precision (mAP) value of 93.25% for multi-military target detection, which improves by 12.42% compared with the mainstream detection algorithm and meets the current combat data acquisition and processing requirements.

**INDEX TERMS** 3X-FPN feature fusion network, long-range infrared military target detection, multi-scale feature extraction, multi-scale loss function optimization, model lightweight.

## I. INTRODUCTION

In complex battlefield environments, infrared target detection is often used to realize multiple functions such as weaponry fire strikes and coordinated operations. Accurately identifying long-distance military targets [1], and accessing target category and location information, can effectively enhance the combat advantage and battlefield control ability. When the military target is obscured by objects in battlefield operations or a night environment, the real-time performance of long-range military target detection is poor. Long-range targets may have only a few pixels in the image, and the shape and texture of which are easily covered by noise and background [2], so the target recognition accuracy is not high. Therefore, intelligent and efficient detection and accurate recognition of remote infrared targets has become a hot research topic in object detection [3].

Various methods are used for military targets. Chen et al. [4] used a heuristic-based posterior probability active learning method based on a random forest algorithm and adversarial generative network for long-range military targets, which solved the problem of insufficient sample data but failed to improve recognition accuracy accordingly. Dai et al. [5] improved the model speed by fusing a parallel attention mechanism with a weighted feature network, which demands expensive sample data and a high experimental

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# 基于赋权偏差传递网络的 6Dof-RUS 并联机构随机误差分析

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**摘要：**对于已经完成加工装配高精度并联机构，当出现使用精度无法满足设计要求时，需要对产生误差的源头进行追溯，只修复部分构件提高机构精度。以单点激光测距仪检测方法与六条由转动副（R）虎克铰链（U）球面副（S）构成单支链的 6 自由度并联机构（6Dof-RUS）随机误差模型之间的映射为研究内容。首先构建了 6Dof-RUS 并联机构赋权偏差传递网络，其次建立了相机坐标系中光斑与平面约束之间的映射方程，通过结构误差雅可比矩阵将结构参数误差映射为可观测的动平台位姿误差。最后进行了实验验证，实验结果表明，在有限次测量次数的情况下可快速对随机误差进行溯源，验证了所提方法的有效性与可靠性，对其他拓扑构型并联机构精度综合具有一定借鉴意义。

**关 键 词：**并联机构；随机误差；误差溯源；6 自由度并联机构
**中图分类号：**U666.1 **文献标志码：**A

# Random error analysis of 6Dof-RUS parallel mechanism based on weighted bias transfer network

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**Abstract:** For high-precision parallel mechanisms that have already completed machining and assembly, when the operational accuracy does not meet design requirements, it is necessary to trace the sources of error and only repair specific components to improve the mechanism's accuracy. The mapping between the single-point laser rangefinder detection method and the random error model of the 6 degrees of freedom revolute-universal-spherical (6Dof-RUS) parallel mechanism is studied. Firstly, the weighted deviation transfer network of 6Dof-RUS parallel mechanism is constructed. Secondly, the mapping equation between light spots and the constraints of planes in the camera coordinate system is established, and the structural parameter error is mapped to the observable pose error of the moving platform by the Jacobian matrix of structural error. Finally, experimental verification is carried out, and the experimental results show that the random errors can be quickly traced with a limited number of measurements, which verifies the effectiveness and reliability of the proposed method. The proposed method provides a reference for improving the accuracy of other topological configurations of parallel mechanisms.

**Key words:** parallel mechanism; random error; error traceability; 6 degrees of freedom parallel mechanism

并联机构以其刚度高、载荷质量比高、精度高的优势弥补了串联机构的不足，具有较高研究价值[1]。并联机构的铰链安装位置、杆长尺寸以及构件弹性变形等因素都会导致机构误差[2]，制约了并联机构在高精度和高可靠性领域的应用，对此国内外学者针对并联机构误差分析、预估与补偿、协作控制[3,4]开展了广泛

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# 基于近红外光谱和残差神经网络的异性纤维分类识别

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**摘 要** 针对传统图像处理方法对棉层中异性纤维检测效果不佳的问题,基于近红外光谱和残差神经网络提出一种对棉层中异性纤维的分类识别方法。采用Savitzky-Golay法对异性纤维的近红外光谱数据进行平滑处理,结合*F*检验和LightGBM分类算法实现特征波长优选,并将优选后的光谱数据经格拉姆角场转换成保留波长序列之间时序性的格拉姆角和场图像;构建残差深度卷积神经网络模型,将转换后的格拉姆角和场图像作为训练样本对残差网络模型进行训练。实验结果表明,该方法能够有效地对复杂环境下棉层中的异性纤维进行分类,分类准确率达到99.69%,与其它数据转换方式和分类模型相比提高了棉层中异性纤维的分类识别精度,为复杂环境下异性纤维分类识别研究提供了新思路。

**关键词** 棉; 异性纤维检测; 近红外光谱; 残差神经网络; 光谱数据; 图像检测
**中图分类号**:TP 391.4; TS 117 **文献标志码**:A

棉花中的异性纤维是影响棉花质量的主要因素[1],其来源广、种类繁多,常见的异性纤维包括丝状的头发、羊毛、丙纶丝,绳状的麻绳、锦纶绳和条块状的羽毛、塑料布等。不同种类的异性纤维对棉花质量会产生不同的影响[2],如何精确地判别异性纤维种类,准确剔除异性纤维是目前纺织行业亟待解决的问题。

早期国内外学者使用图像处理技术提取异性纤维形状、颜色等形态特征,再使用光谱仪获取异性纤维的反射率、透射率等光谱特征,利用机器学习分类方法训练分类器实现异性纤维的分类。如张成梁等[3]在HSI颜色空间分别建立了图像分割和异性纤维识别的支持向量机分类器,适用于边缘对比度低、纹理信息丰富的机采籽棉异性纤维分类;Ji等[4]将决策树和支持向量机结合,采用分层次方式分类异性纤维,该方法对线形异性纤维的识别具有较强的性能;常金强等[5]对提取的高光谱曲线进行主成分分析,并使用线性判别分析对高光谱图像进行像素等级分类判别,但对地膜的识别效果较差;Jiang等[6]采用最小冗余最大相关性算法提取异性纤维高光谱数据中合适的特征波长,分别利用线形判别分析、支持向量机、人工神经网络进行分类比较,提高了高光谱数据的分类速度。目前研究结果表明,采用深度学习方法可提高异性纤维的分类精度[7]。何晓昀等[8]在LED照明和"LED+线激光"双照明条件下,采用Faster RCNN深度学习网络对籽棉中的异性纤维进行检测,对白色异性纤维的识别率大幅提高;Wei等[9]开发了残差卷积神经网络模型,验证了基于嵌入式系统对异性纤维的分类效果,找到了一个在性能和计算之间取得最佳平衡的模型。

上述研究主要是基于图像处理技术的异性纤维分类方法,只适用于异性纤维在棉层表面的环境下;但异性纤维分布具有不确定性,会存在于棉花层的不同位置,图像处理方法难以对棉层中异性纤维进行检测识别。为此,本文提出一种基于近红外光谱结合残差神经网络的异性纤维分类识别方法,采用近红外光谱在棉层较厚的情况下依然可以采集到异性纤维的物质信息,提高异性纤维分类识别率。将近红外光谱数据利用格拉姆角和场转换为格拉姆角和场图像,加入深层残差神经网络的深度学习方法进行异性纤维分类,利用近红外光谱技术与深度学习相结合的方法对异性纤维进行分类识别。

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# 棉花中异性纤维检测图像分割和边缘检测方法研究进展

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**摘 要** 为进一步提高棉花中异性纤维的检测效率,对异性纤维图像处理方法进行探究。通过分析不同异性纤维图像边缘检测方法的定位精度、背景模糊以及受噪声影响情况发现,不同图像分割方法中异性纤维边缘连续性和分割效果存在差异性。统计了常见异性纤维图像边缘检测法和图像分割方法,分析了各类处理方法的优势和局限性,归纳了适用于各类异性纤维的检测方法,总结了现有研究中存在的问题和不足。研究认为:目前对不同种类异性纤维检测适用的图像处理方法不同,还无法同时检测出全部种类的异性纤维;应根据实践中具体异性纤维的种类、含量、物理特性等选择适合的检测算法并进行算法融合,开发普适性好的算法以降低成本和减少计算量。

**关键词** 异性纤维; 图像预处理; 边缘检测; 图像分割; 在线检测
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## Research progress in image segmentation and edge detection methods for alien fibers detection in cotton

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**Abstract** In order to further improve the detection efficiency for picking up alien fibers among cotton, image processing methods for detecting alien fibers were reviewed. This paper analyzed the inaccurate location, background blur and the influence of noise in edge detection methods, and studied the edge continuity and segmentation effect of different alien fibers in the image segmentation methods. The common edge detection methods and image segmentation methods for alien fibers among cotton were discussed, advantages and limitations of various processing methods were analyzed, and the detection methods applicable to various alien fibers were summarized, pointing out the existing problems and deficiencies in current practice. It is concluded that different image processing methods are currently applied to detect different types of alien fibers, and it is not possible to detect all types of alien fibers at the same time. The paper highlighted that the suitable detection algorithms should be selected and combined according to the specific types, contents, physical characteristics of alien fibers to develop an universal algorithm in order to reduce the cost and calculation burden.

**Keywords** alien fiber; image pre-processing; edge detection; image segmentation; online inspection

棉花中的异性纤维是影响棉花质量及棉纺织品质量的主要因素之一[1],世界棉花贸易组织称其为纤维性外来杂质,常见的有人类头发、动物毛发、丝线、布块、丙纶丝、黄麻纤维、塑料绳、树皮、野草、羽毛等[2]。异性纤维来源广泛且种类繁多,若不及时剔除,则会造成纱线断裂或出现疵点的现象,降低纱线和纺织质量,影响企业效益[3]。如何高效、准确地检测剔除棉花中异性纤维已经成为当今纺织行业

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# A multi-feature fusion supervoxel clustering segmentation method based on energy function

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## Abstract

Supervoxels serve as a more natural and compact representation of 3D point clouds, allowing segmentation operations to be performed on regions rather than scattered points. Most current supervoxel segmentation methods rely on random sampling of representative seed points to generate supervoxels with fixed resolution. However, when seed points fall on the object boundary, erroneous growth of supervoxels may occur, leading to over-segmentation or under-segmentation issues. Additionally, the fixed resolution cannot adapt to different scenes. To address the issues in the concave-convex segmentation algorithm for supervoxels, this paper proposes a multi-feature fusion segmentation method based on an energy function. First, ideal seed points are selected based on the mean curvature of the local neighborhood. Then, an energy function incorporating normal and color information is employed to generate supervoxels and exchange boundary points. Finally, an entropy function based on the dimensional feature information of the local neighborhood is constructed to assist in computing the normal vectors of the supervoxels. The experimental results show that the generated supervoxels align more closely with object boundaries and exhibit high robustness across different scenes. Among the three test datasets, the segmentation method proposed in this paper outperforms other region-growing methods in terms of precision, recall, and mean intersection over union.

**Keywords** Supervoxel · Energy minimization · Boundary exchange · Concave-convex segmentation

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# Research and modelling of fiber deformation mechanism of 3D four-direction preform under compression loading

**Baolong Mei, Jiuzhi Dong, Hongqing Ren, Jian Geng and Xiuming Jiang**

## Abstract

In order to investigate further the compaction characteristics of the three-dimensional four-direction preform of carbon/carbon composite, a model of three-dimensional four-direction numerical preform at the micro-scale was established using the programming language in Python based on the ABAQUS simulation platform more realistically to reflect the micro-structure of the preform. A model of three-dimensional fiber numerical growth was built to describe the changes of fiber bundle cross-section under compressive load considering the random distribution, deflection, bending and the physical characteristics of fibers not penetrating each other in three-dimensional space. In addition to exploring the characteristics of the fiber bundle compaction process in the inter-laminar dimension, the interaction between laminated fibers of the preform was analyzed; the method of finite element was employed to construct a compaction model of the three-dimensional four-direction preform; the deformation of inter-laminar fibers under compressive load was studied by the numerical simulation method; the nonlinear mapping relationship between compressive load and compaction height consistent with the preform compaction experiment was obtained. The results demonstrated that the deflection coefficient of the numerical model was 0.32, which was most consistent with the actual result.

## Keywords

Three-dimensional four-direction preform, compaction characteristics, micro-scale, finite element, numerical simulations

The three-dimensional (3D) four-direction preform adopts the moulding method of soft-hard mixing of carbon fiber and carbon fiber rigid rod (hereinafter referred to as carbon rod). The carbon rods are arranged in a regular triangular equidistant arrangement perpendicular to the horizontal plane. The carbon fibers are stacked in layers in three directions of 0°, 120°, and 240°, which are laid horizontally between vertical carbon rods and preformed by a pressurized and dense process. Compression, as a crucial process in the moulding process of the preform, directly determines the moulding density of the preform and affects its moulding quality. It can also establish a micro-structure model that truly reflects the compaction morphology of fibers of the preform while being of great significance to the follow-up process design, matrix penetration, and mechanical performance calculation and prediction.

As the fiber bundle is composed of multiple fibers, the morphological change in each fiber leads to the various forms of the fiber bundle, and the internal mesostructure must be different in different states. At present, the research on the microscopic structure model of fiber assembly is mainly divided into a computer simulation and numerical simulation methods. For example, Wang and colleagues[1,2] first proposed the 'digital unit chain' method, which was utilized to discretize the yarn into digital node elements with a certain

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PAPER

# Research on mobile robot path planning in complex environment based on DRQN algorithm

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**Keywords:** path planning for mobile robots, DRQN algorithm, markov decision making, complex environment, dynamic obstacle avoidance

## Abstract

A deep reinforcement Q learning algorithm (DRQN) based on radial neural network is proposed to achieve path planning and obstacle avoidance for mobile robots in complex ground environments with different types of obstacles, including static and dynamic obstacles. Firstly, the path planning problem is represented as a partially-observed Markov decision process. Steering angle, running characteristics, and other elements are introduced into the state-action decision space and the greedy factor is dynamically adjusted using a simulated annealing algorithm, which improves the mobile robot's environment exploration and action selection accuracy. Secondly, the Q-learning algorithm is improved by replacing the Q-table structure with an RBF neural network to enhance the approximation ability of the algorithm's function values, and the parameters of the implicit layer and the weights between the implicit and the output layer are trained using the dynamic clustering and least-mean methods respectively, which improves the convergence speed and enhances the ability of mobile robots to handle large-scale computation. Lastly, the double reward mechanism is set up to prevent the mobile robot from blind searching in unknown environments, which enhances the learning ability and improves path planning safety and flexibility at the same time. Different types of scenarios are set up for simulation experiments, and the results verified the superiority of the DQRN algorithm. Taking the 30 * 30 complex scene as an example, using the DQRN algorithm for path planning reduces the values of distance, turning angle, and planning time by 27.04%, 7.76%, and 28.05%, respectively, compared to the average values of Q-learning, optimized Q-learning, deep Q-learning, and DDPG algorithms, which can effectively improve the path planning efficiency for mobile robots in complex environments.

## 1. Introduction

With the rapid development of artificial intelligence technology, the environment-sensing ability and the degree of unmanned autonomous control of mobile robots are constantly being improved [1]. Technological research in unmanned aerial vehicles (UAV) and unmanned surface vehicles (USV) are more mature [2], and have been widely used in terrain reconnaissance [3] and underwater exploration [4] missions in different environments. Ground mobile robots are mostly used in indoor environments, such as logistics and warehousing [5], and industrial production [6] environments, and partially applied to autonomous driving in outdoor structured roads [7]. The research on ground mobile robot technology in complex environments needs to be improved. Path planning is the way to complete tasks in complex environments for mobile robots, and it is necessary to achieve an optimal collision-free path from the initial position point to the target position point based on evaluation criteria such as traveling distance, number of turns, and planning time in obstacle environments. Path planning methods can be divided into two categories based on environment information, location point

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# Status of research on parametric methods for the reconstruction of 3D models of the human body for virtual fitting

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## Abstract

**Purpose** – This paper reviews the pros and cons of different parametric modeling methods, which can provide a theoretical reference for parametric reconstruction of 3D human body models for virtual fitting.

**Design/methodology/approach** – In this study, we briefly analyze the mainstream datasets of models of the human body used in the area to provide a foundation for parametric methods of such reconstruction. We then analyze and compare parametric methods of reconstruction based on their use of the following forms of input data: point cloud data, image contours, sizes of features and points representing the joints. Finally, we summarize the advantages and problems of each method as well as the current challenges to the use of parametric modeling in virtual fitting and the opportunities provided by it.

**Findings** – Considering the aspects of integrity and accurate of representations of the shape and posture of the body, and the efficiency of the calculation of the requisite parameters, the reconstruction method of human body by integrating orthogonal image contour morphological features, multifeature size constraints and joint point positioning can better represent human body shape, posture and personalized feature size and has higher research value.

**Originality/value** – This article obtains a research thinking for reconstructing a 3D model for virtual fitting that is based on three kinds of data, which is helpful for establishing personalized and high-precision human body models.

**Keywords** Virtual fitting, Parametric model reconstruction, Two-dimensional images, Feature size, Joint points

**Paper type** Literature review

## Introduction

The production and sale of clothing apparel have gradually become digitalized and intelligent with the development of network technology. Virtual fitting technology plays an important role in the clothing industry due to its characteristics of visualization and personalization. It offers the intelligent fitting of clothing for customers so that they can select appropriate styles and models of clothing, where this reduces the rate of return of items purchased

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# Intelligent decision making algorithm for path planning based on reference Linguistic Fuzzy set

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**Abstract**
This paper proposes a novel path planning algorithm called Reference Linguistic Fuzzy Algorithm (RLFA); moreover, the parametric analysis procedure of the RLFA is described in this paper. It finds the optimal path by calculating the decision value required by path planning. However, most of the research ignores the issue of equal decision scores. The proposed algorithm has been compared to the original distance metrics, the fuzzy synthetic evaluation method, the modified three-way TOPSIS method, and the Generalized TODIM method. Compared with the existing algorithms, the algorithm proposed in this paper improves the reliability of path planning decision making and eliminates the defects of the traditional algorithms, which rely on parameter settings. It combines subjective and objective dual evaluation perspectives to correct the possible bias in the single subjective perspective. This paper is supported by experimental validation, and the results show that the proposed algorithm can achieve the optimal solution under all conditions.

**Keywords** Path planning · Artificial potential field algorithm · Mobile robot · Fuzzy linguistic term set · Decision making

## 1 Introduction

In current industrial production, robots are widely used in automated and mechanized environments for the production and servicing of equipment. In order to improve efficiency, the robots must find the optimal motion path between the start point and the finish point. Therefore, the robots need to perform path planning to perform various tasks efficiently [1]. Traditional path planning algorithms for the robots include Dijkstra [2], A* [3], D* [4], Particle Swarm Optimization [5],

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