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Cable-Driven Rehabilitation

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Smooth Trajectory Planning for a Cable Driven Parallel Waist Rehabilitation Robot Based on Rehabilitation Evaluation Factors
Yuan Li, Bin Zi, Zhi Sun, Ping Zhao

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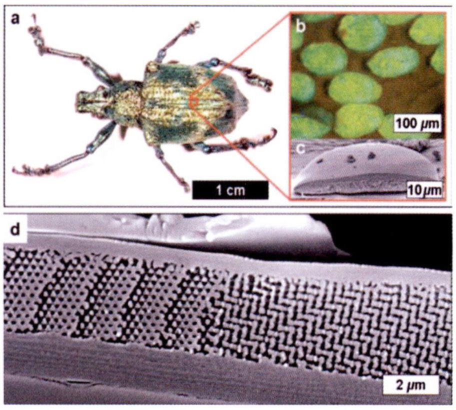
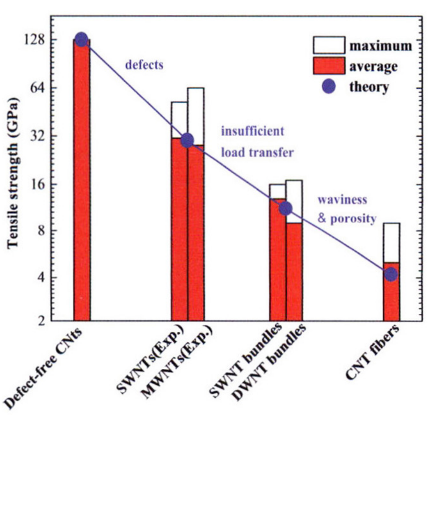
Review

Abstract: Photonic crystals are periodic structural materials that have an impact on the propagation properties of photons. Due to their excellent optical, electrical and magnetic properties, their advantages and potential for applications in the above areas are gradually emerging. Therefore, an increasing number of researchers have focused on photonic crystals. In this paper, the characteristics of biological photonic crystal structures, such as those found in butterfly wings, sea mouse bristles, peacock feathers, melon jellyfish epidermal cells, and weevil exoskeletons, are described. The preparation methods of photonic crystals are systematically summarized (including the template method, self-assembly technology, electron beam evaporation coating technology, chemical vapor deposition technology, femtosecond laser two-photon technology, spin coating technology, and a variety of technology mixing), and the characteristics, advantages, and disadvantages of the different methods are compared. Furthermore, the development of photonic crystals in the field of sensors, solar cells, filters, and infrared stealth is discussed, demonstrateing the great development potential of photonic crystals. It is concluded that the realization of photonic crystals with high precision, high sensitivity, angle independence, and large-area uniform preparation is a key problem requiring urgent solution. Moreover, photonic crystals have potential development prospects in the fields of equipment stealth, new concept weapons, production, an daily life.



Abstract: Carbon nanotube (CNT) networks enable CNTs to be used as building blocks for synthesizing novel advanced materials, thus taking full advantage of the superior properties of individual CNTs. Multiscale analyses have to be adopted to study the load transfer mechanisms of CNT networks from the atomic scale to the macroscopic scale due to the huge computational cost. Among them, fully resolved structural features include the graphitic honeycomb lattice (atomic), inter-tube stacking (nano) and assembly (meso) of CNTs. On an atomic scale, the elastic properties, ultimate stresses, and failure strains of individual CNTs with distinct chiralities and radii are obtained under various loading conditions by molecular mechanics. The dependence of the cohesive energies on spacing distances, crossing angles, size and edge effects between two CNTs is analyzed through continuum modeling in nanoscale. The mesoscale models, which neglect the atomic structures of individual CNTs but retain geometrical information about the shape of CNTs and their assembly into a network, have been developed to study the multi-level mechanism of material deformation and microstructural evolution in CNT networks under stretching, from elastic elongation, strengthening to damage and failure. This paper summarizes the multiscale theories mentioned above, which should provide insight into the optimal assembling of CNT network materials for elevated mechanical performance.



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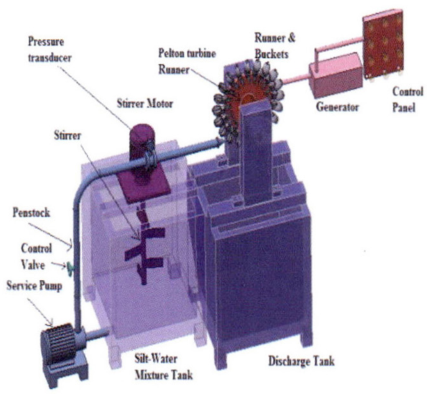
DOI: 10.1186/s10033-023-00880-y

Sediment Erosion on Pelton Turbines: A Review

Xinfeng Ge • Jie Sun • Dongdong Chu • Juan Liu • Ye Zhou • Hui Zhang
Lei Zhang • Huixiang Chen • Kan Kan • Maxime Binama • Yuan Zheng



Abstract: The Pelton turbine has been widely used to develop high-head water resources with sediments because of its advantages in life cycle costs. When a flood or monsoon season occurs, the sediment concentration in the river increases suddenly, causing severe erosion to the nozzle, needle, and runner of Pelton turbines. After decades of development, researchers have developed practical engineering experience to reduce the sediment concentration of the flow through the turbine and ensure the safety and efficiency of power generation. Research on the mechanism of sediment erosion, development of anti-erosion materials, and establishment of erosion prediction models have attracted scholarly interest in recent years. Extensive research has been conducted to determine a complete and valuable syndication erosion model. However, owing to the complexity of the flow and wear mechanisms, the influence of specific parameters of erosion and the syndication effect is still difficult to determine. Computational fluid dynamics and erosion monitoring technology have also been evaluated and applied. This paper presents a comprehensive review of the erosion of Pelton turbines, some of the latest technical methods, and possible future development directions.

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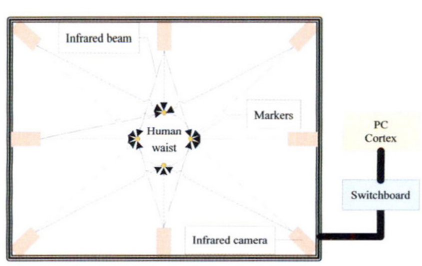
DOI: 10.1186/s10033-023-00906-5

Smooth Trajectory Planning for a Cable Driven Parallel Waist Rehabilitation Robot Based on Rehabilitation Evaluation Factors

Yuan Li • Bin Zi • Zhi Sun • Ping Zhao



Abstract: Rehabilitation robots can help physiatrists to assist patients in improving their movement ability. Due to the interaction between rehabilitation robots and patients, the robots need to complete rehabilitation training on a safe basis. This paper presents an approach for smooth trajectory planning for a cable-driven parallel waist rehabilitation robot (CDPWRR) based on the rehabilitation evaluation factors. First, motion capture technology is used to collect the motion data of several volunteers in waist twisting. Considering the impact of motion variability, the feature points at the center of the human pelvis are obtained after eliminating unreasonable data through rationality judgments. Then, point-to-point waist training trajectory planning based on quintic polynomial and cycloid functions, and multipoint waist training trajectory planning based on quintic B-spline functions are carried out. The corresponding planned curves and kinematics characteristics using three methods are compared and analyzed. Subsequently, the rehabilitation evaluation factors are introduced to conduct smooth trajectory planning for waist training, and the waist trajectory with better compliance is obtained based on the safety and feasibility of waist motion. Finally, the physical prototype of the CDPWRR is built, and the feasibility and effectiveness of the proposed smooth trajectory planning method are proved by numerical analysis and experiments.

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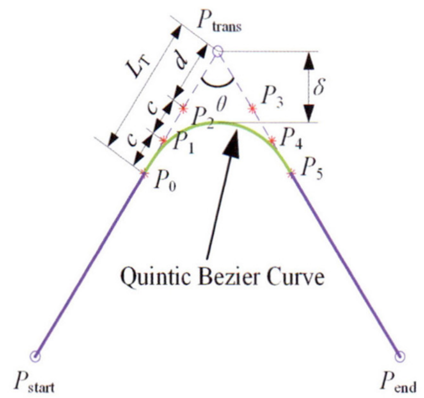
DOI: 10.1186/s10033-023-00881-x

A Real-time Look-ahead Trajectory Planning Methodology for Multi Small Line Segments Path

Sai Zhang • Xinjun Liu • Bingkai Yan • Jie Bi • Xiangdong Han

Abstract: When a robot is required to machine a complex curved workpiece with high precision and speed, the tool path is typically dispersed into a series of points and transmitted to the robot. The conventional trajectory planning method requires frequent starts and stops at each dispersed point to complete the task. This method not only reduces precision but also causes damage to the motors and robot. A real-time look-ahead algorithm is proposed in this paper to improve precision and minimize damage. The proposed algorithm includes a path-smoothing algorithm, a trajectory planning method, and a bidirectional scanning module. The path-smoothing method inserts a quintic Bezier curve between small adjacent line segments to achieve G^2 continuity at the junctions. The trajectory planning method utilizes a quartic polynomial and a double-quartic polynomial that can achieve a constant velocity at the velocity limitation. The bidirectional scanning module calculates the velocity at each trajectory planning segment point, simplifying calculation complexity and can be run in real time. The feasibility of the proposed algorithm is verified through simulations and experiments, which can be run in real time. In addition, high machining precision can be achieved by adjusting the relevant parameters.

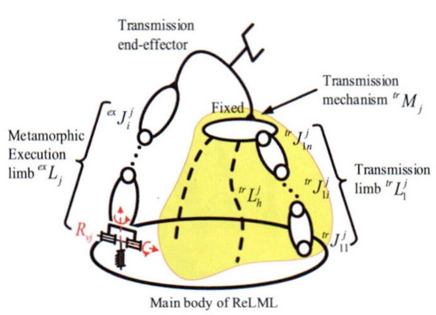


(2023)36:77
DOI: 10.1186/s10033-023-00899-1

Task-Oriented Topology System Synthesis of Reconfigurable Legged Mobile Lander Integrating Active and Passive Metamorphoses

Youcheng Han • Ziyue Li • Gaohan Zhu • Weizhong Guo • Jianzhong Yang • Wei Liu

Abstract: To explore hostile extraterrestrial landforms and construct an engineering prototype, this paper presents the task-oriented topology system synthesis of reconfigurable legged mobile lander (ReLML) with three operation modes from adjusting, landing, to roving. Compared with our preceding works, the adjusting mode with three rotations (3R) provides a totally novel exploration approach to geometrically matching and securely arriving at complex terrains dangerous to visit currently; the landing mode is redefined by two rotations one translation (2R1T), identical with the tried-and-tested Apollo and Chang'E landers to enhance survivability via reasonable touchdown buffering motion; roving mode also utilizes 2R1T motion for good motion and force properties. The reconfigurable mechanism theory is first brought into synthesizing legged mobile lander integrating active and passive metamorphoses, composed of two types of metamorphic joints and metamorphic execution and transmission mechanisms. To reveal metamorphic principles with multiple finite motions, the finite screw theory is developed to present the procedure from unified mathematical representation, modes and source phase derivations, metamorphic joint and limb design, to final structure assembly. To identify the prototype topology, the 3D optimal selection matrix method is proposed considering three operation modes, five evaluation criteria, and two topological subsystems. Finally, simulation verifies the whole task implementation process to ensure the reasonability of design.



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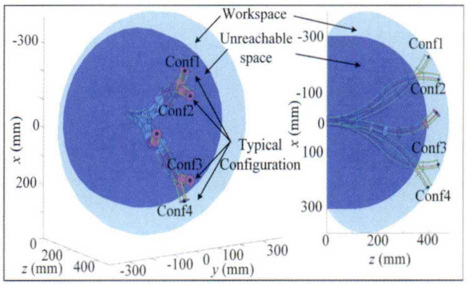
DOI: 10.1186/s10033-023-00893-7

General Kinetostatic Modeling and Deformation Analysis of a Two-Module Rod-Driven Continuum Robot with Friction Considered

Peiyi Wang • Xinhua Yang • Xiangyang Wang • Sheng Guo



Abstract: Continuum robots actuated by flexible rods have large potential applications, such as detection and operation tasks in confined environments, since the push and pull actuation of flexible rods withstand tension and compressive force, and increase the structure's rigidity. In this paper, a generalized kinetostatics model for multi-module and multi-segment continuum robots considering the effect of friction based on the Cosserat rod theory is established. Then, the model is applied to a two-module rod-driven continuum robot with winding ropes to analyze its deformation and load characteristics. Four different in-plane configurations under the external load term as S1, S2, C1, and C2 are defined. Taking a bending plane as an example, the tip deformation along the *x*-axis of these shapes is simulated and compared, which shows that the load capacity of C1 and C2 is generally larger than that of S1 and S2. Furthermore, the deformation experiments and simulations show that the maximum error ratio without external loads relative to the total length is no more than 3%, and it is no more than 4.7% under the external load. The established kinetostatics model is proven sufficient to accurately analyze the rod-driven continuum robot with the consideration of internal friction.

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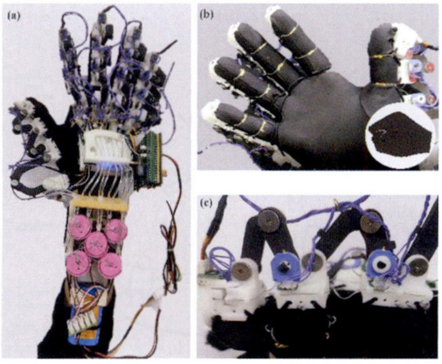
An Adaptive Hand Exoskeleton for Teleoperation System

WeiWei • Bangda Zhou • Bingfei Fan • Mingyu Du • Guanjun Bao • Shibo Cai



Abstract: Teleoperation can assist people to complete various complex tasks in inaccessible or high-risk environments, in which a wearable hand exoskeleton is one of the key devices. Adequate adaptability would be available to enable the master hand exoskeleton to capture the motion of human fingers and reproduce the contact force between the slave hand and its object. This paper presents a novel finger exoskeleton based on the cascading four-link closed-loop kinematic chain. Each finger has an independent closed-loop kinematic chain, and the angle sensors are used to obtain the finger motion including the flexion/extension and the adduction/abduction. The cable tension is changed by the servo motor to transmit the contact force to the fingers in real time. Based on the finger exoskeleton, an adaptive hand exoskeleton is consequently developed. In addition, the hand exoskeleton is tested in a master-slave system. The experiment results show that the adaptive hand exoskeleton can be worn without any mechanical constraints, and the slave hand can follow the motions of each human finger. The accuracy and the real-time capability of the force reproduction are validated. The proposed adaptive hand exoskeleton can be employed as the master hand to remotely control the humanoid five-fingered dexterous slave hand, thus, enabling the teleoperation system to complete complex dexterous manipulation tasks.

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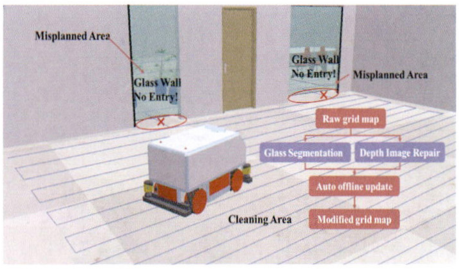
Glass Recognition and Map Optimization Method for Mobile Robot Based on Boundary Guidance

Yong Tao • He Gao • Yufang Wen • Lian Duan • Jiangbo Lan

Abstract: Current research on autonomous mobile robots focuses primarily on perceptual accuracy and autonomous performance. In commercial and domestic constructions, concrete, wood, and glass are typically used. Laser and visual mapping or planning algorithms are highly accurate in mapping wood panels and concrete walls. However, indoor and outdoor glass curtain walls may fail to perceive these transparent materials. In this study, a novel indoor glass recognition and map optimization method based on boundary guidance is proposed. First, the status of glass recognition techniques is analyzed comprehensively. Next, a glass image segmentation network based on boundary data guidance and the optimization of a planning map based on depth repair are proposed. Finally, map optimization and path-planning tests are conducted and compared using different algorithms. The results confirm the favorable adaptability of the proposed method to indoor transparent plates and glass curtain walls. Using the proposed method, the recognition accuracy of a public test set increases to 94.1%. After adding the planning map, incorrect coverage redundancies for two test scenes reduce by 59.84% and 55.7%. Herein, a glass recognition and map optimization method is proposed that offers sufficient capacity in perceiving indoor glass materials and recognizing indoor no-entry regions.

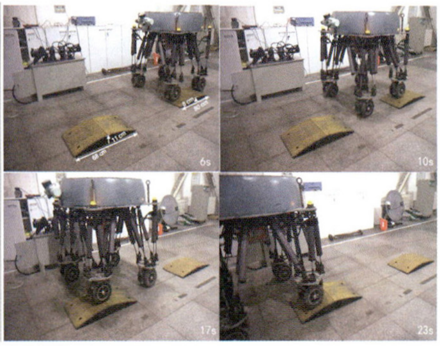


(2023)36:79
DOI: 10.1186/s10033-023-00897-3

A Closed-Loop Dynamic Controller for Active Vibration Isolation Working on A Parallel Wheel-Legged Robot

Fei Guo • Shoukun Wang • Daohe Liu • Junzheng Wang

Abstract: Serving the Stewart mechanism as a wheel-legged structure, the most outstanding superiority of the proposed wheel-legged hybrid robot (WLHR) is the active vibration isolation function during rolling on rugged terrain. However, it is difficult to obtain its precise dynamic model, because of the nonlinearity and uncertainty of the heavy robot. This paper presents a dynamic control framework with a decentralized structure for single wheel-leg, position tracking based on model predictive control (MPC) and adaptive impedance module from inside to outside. Through the Newton-Euler dynamic model of the Stewart mechanism, the controller first creates a predictive model by combining Newton-Raphson iteration of forward kinematic and inverse kinematic calculation of Stewart. The actuating force naturally enables each strut to stretch and retract, thereby realizing six degrees-of-freedom (6-DOFs) position-tracking for Stewart wheel-leg. The adaptive impedance control in the outermost loop adjusts environmental impedance parameters by current position and force feedback of wheel-leg along *Z*-axis. This adjustment allows the robot to adequately control the desired support force tracking, isolating the robot body from vibration that is generated from unknown terrain. The availability of the proposed control methodology on a physical prototype is demonstrated by tracking a Bezier curve and active vibration isolation while the robot is rolling on decelerate strips. By comparing the proportional and integral (PI) and constant impedance controllers, better performance of the proposed algorithm was operated and evaluated through displacement and force sensors internally-installed in each cylinder, as well as an inertial measurement unit (IMU) mounted on the robot body. The proposed algorithm structure significantly enhances the control accuracy and vibration isolation capacity of parallel wheel-legged robot.



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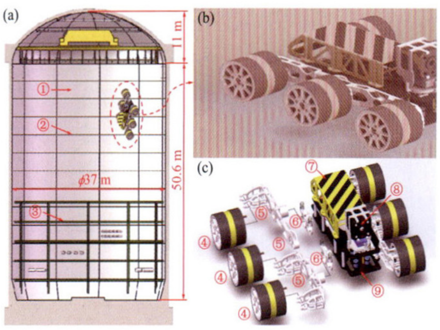
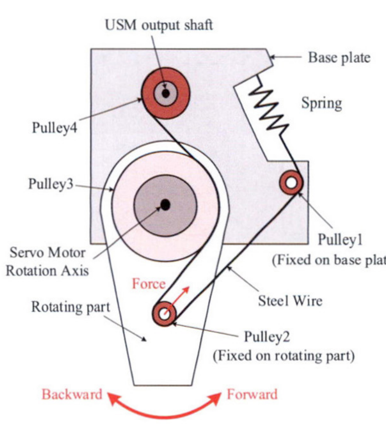


(2023)36:90
DOI: 10.1186/s10033-023-00905-6

NuBot: A Magnetic Adhesion Robot with Passive Suspension to Inspect the Steel Lining

Hao Xu • Youcheng Han • Mingda He • Yinghui Li • Weizhong Guo

Abstract: The steel lining of huge facilities is a significant structure, which experiences extreme environments and needs to be inspected periodically after manufacture. However, due to the complexity (crisscross welds, curved surface, etc.) of their inside environments, high demands for stable adhesion and curvature adaptability are put forward. This paper presents a novel wheeled magnetic adhesion robot with passive suspension applied in nuclear power containment called NuBot, and mainly focuses on the following aspects: (1) proposing the wheeled locomotion suspension to adapt the robot to the uneven surface; (2) implementing the parameter optimization of NuBot. A comprehensive optimization model is established, and global optimal dimensions are properly chosen from performance atlases; (3) determining the normalization factor and actual dimensional parameters by constraints of the steel lining environment; (4) structure design of the overall robot and the magnetic wheels are completed. Experiments show that the robot can achieve precise locomotion on both strong and weak magnetic walls with various inclination angles, and can stably cross the 5 mm weld seam. Besides, its maximum payload capacity reaches 3.6 kg. Results show that the NuBot designed by the proposed systematic method has good comprehensive capabilities of surface-adaptability, adhesion stability, and payload. Besides, the robot can be applied in more ferromagnetic environments and the design method offers guidance for similar wheeled robots with passive suspension.



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A Wire-Driven Series Elastic Mechanism Based on Ultrasonic Motor for Walking Assistive System

Weihao Ren • Hiroki Yoshioka • Lin Yang • Takeshi Morita

Abstract: In order to improve the elderly people's quality of life, supporting their walking behaviors is a promising technology. Therefore, based on one ultrasonic motor, a wire-driven series elastic mechanism for walking assistive system is proposed and investigated in this research. In contrast to tradition, it innovatively utilizes an ultrasonic motor and a wire-driven series elastic mechanism to achieve superior system performances in aspects of simple structure, high torque/weight ratio, quiet operation, quick response, favorable electromagnetic compatibility, strong shock resistance, better safety, and accurately stable force control. The proposed device is mainly composed of an ultrasonic motor, a linear spring, a steel wire, four pulleys and one rotating part. To overcome the ultrasonic motor's insufficient output torque, a steel wire and pulleys are smartly combined to directly magnify the torque instead of using a conventional gear reducer. Among the pulleys, there is one tailored pulley playing an important role to keep the reduction ratio as 4.5 constantly. Meanwhile, the prototype is manufactured and its actual performance is verified by experimental results. In a one-second operating cycle, it only takes 86 ms for this mechanism to output an assistive torque of 1.6 N·m. At this torque, the ultrasonic motor's speed is around 4.1 rad/s. Moreover, experiments with different operation periods have been conducted for different application scenarios. This study provides a useful idea for the application of ultrasonic motor in walking assistance system.

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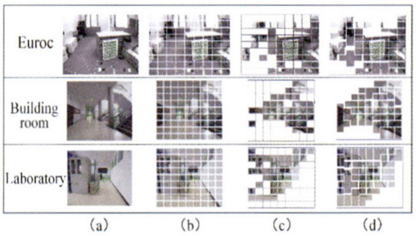
Human Visual Attention Mechanism-Inspired Point-and-Line Stereo Visual Odometry for Environments with Uneven Distributed Features

Chang Wang • Jianhua Zhang • Yan Zhao • Youjie Zhou • Jincheng Jiang

Abstract: Visual odometry is critical in visual simultaneous localization and mapping for robot navigation. However, the pose estimation performance of most current visual odometry algorithms degrades in scenes with unevenly distributed features because dense features occupy excessive weight. Herein, a new human visual attention mechanism for point-and-line stereo visual odometry, which is called point-line-weight-mechanism visual odometry (PLWM-VO), is proposed to describe scene features in a global and balanced manner. A weight-adaptive model based on region partition and region growth is generated for the human visual attention mechanism, where sufficient attention is assigned to position-distinctive objects (sparse features in the environment). Furthermore, the sum of absolute differences algorithm is used to improve the accuracy of initialization for line features. Compared with the state-of-the-art method (ORB-VO), PLWM-VO show a 36.79% reduction in the absolute trajectory error on the Kitti and Euroc datasets. Although the time consumption of PLWM-VO is higher than that of ORB-VO, online test results indicate that PLWM-VO satisfies the real-time demand. The proposed algorithm not only significantly promotes the environmental adaptability of visual odometry, but also quantitatively demonstrates the superiority of the human visual attention mechanism.



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(2023)36:71

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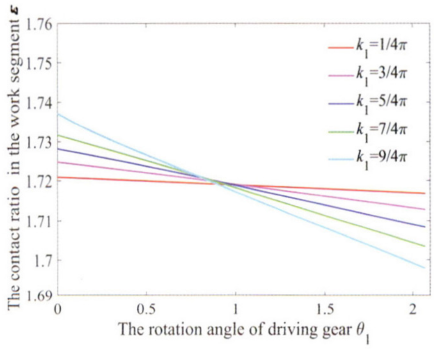
Design of Linear Functional Noncircular Gear with High Contact Ratio Used in Continuously Variable Transmission

Yanan Hu • Chao Lin • Chunjiang He • Yongquan Yu • Zhiqin Cai

Abstract: Continuously variable transmission (CVT) of noncircular gear has the technical advantages of large bearing capacity and high transmission efficiency. The key technology of CVT with noncircular gear has been broken through some countries, and is in the stage of deep application research. Although the characteristics and design methods of noncircular gear pairs have been continuously studied in China, the noncircular gear CVT is still in the preliminary exploration and research stage. The linear functional noncircular gear pair, whose transmission ratio is a linear function in the working section, to realize continuously variable transmission was the research object in this paper. According to the required transmission ratio in the working section, the transmission ratio function in the non-working section was constructed by using a polynomial. And then the influence of pitch curve parameters in the working section on which in the non-working section was also analyzed to obtain the pitch curve suitable for transmission of this gear pair. In addition, for improving the stability and bearing capacity of gear transmission, the noncircular gear pair transmission with high contact ratio was designed. Furthermore, the accurate value of the contact tooth length was calculated based on the gear principle and the characteristics of the involute tooth profile, from this the contact tooth length error was calculated by comparing the accurate value with its actual value obtained by the rolling experiment. Finally, an indirect method to verify the contact ratio by detecting the contact length error of the tooth profile was proposed.



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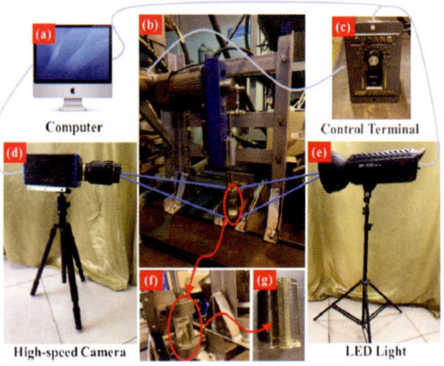
DOI: 10.1186/s10033-023-00890-w

Generation and Evolution of Cavitation Bubbles in Volume Alternate Cavitation (VAC)

Shangshuang Chen • Yun Wang • Fuzhu Li • Shenwei Xue • Zhenying Xu • Chao Yu • Kun Zhang

Abstract: Cavitation generation methods have been used in multifarious directions because of their diversity, and numerous studies and discussions have been conducted on cavitation generation methods. This study aims to explore the generating mechanism and evolution law of volume alternate cavitation (VAC). In the VAC, liquid water is placed in an airtight container with a variable volume. As the volume alternately changes, the liquid water inside the container continues to cavitate. Then, the mixture turbulence model and in-cylinder dynamic grid model are adopted to conduct computational fluid dynamics simulation of volume alternate cavitation. In the simulation, the cloud images at seven heights on the central axis are monitored, and the phenomenon and mechanism of height and eccentricity are analyzed in detail. By employing the cavitation flow visualization method, the generating mechanism and evolution law of cavitation are revealed. The synergistic effects of experiments and high-speed camera capturing confirm the correctness of the simulation results. In the experiment, the volume change stroke of the airtight container is set to 20 mm, the volume change frequency is 18 Hz, and the shooting frequency of the high-speed camera is set to 10000 FPS. The experimental results indicate that the position of the cavitation phenomenon has a reasonable law during the whole evolution cycle of the cavitation cloud. Also, the volume alternation cycle corresponds to the generation, development, and collapse stages of cavitation bubbles.



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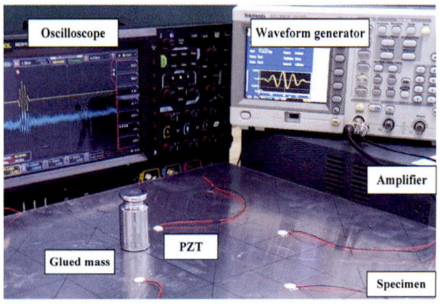
Robust Damage Detection and Localization Under Complex Environmental Conditions Using Singular Value Decomposition-based Feature Extraction and One-dimensional Convolutional Neural Network

Shengkang Zong • Sheng Wang • Zhitao Luo • Xinkai Wu • Hui Zhang • Zhonghua Ni

Abstract: Ultrasonic guided wave is an attractive monitoring technique for large-scale structures but is vulnerable to changes in environmental and operational conditions (EOC), which are inevitable in the normal inspection of civil and mechanical structures. This paper thus presents a robust guided wave-based method for damage detection and localization under complex environmental conditions by singular value decomposition-based feature extraction and one-dimensional convolutional neural network (1D-CNN). After singular value decomposition-based feature extraction processing, a temporal robust damage index (TRDI) is extracted, and the effect of EOCs is well removed. Hence, even for the signals with a very large temperature-varying range and low signal-to-noise ratios (SNRs), the final damage detection and localization accuracy retain perfect 100%. Verifications are conducted on two different experimental datasets. The first dataset consists of guided wave signals collected from a thin aluminum plate with artificial noises, and the second is a publicly available experimental dataset of guided wave signals acquired on a composite plate with a temperature ranging from 20℃ to 60℃. It is demonstrated that the proposed method can detect and localize the damage accurately and rapidly, showing great potential for application in complex and unknown EOC.



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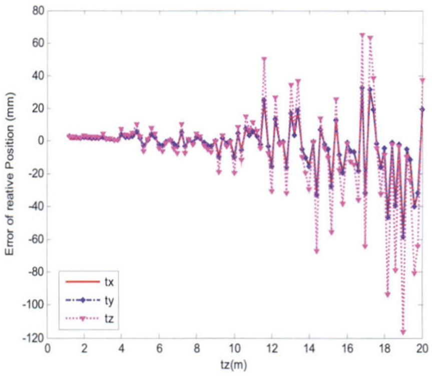
DOI: 10.1186/s10033-023-00884-8

Spacecraft Pose Estimation Based on Different Camera Models

Lidong Mo • Naiming Qi • Zhenqing Zhao



Abstract: Spacecraft pose estimation is an important technology to maintain or change the spacecraft orientation in space. For spacecraft pose estimation, when two spacecraft are relatively distant, the depth information of the space point is less than that of the measuring distance, so the camera model can be seen as a weak perspective projection model. In this paper, a spacecraft pose estimation algorithm based on four symmetrical points of the spacecraft outline is proposed. The analytical solution of the spacecraft pose is obtained by solving the weak perspective projection model, which can satisfy the requirements of the measurement model when the measurement distance is long. The optimal solution is obtained from the weak perspective projection model to the perspective projection model, which can meet the measurement requirements when the measuring distance is small. The simulation results show that the proposed algorithm can obtain better results, even though the noise is large.

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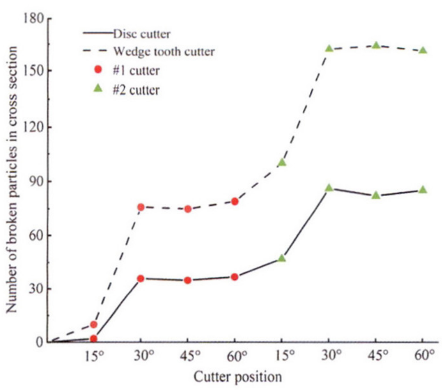
DOI: 10.1186/s10033-023-00888-4

Comparative Study of the Rock-breaking Mechanism of a Disc Cutter and Wedge Tooth Cutter by Discrete Element Modelling

Hua Jiang • Huiyan Zhao • Xiaoyan Zhang • Yusheng Jiang • Yaofu Zheng



Abstract: The operation of a shield tunnel boring machine (TBM) in a high-strength hard rock stratum results in significant cutter damage, adversely affecting the thrust and torque of the cutter head. Therefore, it is very important to carry out the research on the stress characteristics and optimize the cutter parameters of cutters break high-strength hard rock. In this paper, the rock-breaking performance of cutters in an andesite stratum in the tunnel of Qingdao Metro Line No. 8 was investigated using the discrete element method and theoretical analysis. The rock-breaking processes of a disc cutter and wedge tooth cutter were simulated by software particle flow code PFC^{3D}, and the rock-breaking degree, stress of the cutter, and rock-breaking specific energy were analyzed. The rock damage caused by the cutter in a specific section was divided into three stages: the advanced influence, crushing, and stabilizing stages. The rock-breaking degree and the tangential and normal forces of the wedge tooth cutter are larger than that of the disc cutter under the same conditions. The disc cutter (wedge tooth cutter) has the highest rock-breaking efficiency at a cutter spacing of 100 mm (110 mm) and a penetration depth of 8 mm (10 mm), and the rock-breaking specific energy is 11.48 MJ/m^3 (12.05 MJ/m^3). Therefore, two types of cutters with different penetration depths or cutter spacing should be considered. The number of teeth of wedge tooth cutters can be increased in hard strata to improve the rock-breaking efficiency of the shield. The research results provide a reference for shield cutterhead selection and cutter layout in similar projects.

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Advanced Transportation Equipment

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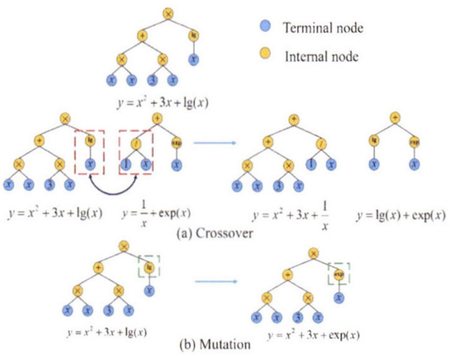
DOI: 10.1186/s10033-023-00876-8

Crack Growth Rate Model Derived from Domain Knowledge-Guided Symbolic Regression

Shuwei Zhou • Bing Yang • Shoune Xiao • Guangwu Yang • Tao Zhu

Abstract: Machine learning (ML) has powerful nonlinear processing and multivariate learning capabilities, so it has been widely utilised in the fatigue field. However, most ML methods are inexplicable black-box models that are difficult to apply in engineering practice. Symbolic regression (SR) is an interpretable machine learning method for determining the optimal fitting equation for datasets. In this study, domain knowledge-guided SR was used to determine a new fatigue crack growth (FCG) rate model. Three terms of the variable subtree of ΔK, R-ratio, and ΔK_{th} were obtained by analysing eight traditional semi-empirical FCG rate models. Based on the FCG rate test data from other literature, the SR model was constructed using Al-7055-T7511. It was subsequently extended to other alloys (Ti-10V-2Fe-3Al, Ti-6Al-4V, Cr-Mo-V, LC9cs, Al-6013-T651, and Al-2324-T3) using multiple linear regression. Compared with the three semi-empirical FCG rate models, the SR model yielded higher prediction accuracy. This result demonstrates the potential of domain knowledge-guided SR for building the FCG rate model.



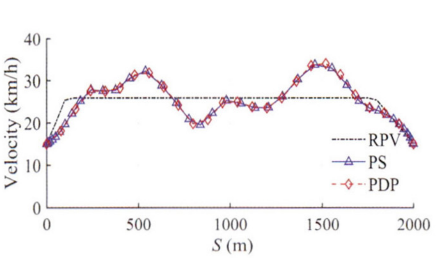
(2023)36:82

DOI: 10.1186/s10033-023-00891-9

Energy-Saving and Punctuality Combined Velocity Planning for the Autonomous-Rail Rapid Tram with Enhanced Pseudospectral Method

Jinxiang Wang • Dongming Han • Yongjun Yan • Neng Liu • Ning Sun • Guodong Yin

Abstract: Autonomous-rail rapid transit (ART) is a new medium-capacity rapid transportation system with punctuality, comfort and convenience, but low-cost construction. Combined velocity planning is a critical approach to meet the requirements of energy-saving and punctuality. An ART velocity pre-planning and re-planning strategy based on the combination of punctuality dynamic programming (PDP) and pseudospectral (PS) method is proposed in this paper. Firstly, the longitudinal dynamics model of ART is established by a multi-particle model. Secondly, the PDP algorithm with global optimal characteristics is adopted as the pre-planning strategy. A model for determining the number of collocation points of the real-time PS method is proposed to improve the energy-saving effect while ensuring computation efficiency. Then the enhanced PS method is utilized to design the velocity re-planning strategy. Finally, simulations are conducted in the typical scenario with sloping roads, traffic lights, and intrusion of the pedestrian. The simulation results indicate that the ART with the proposed velocity trajectory optimization strategy can meet the punctuality requirement, and obtain better economy efficiency compared with the punctuality green light optimal speed advisory (PGLOSA).



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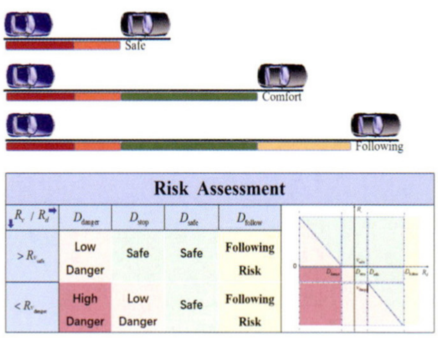

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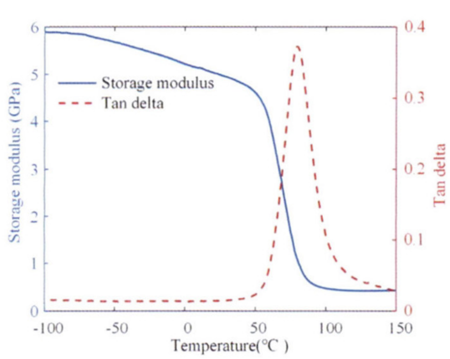
DOI: 10.1186/s10033-023-00904-7

A Combined Reinforcement Learning and Model Predictive Control for Car-Following Maneuver of Autonomous Vehicles

Liwen Wang • Shuo Yang • Kang Yuan • Yanjun Huang • Hong Chen

Abstract: Model predictive control is widely used in the design of autonomous driving algorithms. However, its parameters are sensitive to dynamically varying driving conditions, making it difficult to be implemented into practice. As a result, this study presents a self-learning algorithm based on reinforcement learning to tune a model predictive controller. Specifically, the proposed algorithm is used to extract features of dynamic traffic scenes and adjust the weight coefficients of the model predictive controller. In this method, a risk threshold model is proposed to classify the risk level of the scenes based on the scene features, and aid in the design of the reinforcement learning reward function and ultimately improve the adaptability of the model predictive controller to real-world scenarios. The proposed algorithm is compared to a pure model predictive controller in car-following case. According to the results, the proposed method enables autonomous vehicles to adjust the priority of performance indices reasonably in different scenarios according to risk variations, showing a good scenario adaptability with safety guaranteed.

Smart Materials



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Shape Memory Polymer Composite Booms with Applications in Reel-Type Solar Arrays

Hong Xiao • Sijie Wu • Dongdong Xie • Hongwei Guo • Li Ma • Yuxuan Wei • Rongqiang Liu

Abstract: Solar arrays are the primary energy source for spacecraft. Although traditional rigid solar arrays improve power supply, the quality increases proportionally. Hence, it is difficult to satisfy the requirements of high-power and low-cost space applications. In this study, a shape-memory polymer composite (SMPC) boom was designed, fabricated, and characterized for flexible reel-type solar arrays. The SMPC boom was fabricated from a smart material, a shape-memory polymer composite, whose mechanical properties were tested. Additionally, a mathematical model of the bending stiffness of the SMPC boom was developed, and the bending and buckling behaviors of the boom were further analyzed using the ABAQUS software. An SMPC boom was fabricated to demonstrate its shape memory characteristics, and the driving force of the booms with varying geometric parameters was investigated. We also designed and manufactured a reel-type solar array based on an SMPC boom and verified its self-deployment capability. The results indicated that the SMPC boom can be used as a deployable unit to roll out flexible solar arrays.

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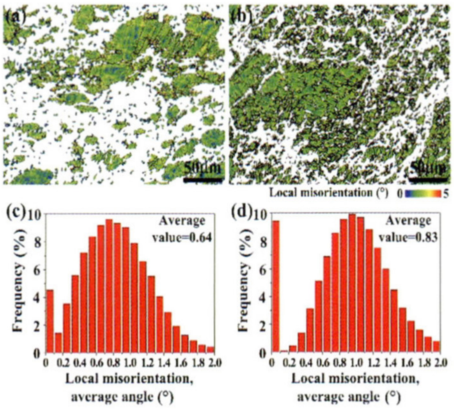
Effect of Initial Microstructure Prior to Extrusion on the Microstructure and Mechanical Properties of Extruded AZ80 Alloy with a Low Temperature and a Low Ratio

Hang Zhang • Haipeng Li • Rongguang Li • Boshu Liu • Ruizhi Wu •
Dongyue Zhao • Shanshan Li



Abstract: Magnesium (Mg) alloys are the lightest metal structural material for engineering applications and therefore have a wide market of applications. However, compared to steel and aluminum alloys, Mg alloys have lower mechanical properties, which greatly limits their application. Extrusion is one of the most important processing methods for Mg and its alloys. However, the effect of such a heterogeneous microstructure achieved at low temperatures on the mechanical properties is lacking investigation. In this work, commercial AZ80 alloys with different initial microstructures (as-cast and as-homogenized) were selected and extruded at a low extrusion temperature of 220°C and a low extrusion ratio of 4. The microstructure and mechanical properties of the two extruded AZ80 alloys were investigated. The results show that homogenized-extruded (HE) sample exhibits higher strength than the cast-extruded (CE) sample, which is mainly attributed to the high number density of fine dynamic precipitates and the high fraction of recrystallized ultrafine grains. Compared to the coarse compounds existing in CE sample, the fine dynamical precipitates of $Mg_{17}(Al, Zn)_{12}$ form in the HE sample can effectively promote the dynamical recrystallization during extrusion, while they exhibit a similar effect on the size and orientation of the recrystallized grains. These results can facilitate the designing of high-strength wrought magnesium alloys by rational microstructure construction.

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