NOKOV

Published Papers in English Using NOKOV Motion Capture Systems

June.2022

目录

*The content of this document is updated to June 2022

Part Ⅰ UAV，UGV

Multi-target Coverage with Connectivity Maintenance using Knowledge-incorporated Policy Framework

Abstract

This paper considers a multi-target coverage problem where a robot team aims to efficiently cover multi-targets while maintaining connectivity in a distributed manner. A novel knowledge-incorporated policy framework is proposed to derive a distributed, efficient, and connectivity guaranteed coverage policy. In particular, a knowledge-guided policy network (KGPnet) is designed, which consists of observation attention representation, interaction attention representation, and knowledge-guided policy learning. Giving credit to the KGPnet, the connectivity guaranteed coverage policy can be applied to different number targets. Moreover, based on the knowledge of the algebraic connectivity and coverage rate, a comprehensive reward is designed to guide the training of the behavior of multi-target coverage with connectivity maintenance. Furthermore, since the policy learned through deep reinforcement learning (DRL) can not guarantee the connectivity of the robot team, a knowledge-nested policy filtering is designed to filter dis-connectivity policies to satisfy the connectivity constraint based on the knowledge model of connectivity maintenance. Various simulations are conducted to verify the effectiveness of the proposed method. Besides, numerous real-world experiments with three-wheel omnidirectional cars and a motion capture system are presented to demonstrate the practicability of the proposed method.

How NOKOV Contributes to the Research

In order to verify the practicability of the proposed method in practical application, some real-world experiments are conducted. As shown in Fig.3 (b), a robot team consisting of three holomonic robots is used to test the derived policy. To improve the real-time of the policy generating, each robot is equipped with onboard computer (Nvidia Jetson TX2). In addition, the positions and velocities of the robots are provided by the NOKOV motion capture system.

References Wu S, Pu Z, Liu Z, et al. Multi-target Coverage with Connectivity Maintenance using Knowledge-incorporated Policy Framework[C]//2021 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2021: 8772-8778.

Link https://ieeexplore.ieee.org/abstract/document/9562017

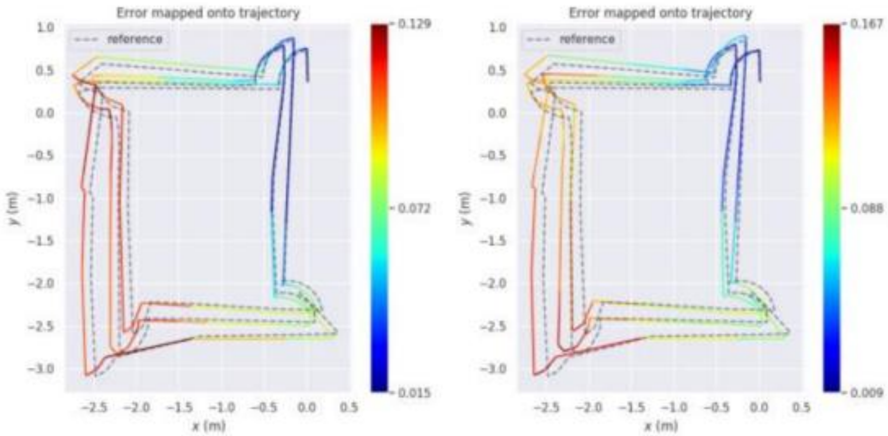
Stereo Visual Inertial Mapping Algorithm for Autonomous Mobile Robot

Keywords

Visual inertial mapping; Stereo camera; AMR; SLAM

Abstract

Simultaneous Localization and Mapping (SLAM) is a fundamental problem for autonomous mobile robots (AMRs). AMRs are widely used in automated warehousing, factory material transfer systems, flexible assembly systems, and other intelligent transportation sites. The visual Inertial Odometry (VIO) which consists of the camera and inertial-measurement-unit (IMU), is a popular approach to achieve accurate 6-DOF state estimation. However, such locally accurate VIO is prone to drift and cannot provide a global consistent map. The prerequisite for re-localizing the robot and ensuring precise autonomous navigation is an accurate and global consistent map of its environment. In this study, we propose a stereo visual-inertial mapping system. The front-end is a robust stereo VIO based on a tightly-coupled sliding window optimization. The core of the back-end is the global Bundle-Adjustment (BA) which is a nonlinear optimization, in which IMU is also added as a time-domain constraint. Meanwhile, stereo-camera-IMU extrinsic calibration is performed in BA to improve mapping accuracy. The selection principles of keyframes and map points are also designed according to the AMRs application characteristics. Further, the forward and backward Perspective-n-Point (PNP) method is also adopted to avoid the loop-detection mismatch. The performance of the system was validated and compared against other state-of-the-art algorithms. The findings revealed the effectiveness and robustness of this stereo visual-inertial mapping algorithm.



How NOKOV Contributes to the Research

The algorithm is verified by comparing two different scenes: one is a small-scale laboratory scene and the other is a large-scale scene (≥1000 square meters). A motion capture system (Nokov Mars1.3H) is a physically-based ground truth in laboratory scenes. In a large-scale scene, the surrounding environment is not friendly to visual SLAM, which contains pedestrians, a long corridor, low-light condition, textureless area, glass, and reflection. In this experiment, we compare our algorithm with another state- of-the-art algorithm VINS- Fusion [36]. For a fair comparison, most config parameters of both our algorithm and VINS-Fusion are similar.

References **Zhang M, Han S, Wang S, et al. Stereo Visual Inertial Mapping Algorithm for Autonomous Mobile Robot[C]//2020 3rd International Conference on Intelligent Robotic and Control Engineering (IRCE). IEEE, 2020: 97-104.**
Link https://ieeexplore.ieee.org/abstract/document/9199252

Continuous-time Gaussian Process Trajectory Generation for Multi-robot Formation via Probabilistic Inference

Abstract

In this paper, we extend a famous motion plan- ning approach GPMP2 to multi-robot cases, yielding a novel centralized trajectory generation method for the multi-robot formation. A sparse Gaussian Process model is employed to represent the continuous-time trajectories of all robots as a limited number of states, which improves computational efÞciency due to the sparsity. We add constraints to guarantee collision avoidance between individuals as well as formation maintenance, then all constraints and kinematics are formu- lated on a factor graph. By introducing a global planner, our proposed method can generate trajectories efÞciently for a team of robots which have to get through a width-varying area by adaptive formation change. Finally, we provide the implemen- tation of an incremental replanning algorithm to demonstrate the online operation potential of our proposed framework. The experiments in simulation and real world illustrate the feasibility, efÞciency and scalability of our approach.

How NOKOV Contributes to the Research

> *We test the proposed framework with a team of quadrotors on three common scenarios: formation maintenance, replanning for a changed destination and adaptive formation change for moving through a width-varying area. Experiments in the real world are conducted with a group of Crazyflie nano-quadrotors flying under the supervision of a NOKOV motion capture system.*

References Guo S, Liu B, Zhang S, et al. Continuous-time Gaussian Process Trajectory Generation for Multi-robot Formation via Probabilistic Inference[J]. arXiv preprint arXiv:2010.13148, 2020.
Link https://arxiv.org/abs/2010.13148

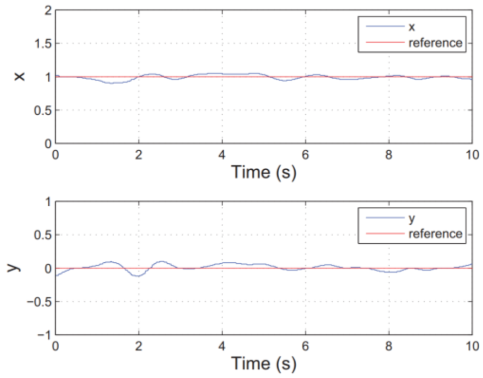
A Feedback Linearization and Saturated Control Structure for Quadrotor UAV

Keywords

UAV; Feedback linearization control; LESO

Abstract

In this paper,attitude controller and position controller are investigated for a small quadrotor unmanned aerial vehicle (UAV). A feedback linearization method is proposed to design attitude tracking control of UAV, with linear extended state observer (LESO) to estimate and compensate for the disturbances. Meanwhile, a saturated control law with arc tangent functions is adopted as the position controller. Then the convergence of LESO, stability of attitude system and position system are proved. Finally, experiment results are given to illustrate the effectiveness of the proposed method.



How NOKOV Contributes to the Research

The quadrotor position experimental platform is shown in Fig.3b, which exits three parts: Nokov motion capture sys- tem, quadrotors and communication system. Nokov motion capture system gets the position of the quadrotor by Nokov markers (reßective balls), the quadrotor can get the informa- tion of its own precise position via communication system (WiFi). Based on the quadrotor position experimental plat- form, a hovering test is done to verify the effectiveness of position system control. The parameters of position system are given in Table.2. In this case, the experimental results are shown in Fig.6 and Fig.7. Fig.6 shows the position tracking performance and Fig.5 shows the inputs of position system. From results, the errors of position from x and y axes are less than 0.1 meter and inputs are reasonable. In other word, it can accurately track the reference position.

References Jiang H, Xia Y, Hu R, et al. A feedback linearization and saturated control structure for quadrotor UAV[C]//2019 Chinese Control Conference (CCC). IEEE, 2019: 8277-8282.
Link https://ieeexplore.ieee.org/abstract/document/8866172

On-demand Precise Tracking for Energy-constrained UAVs in Underground Coal Mines

Keywords

Unmanned aerial vehicle; unscented Kalman; filte; energy-efficient; on-demand precise tracking; coal mines.

Abstract

The precise tracking of unmanned aerial vehicle (UAV) in coal mines remains a challenging task that faces strict energy constraints. The existing approaches mainly focus on achieving better accuracy but ignore energy consumption. This paper proposes an on-demand precise tracking (OPT) framework based on the fusion of the ultra-wideband (UWB) and inertial measurement unit (IMU). The fusion unscented Kalman filter (fu-sion UKF) is devised for energy-efficient tracking with customized performance. First, OPT provides an adaptive adjustment mech- anism of UWB signal transmission to trade-off between accuracy and energy consumption for UAV local positioning in coal mines. Second, we propose an on-demand trigger algorithm for UAV remote tracking to determine whether the data is transmitted to the ground server. Especially, the on-demand trigger condition is ameliorated owing to the existence of packet drops in complicated coal mines. Finally, extensive simulations in the Gazebo Platform and field experiments utilizing P440 UWB nodes in the indoor and coal mine laboratories have been conducted to verify the fea- sibility. Results show that OPT is efficient, practical and balances the performance and energy consumption under appropriate parameters. Compared with the existing event-triggered extended Kalman filter (ET-EKF) scheme, the accuracy is improved by 10.3%, and the communication rate is contracted by 11.4% in the coal mine environment.

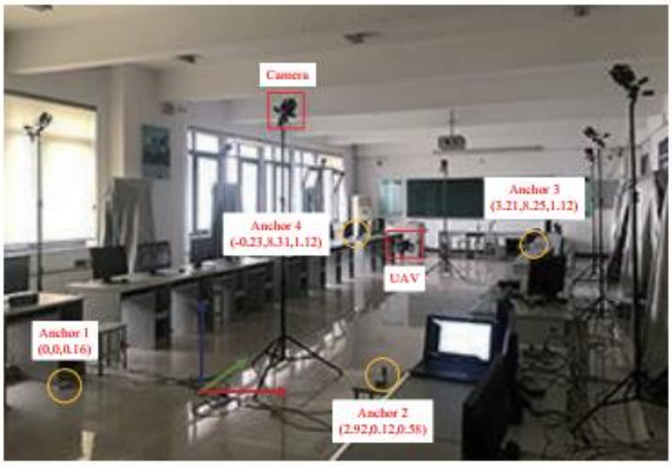


Fig. 11. The experiments in the indoor laboratory.

How NOKOV Contributes to the Research

Since the ground truth of position cannot be obtained directly in experiments, an optical motion capture system (NOKOV VICON) that provides almost minor positioning errors is utilized to provide the reference position. We arrange eight cameras forming a square to capture the position of the UAV in the indoor laboratory.

References Zhang K, Chen P, Ma T, et al. On-Demand Precise Tracking for Energy-Constrained UAVs in Underground Coal Mines[J]. IEEE Transactions on Instrumentation and Measurement, 2022, 71: 1-14.
Link https://ieeexplore.ieee.org/abstract/document/9694638

Motion Planning of Multi-Robots Object Transport with Deformable Sheet

Keywords

Multi-robot manipulation; Path planning for multiple mobile robots

Abstract

Using a deformable sheet to handle objects is convenient and found in many practical applications. Modeling of deformable sheet-object interactions and robot formation are among the main challenges in multi-robot object manipulation through deformable sheets. Motion planning of robotic team is critical for object manipulation quality. We present a computational robots-sheet-object model and the dual-capability robotic motion planner for optimal trajectory. A computational virtual variable cables model (VVCM) is presented to simplify the modeling of the deformable sheet with an arbitrary number of used robots. The motion planner is first formulated as a formation optimization problem. A path generation algorithm is then employed for obstacle avoidance and crossing features. The motion planner successfully produces an obstacle crossing path in complex scenarios where other benchmark planners fail. The effectiveness and versatility of the motion planner are verified and demonstrated by a robotic team of three robots. We further extend the results to a larger number of robots to illustrate the algorithms and analysis.

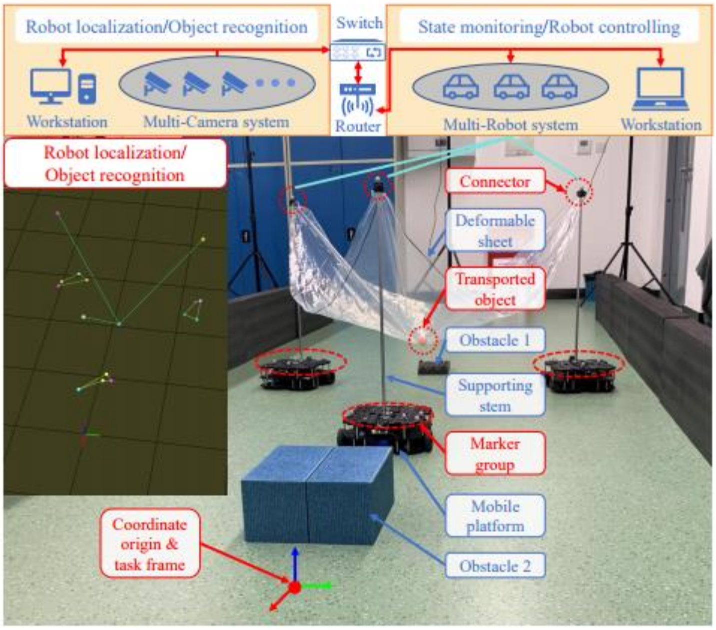


Fig. 6. Experimental setup and communication network of the multi-mobile robot transportation system.

How NOKOV Contributes to the Research

> *The position of robots and object were acquired at a rate of 60 Hz by the NOKOV motion capture system with 8 cameras.*

References Hu J, Liu W, Zhang H, et al. Multi-Robot Object Transport Motion Planning With a Deformable Sheet[J]. IEEE Robotics and Automation Letters, 2022, 7(4): 9350-9357.
Link https://arxiv.org/abs/2111.09046

Risk-aware Trajectory Sampling for Quadrotor Obstacle Avoidance in Dynamic Environments

Keywords

Collision Avoidance; Motion and path planning; Aerial Systems; Perception and Autonomy

Abstract

Obstacle avoidance of quadrotors in dynamic environments, with both static and dynamic obstacles, is still a very open problem. Current works commonly leverage traditional static maps to represent static obstacles and the detection and tracking of moving objects (DATMO) method to model dynamic obstacles separately. The dynamic obstacles are pretrained in the detector and can only be modeled with certain shapes, such as cylinders or ellipsoids. This work utilizes our dual-structure particle-based (DSP) dynamic occupancy map to represent the arbitrary-shaped static obstacles and dynamic obstacles simultaneously and proposes an efficient risk-aware sampling-based local trajectory planner to realize safe flights in this map. The trajectory is planned by sampling motion primitives generated in the state space. Each motion primitive is divided into two phases: short-term planning with a strict risk limitation and relatively long-term planning designed to avoid high-risk regions. The risk is evaluated with the predicted future occupancy status, represented by particles, considering the time dimension. With an approach to split from and merge to global trajectories, the planner can also be used with an arbitrary preplanned global trajectory. Comparison experiments show that the obstacle avoidance system composed of the DSP map and our planner performs the best in dynamic environments. In real-world tests, our quadrotor reaches a speed of 6 m/s with the motion capture system and 2 m/s with everything computed on a low-price single board computer.

Fig. 8. The hardware structure of the quadrotor.

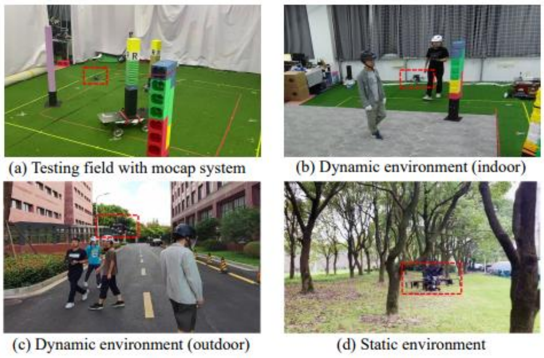


Fig. 9. Testing scenarios in the real world. In subplot (a), the position of the quadrotor and the position of obstacles are given by the motion capture system. The dynamic obstacles are two foam pillars mounted on mobile robots. Subplot (b) and (c) show two dynamic environments. Subplot (d) shows a static woods.

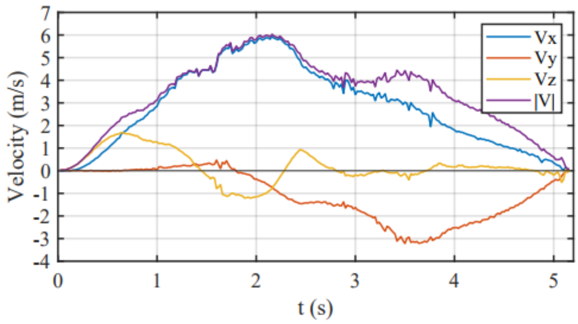


Fig. 10. The velocity curve of a test with the motion capture system.

How NOKOV Contributes to the Research

> *Tests with the motion capture system: As is shown in Fig. 9 (a), two static obstacles and two dynamic obstacles were in the testing field. The dynamic obstacles moved with a constant velocity, about 1m/s for the faster one and 0.5m/s for the slower one. The Nokov motion capture system was used to capture the position of the quadrotor and the obstacles. The future occupancy status of the dynamic obstacles was predicted with the constant velocity model. The quadrotor was able to fly rapidly and safely in the tests. The maximum speed reached 6m/s. The corresponding velocity curve is shown in Fig. 10.*

References Chen G, Peng P, Zhang P, et al. Risk-aware Trajectory Sampling for Quadrotor Obstacle Avoidance in Dynamic Environments[J]. arXiv preprint arXiv:2201.06645, 2022.
Link https://arxiv.org/abs/2201.06645

Obstacle Crossing by Multi-mobile Robots in Object Transportation with Deformable Sheet

Keywords

Multi-robot systems; Intelligent transportation systems; Path planning for multiple mobile robots;

Abstract

Multi-robot transportation (MRT) is to transport the object to the destination by the cooperation of multiple robots. In the process of object transportation, obstacle avoidance is an indispensable feature. In traditional local planners, obstacles are usually considered insurmountable, so the robot team bypasses the obstacles as a whole. However, many obstacles can be crossed in real situation. Studying the obstacle crossing ability of robot team can improve the efficiency of MRT and increase the planning success rate in complex environment. Inspired by the patient transfer through bed sheet, this paper focuses on the object transportation by multi-mobile robots with deformable sheet. A new local planner with obstacle crossing capability is proposed, which consists of three parts: deformable sheet modeling, formation optimization and local path generation. It can successfully find an obstacle crossing path in complex scenarios where other planners fail. The effectiveness and the versatility of the planner is verified by a case study with three mobile robots in the experiment and a simulation with four robots.

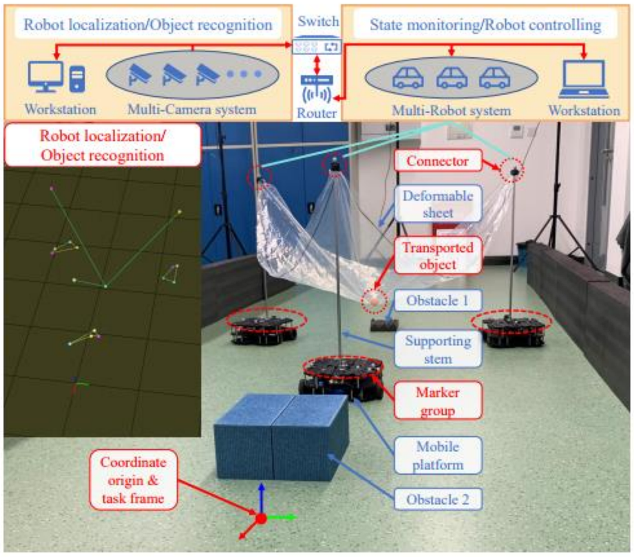


Fig. 7. Experimental setup and communication network of the multi-mobile robot transportation system.

How NOKOV Contributes to the Research

> *Three robots (turtlebot3 waffle-pi) are applied in this experiment. The transported object is a billiard ball. The position of robots and object can be acquired at a rate of 60 Hz by the NOKOV motion capture system with 8 cameras. The deformable sheet are fabric cloth and plastic cloth, the latter is convenient for the camera to capture the position of the robot in real time. Each side length of the original sheet is 1600 mm, and the height of each vertex is 790 mm. The experimental environment is a corridor (2 meters wide, 6 meters long) with two different obstacles in the middle. One has a radius of 100 mm and a height of 50 mm, and the other has a radius of 200 mm and a height of 200 mm. The simulation result is obtained by MATLAB 2019b, and the whole control architecture is implemented based on robot operating system (ROS). A remote laptop (Intel i7-4710HQ CPU with four cores and 8 GB RAM) is set up for state monitoring and robot controlling. Experimental setup and communication network of the system are shown in Fig. 7.*

References Hu J, Liu W, Zhang H, et al. Obstacle Crossing by Multi-mobile Robots in Object Transportation with Deformable Sheet[J]. arXiv preprint arXiv:2111.09046, 2021.
Link https://arxiv.org/abs/2111.09046

Stabilizing Angle Rigid Formations With Prescribed Orientation and Scale

Keywords

Bearing measurement; formation control; multi-agent systems; prescribed orientation and scale;

Abstract

Angle rigid formations have the advantage of requiring only bearing measurements in their implementation. However, the capability of controlling the orientation and scale of these formations has not been explored. This undetermined orientation and scale can degrade the robustness of the formation against measurement noise. To maintain both advantages of requiring less sensor measurements and sustaining robustness against measurement noise, this paper aims to achieve a desired angle rigid formation while simultaneously controlling its orientation and scale. We first design a formation algorithm for the first three agents to achieve a desired triangular formation with prescribed orientation and scale. Using the control gain design technique, we then design formation control algorithms for the remaining agents such that the overall desired formation can be achieved under a vertex addition operation. We present the role of generic property from angle rigidity for the formation's stability analysis. We also highlight that with one additional relative position measurement or two additional communication channels, the local convergence to the desired formation can be improved to a global convergence. Experiments are conducted to validate the theoretical results and the advantages are highlighted in comparison with other two formation control laws.

How NOKOV Contributes to the Research

In this section, we validate the results of Theorems 1-4 using four wheeled robots to achieve a desired rectangular formation. The size of each robot is 60cm length, 46cm width, and 46cm height. Each robot has four wheels and is controlled by an on-board computer. Since wheeled robots are unicycles, we apply feedback linearization [20], [21] towards a reference point that is inside of the robot to obtain the single-integrator dynamics (1). The measurements of relative positions or bearings among robots are captured by the NOKOV Mocap system sampling at the rate of 120 Hz. Each robot will calculate the control input along its X-axis and Y-axis according to the designed controllers, then apply it to the robots.

References Chen L, Yang Q, Shi M, et al. Stabilizing Angle Rigid Formations With Prescribed Orientation and Scale[J]. IEEE Transactions on Industrial Electronics, 2021, 69(11): 11654-11664.
Link https://ieeexplore.ieee.org/abstract/document/9583880

Part II Exoskeleton

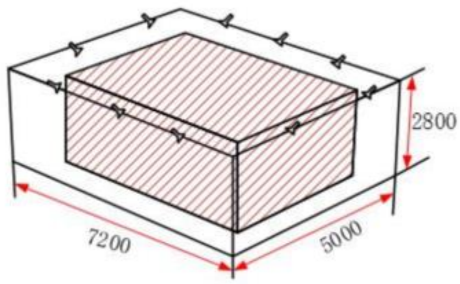
Design and Experimental Research of Knee Joint Prosthesis Based on Gait Acquisition Technology

Keywords

Gait acquisition; Lower limb prosthesis; Instantaneous movement; Bionic performance

Abstract

Whether the lower limb prosthesis can better meet the needs of amputees, the biomimetic performance of the knee joint is particularly important. In this paper, Nokov(metric) optical 3D motion capture system was used to collect motion data of normal human lower limbs, and the motion instantaneous center of multi-gait knee joint was obtained. Taking the error of knee joint motion instantaneous center line as the objective function, a set of six-bar mechanism prosthetic knee joint was designed based on a genetic algorithm. The experimental results show that the movement trajectory of the instantaneous center of the knee joint is basically similar to that of the human knee joint, so it can help amputees complete a variety of gaits and has good biomimetic performance. Gait acquisition technology can provide important data for prosthetic designers and it will be widely used in prosthetic design and other Þelds.



(a)

(b)

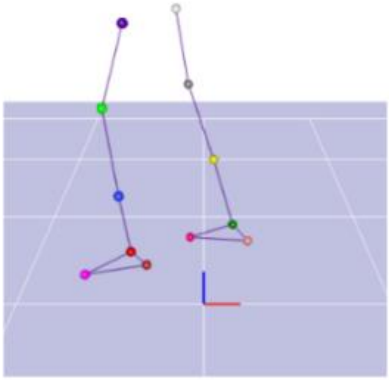


Figure 4. Gait acquisition interface.

(a) (b) (c)

How NOKOV Contributes to the Research

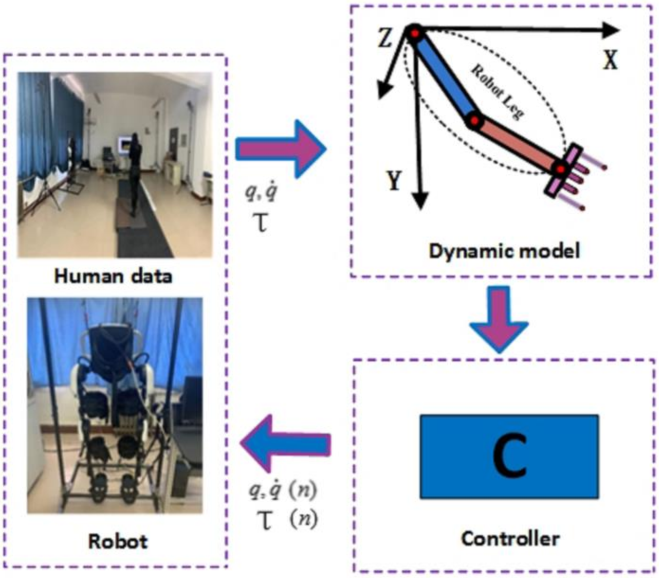
> *A Nokov motion information collection system was established, and 30 bone healthy and normal gaiters were selected to collect motion data on their knee and ankle joints. This paper mainly studies the motion status of the lower limbs, namely the motion data of the knee joint and the ankle joint, and then marks the positions shown in Figure 3 in combination with the human body structure.*

References Zhang Y, Wang E, Wang M, et al. Design and Experimental Research of Knee Joint Prosthesis Based on Gait Acquisition Technology[J]. Biomimetics, 2021, 6(2): 28.
Link https://www.mdpi.com/2313-7673/6/2/28

Human-Like Robust Adaptive PD Based Human Gait Tracking for Exoskeleton Robot

Abstract

For patients with dyskinesias caused by central nervous system diseases such as stroke, in the early stage of rehabilitation training, lower limb rehabilitation robots are used to provide passive rehabilitation training. This paper proposed a human-like robust adaptive PD control strategy of the exoskeleton robot based on healthy human gait data. When the error disturbance is bounded, a human-like robust adaptive PD control strategy is designed, which not only enables the rehabilitation exoskeleton robot to quickly track the human gait trajectory obtained through the 3D NOKOV motion capture system, but also can well identify the structural parameters of the system and avoid excessively initial output torque for the robot. MATLAB simulation verifies that the proposed method has a better performance to realize tracking the experimental trajectory of human movement and anti-interference ability under the condition of ensuring global stability for a lower limb rehabilitation exoskeleton robot.



How NOKOV Contributes to the Research

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References Wang A, Hu N, Yu J, et al. Human-Like Robust Adaptive PD Based Human Gait Tracking for Exoskeleton Robot[J]. Journal of Robotics and Mechatronics, 2021, 33(1): 88-96.
Link https://www.jstage.jst.go.jp/article/jrobomech/33/1/33_88/_article/-char/ja/

Adaptive Control of the Rehabilitation Robot with the Model Uncertainty based on Real Human Gait

Keywords

True human gait; Model uncertainty; Adaptive control; Rehabilitation robot; Structural parameters

Abstract

The lower limbs exoskeleton rehabilitation robot (LLERR) has been used widely in rehabilitation training of human lower limb injury, where the control research of LLERR is still a hot point in robotics. Therefore, in this paper, a trajectory tracking adaptive control based on human gait is proposed. Where, the real gait trajectory of human body mechanism by using NOKOV motion capture system is used in control system design. In the simulation results, the dynamics model uncertainty are also considered, and the real gait trajectory data of human body is used to the control system. According to the simulation results, when there is uncertainty in the LLERR model, the proposed trajectory tracking adaptive control method can improve the accuracy and reliability of the trajectory tracking, which makes it suitable for different patients. By adaptive control, the uncertain part of the LLERR is compensated, and the structure parameters of the robot are obtained

How NOKOV Contributes to the Research

In this paper, the NOKOV motion capture system was used to collect the gait movement of the experimenter and obtain hip and knee trajectories. The sampling frequency of this test was 120Hz, and 70 groups were collected. The resulting trajectories of the hip and knee joints will be unsmooth and need to be Þltered to obtain a smooth curve. The existing Þltering methods include least square method and Kalman Þlter, etc. In this paper, the least square method is used for Þltering. The NOKOV motion capture system combines with a pressure test bench to measure plantar torque, which can be calculated to obtain hip and knee torques, as shown in Fig3 and Fig4.

References Lu J, Aihui W, Ma Z. Adaptive control of the rehabilitation robot with the model uncertainty based on real human gait[C]//2020 International Conference on Advanced Mechatronic Systems (ICAMechS). IEEE, 2020: 282-285.
Link https://ieeexplore.ieee.org/abstract/document/9310078

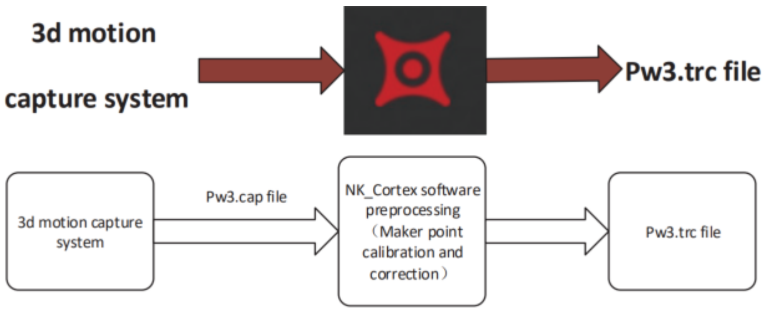
Human Gait Analysis based on OpenSim

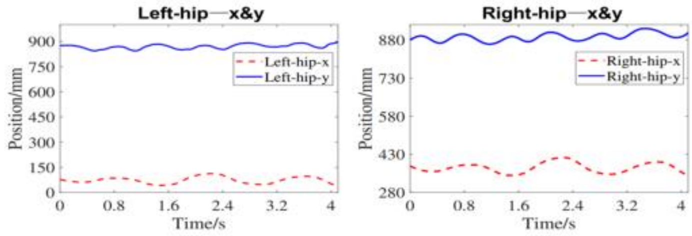
Keywords

Lower limb exoskeleton; OpenSim; Human gait; Simulation; NoKov optical 3D motion

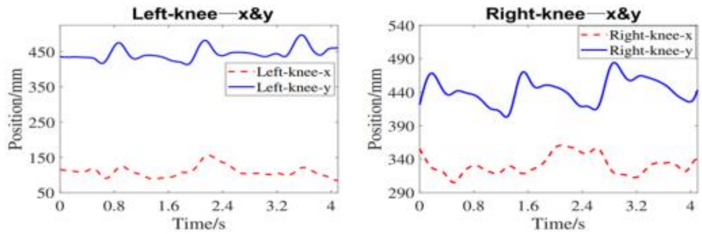
Abstract

The gait motion is fundamental human locomotion that is associated with the human lower limb. Considering the complex structural characteristics of gait, the major challenge is the dynamics model's accuracy and certainty. This paper pro- poses a method for analyzing human gait in walking. This paper adopted the NoKov optical three-dimensional motion capture system to collect human gait data, built dynamics and kine- matics exoskeleton model, and then designed inverse kinematics algorithms. To obtain human gait characteristics, we established a high-precision human lower limb musculoskeletal model in OpenSim, and then imported gait data into the model for kinematics and dynamics simulation. To verify the effectiveness of the proposed method, in this paper, joint angles changes obtained through inverse kinematics analysis of MATLAB are compared with joint angle changes simulated by OpenSim musculoskeletal model.

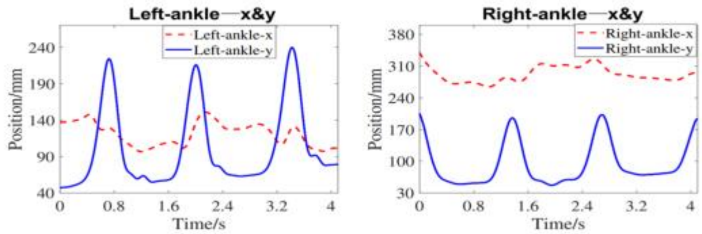




(a) Left hip trajectory on axis X&Y (b) Right hip trajectory on axis X&Y



(c) Left knee trajectory on axis X&Y (d) Right knee trajectory on axis X&Y



(e) Left ankle trajectory on axis X&Y (f) Right ankle trajectory on axis X&Y

How NOKOV Contributes to the Research

The gait motion is fundamental human locomotion that is associated with the human lower limb. Considering the complex structural characteristics of gait, the major challenge is the dynamics model's accuracy and certainty. This paper pro- poses a method for analyzing human gait in walking. This paper adopted the NoKov optical three-dimensional motion capture system to collect human gait data, built dynamics and kine- matics exoskeleton model, and then designed inverse kinematics algorithms. To obtain human gait characteristics, we established a high-precision human lower limb musculoskeletal model in OpenSim, and then imported gait data into the model for kinematics and dynamics simulation. To verify the effectiveness of the proposed method, in this paper, joint angles changes obtained through inverse kinematics analysis of MATLAB are compared with joint angle changes simulated by OpenSim musculoskeletal model.

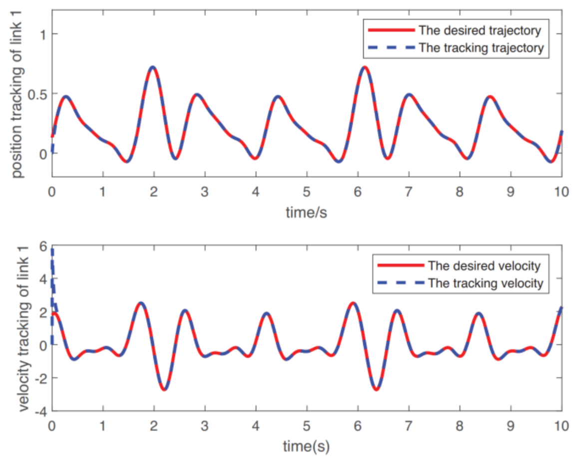
References Yu J, Zhang S, Wang A, et al. Human gait analysis based on OpenSim[C]//2020 International Conference on Advanced Mechatronic Systems (ICAMechS). IEEE, 2020: 278-281.

Link https://ieeexplore.ieee.org/abstract/document/9310111

Research on Robot Control System of Lower Limbrehabilitation Robot Based on Human Gait Comfort

Abstract

Aiming at the comfort of wearing rehabilitation training robot for patients with lower limb movement disorder, this paper proposes a control method based on real human gait data as the reference trajectory, and designs a control strategy with the comfort of human wearable robot as the objective function, and the wearing rehabilitation training robot can realize the real-time tracking of experimental trajectory of human movement. Firstly, NOKOV motion capture system is used to collect human gait data. Then, the dynamics model of the lower limb rehabilitation training robot's unilateral leg is identified by Lagrange method, and the controller with comfort level as the objective function is designed. The feasibility of the designed control method is proved by Lyapunov stability theorem. Finally, the effectiveness of the proposed method is verified by MATLAB simulation based experimental data on the lower limb rehabilitation training robot prototype.



How NOKOV Contributes to the Research

> *Aiming at the comfort of wearing rehabilitation training robot for patients with lower limb movement disorder, this paper proposes a control method based on real human gait data as the reference trajectory, and designs a control strategy with the comfort of human wearable robot as the objective function, and the wearing rehabilitation training robot can realize the real-time tracking of experimental trajectory of human movement. Firstly, NOKOV motion capture system is used to collect human gait data. Then, the dynamics model of the lower limb rehabilitation training robot's unilateral leg is identified by Lagrange method, and the controller with comfort level as the objective function is designed. The feasibility of the designed control method is proved by Lyapunov stability theorem. Finally, the effectiveness of the proposed method is verified by MATLAB simulation based experimental data on the lower limb rehabilitation training robot prototype.*

References Wang A, Hu N, Yu J, et al. Research on robot control system of lower limb rehabilitation robot based on human gait comfort[C]//2019 International Conference on Advanced Mechatronic Systems (ICAMechS). IEEE, 2019: 34-39.
Link https://ieeexplore.ieee.org/abstract/document/8861558

Adaptive Control of Lower Limb Robot based on Human Comfort under Minimum Inertial Parameters

Keywords

Gait data analysis; Comfortable function; Minimum inertia parameters; Adapt tracking control

Abstract

For patients with dyskinesia caused by central ner-vous system diseases such as stroke, the lower limb rehabilitation robot is required to provide passive rehabilitation training during the initial rehabilitation training, and a trajectory for healthy human body is used as a reference trajectory, this paper designs an adaptive controller to help patients with rehabilitation training methods. First, the gait trajectory of a healthy human body is obtained using an optical motion capture system and used as a reference trajectory for rehabilitation training. Then, the unilateral oscillating leg of the lower limb rehabilitation robot is modeled by dynamics. Based on this, an adaptive controller is designed to enable the lower limb rehabilitation robot to quickly track the desired trajectory, and a similarity function for evaluating the follow ability of the lower limb rehabilitation robot is proposed. Finally, experiments on the prototype of MATLAB simulation and lower limb rehabilitation robot demonstrates the feasibility of the proposed method.

How NOKOV Contributes to the Research

In most human gait acquisition devices, optical motion capture is preferred because it can accurately measure small reßective markers attached to some relevant body landmarks. Therefore, in this paper, the NOKOV 3d infrared passive optical motion capture system is used to collect human movement gait data as input data of exoskeleton robot controller, and then proposes a human body comfort function based on human-computer interaction, in the case of model parameter uncertainty adaptive controller is designed for lower limb rehabilitation robot trajectory tracking control, so as to realize more comfortable natural gait trajectory, and improve the efÞciency of rehabilitation, Þnally simulation experiment and in lower limb exoskeleton rehabilitation training robot experiments verify the feasibility and effectiveness of the proposed method.

References Hu N, Wang A, Yu J, et al. Adaptive control of lower limb robot based on human comfort under minimum inertial parameters[C]//2019 International Conference on Advanced Mechatronic Systems (ICAMechS). IEEE, 2019: 40-45.
Link
https://www.researchgate.net/publication/336436874_Adaptive_control_of_lower_limb_robot_based_on_human_comfort_under_minimum_inertial_parameters

Adaptive Research of Lower Limb Rehabilitation Robot Based on Human Gait

Abstract

For patients with dyskinesia caused by central nervous system diseases such as stroke, the lower limb rehabilitation robot is required to provide passive rehabilitation training during the initial rehabilitation training, and a trajectory for healthy human body is used as a reference trajectory, this paper designs an adaptive controller to help patients with rehabilitation training methods. First, the gait trajectory of a healthy human body is obtained using an optical motion capture system and used as a reference trajectory for rehabilitation training. Then, the unilateral oscillating leg of the lower limb rehabilitation robot is modeled by dynamics. Based on this, an adaptive controller is designed to enable the lower limb rehabilitation robot to quickly track the desired trajectory, and a similarity function for evaluating the follow ability of the lower limb rehabilitation robot is proposed. Finally, experiments on the prototype of MATLAB simulation and lower limb rehabilitation robot demonstrates the feasibility of the proposed method.

How NOKOV Contributes to the Research

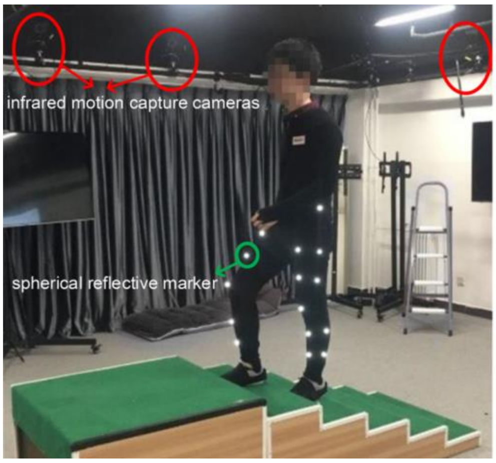
Using the NOKOV 3D infrared passive optical motion capture system can only obtain the coordinates of the outside of the lower extremities of the human body. Therefore, the center position of each joint of the human lower extremity needs to be calculated based on the anthropometric experience formula to determine the walking parameters of the human body. Take the right lower limb of the human body as an example. The key points and world coordinates are shown in Fig.3. The positive direction is the direction of the human body as the axis, the positive direction of the axis is the left-hand side, and the positive direction of the axis is the vertical direction.For the hip joint of the right lower extremity of the human body, a local coordinate is established with the marker point 8, ie, the sacrum, as the origin, and the local coordinate unit vector is deÞned as,

References Yu J, Cai F, Wang A, et al. Adaptive Research of Lower Limb Rehabilitation Robot Based on Human Gait[C]//2018 International Conference on Advanced Mechatronic Systems (ICAMechS). IEEE, 2018: 86-92.
Link https://ieeexplore.ieee.org/abstract/document/8507128
Official Website Case Link
https://www.nokov.com/en/support/case_studies_detail/Motion-planning-of-bio-inspired-robot.html

An Adaptive Stair-ascending Gait Generation Approach based on Depth Camera for Lower Limb Exoskeleton

Abstract

The mobility on stairways is a daily challenge for seniors and people with dyskinesia. Lower limb exoskeletons can be effective assistants to improve their life quality. In this paper, we present an adaptive stair-ascending gait generation algorithm based on a depth camera for lower limb exoskeletons. We first construct a linked-list-based stairway model with the point cloud captured from the depth camera. Then, an optimal foothold point is calculated based on the linked-list stair model for gait generation. Finally, the exoskeleton takes the stair-ascending gait of healthy people as a reference and generates appropriate gait for the stair. The proposed gait generation algorithm is initially validated through holistic simulation analyses. We tested the stairway modeling algorithm on varieties of indoor and outdoor stairways and evaluated the gait generation algorithm on stairs of different height. The subjects' stair walking tests with lower limb exoskeletons show the effectiveness of the proposed stairway modeling and gait generation approaches.



How NOKOV Contributes to the Research

To generate a natural stair walking gait as a reference, we built a motion capture site and collected a series of motion postures of healthy people walking on flat ground and stairs with the NOKOV motion capture system (Fig. 3). The infrared cameras capture the 3D location of each spherical reflective markers on the suit, and the motion posture analysis software associates each marker to a specific position of a human model. During the marker association process, all the incorrect markers with the wrong position are identified and removed manually. Then, the lower limbs and torso are fitted with the position of the markers. In this research, we denote the sequence of hip joint angles (α) and knee joint angles (β) as the lower limb exoskeleton walking gait. Hence, we can compute and filter the joint angles (α and β) with the fitted limbs and torso. Each gait angle data are fitted by an 8th order multiple sinusoidal functions for a smooth reference average gait curve,

References Zhao X, Chen W H, Li B, et al. An adaptive stair-ascending gait generation approach based on depth camera for lower limb exoskeleton[J]. Review of Scientific Instruments, 2019, 90(12): 125112.
Link https://aip.scitation.org/doi/abs/10.1063/1.5109741

Mechanical Design and Kinematic Modeling of a Cable-Driven Arm Exoskeleton Incorporating Inaccurate Human Limb Anthropomorphic Parameters

Keywords

Cable-driven exoskeleton; Rehabilitation robot; Upper limb

Abstract

Compared with conventional exoskeletons with rigid links, cable-driven upper-limb exoskeletons are light weight and have simple structures. However, cable-driven exoskeletons rely heavily on the human skeletal system for support. Kinematic modeling and control thus becomes very challenging due to inaccurate anthropomorphic parameters and ßexible attachments. In this paper, the mechanical design of a cable-driven arm rehabilitation exoskeleton is proposed to accommodate human limbs of different sizes and shapes. A novel arm cuff able to adapt to the contours of human upper limbs is designed. This has given rise to an exoskeleton which reduces the uncertainties caused by instabilities between the exoskeleton and the human arm. A kinematic model of the exoskeleton is further developed by considering the inaccuracies of human-arm skeleton kinematics and attachment errors of the exoskeleton. A parameter identiÞcation method is used to improve the accuracy of the kinematic model. The developed kinematic model is Þnally tested with a primary experiment with an exoskeleton prototype.

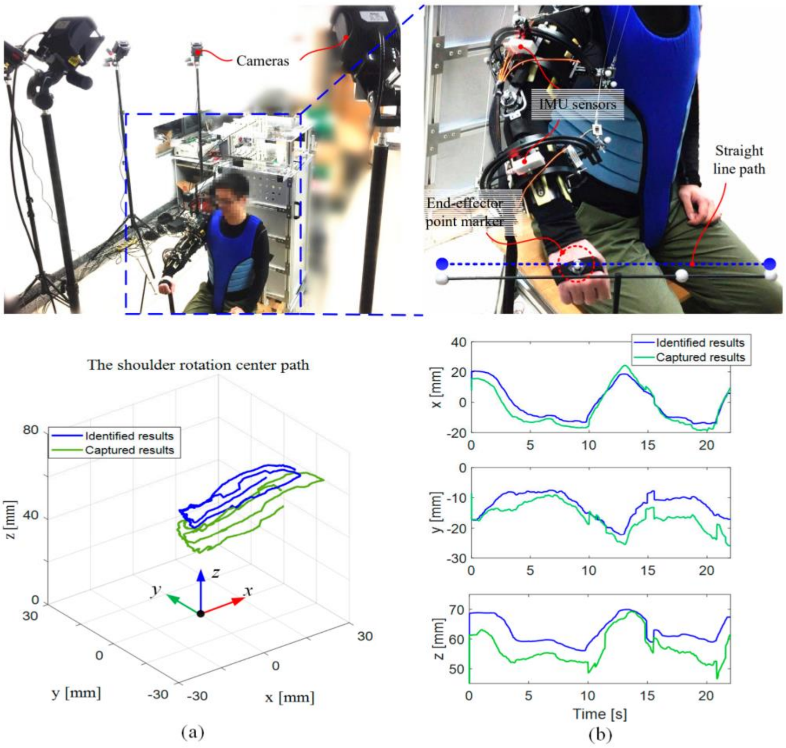


Figure 9. The movement of the shoulder joint center in (**a**) 3D and (**b**) 2D plots.

How NOKOV Contributes to the Research

To verify the accuracy of the kinematic models with identiÞed parameters, a Nokov motion capture system was used, as shown in Figure 6. In the motion capture system, a marker was mounted onto the hand of the subjects to measure their tracking results in the experiments. Fourteen markers were mounted onto the cable-routing points of the cuffs to capture changes in the lengths of the cables in the exoskeleton in the tracking task. A marker mounted on the subject' s shoulder joint recorded the movement of the joint center. Noting that as the Nokov system captures motion with sub-millimeter accuracy, the measurements can be considered as the real results in this work. The captured results can be compared with the identiÞed results to validate the accuracy of the kinematic model.

References Chen W, Li Z, Cui X, et al. Mechanical design and kinematic modeling of a cable-driven arm exoskeleton incorporating inaccurate human limb anthropomorphic parameters[J]. Sensors, 2019, 19(20): 4461.
Link https://www.mdpi.com/1424-8220/19/20/4461

Robust Adaptive PD-like control of Lower Limb Rehabilitation Robot based on Human Movement Data

Keywords

Human movement data; Rehabilitation robot; Trajectory tracking; S-curve function; Similarity function

Abstract

The combination of biomedical engineering and robotics engineering brings hope of rehabilitation to patients with lower limb movement disorders caused by diseases of the central nervous system. For the comfort during passive training, anti-interference and the convergence speed of tracking the desired trajectory, this paper analyzes human body movement mechanism and proposes a robust adaptive PD-like control of the lower limb exoskeleton robot based on healthy human gait data. In the case of bounded error perturbation, MATLAB simulation verifies that the proposed method can ensure the global stability by introducing an S-curve function to make the design robust adaptive PD-like control. This control strategy allows the lower limb rehabilitation robot to track the human gait trajectory obtained through the motion capture system more quickly, and avoids excessive initial output torque. Finally, the angle similarity function is used to objectively evaluate the human body for wearing the robot comfortably.

How NOKOV Contributes to the Research

Therefore, this paper adopts an nonlinear complex exoskeleton robot as the research object, and designs a robust adaptive PD-like control (RAPLC) based on real data. The schematic diagram of the principle is shown in Fig. 1. First, NOKOV three-dimensional (3D) infrared motion capture equipment and three-dimensional force measurement platform equipment are used to collect human gait movement data and plantar force data. The collected data is analyzed for human kinematics and dynamic characteristics and the processed gait data is used as the reference expected motion trajectory of the LLRR control system. Second, the S-curve function is introduced on the basis of the traditional robust adaptive PD controller, which improves the convergence speed of the joint angular displacement and reduces the joint initial torque. Finally, the quadratic function of the error is used as the energy function of the system, and the stability of the control system of the LLRR based on the Lyapunov stability theory is guaranteed under the condition of the coupling and nonlinearity of each joint. The trajectory tracking simulations results show that the LLRR system joint angular displacement has good tracking performance. Comparing the LLRR system joint torque obtained from simulation with experimenter's lower limbs can safely and comfortably complete the rehabilitation training.

References Hu N, Wang A, Wu Y. Robust adaptive PD-like control of lower limb rehabilitation robot based on human movement data[J]. PeerJ Computer Science, 2021, 7: e394.
Link https://peerj.com/articles/cs-394/

Kinematics and Dynamics Analysis of Lower Limbs based on Human Motion Data

Keywords

Gait trajectory; Data processing; Kinesiology; Human biomechanics

Abstract

For patients with an aging population and patients suffering from movement disorders, the combination of robotic systems and biomedical engineering principles has brought good news to the majority of patients. The analysis of human gait laws can help better develop and research robotic systems. Therefore, this article is based on the idea of using the gait trajectory of a healthy person as the input reference trajectory of the robot, using NOKOV three-dimensional infrared motion capture equipment and three-dimensional force measurement platform equipment to collect human gait movement data and plantar force data, and analyze the collected data Kinematics and dynamics characteristics of human body data.

How NOKOV Contributes to the Research

Through the comparison of domestic motion capture systems, this paper adopts the NOKOV 3D infrared passive optical motion capture system with better effect. Its system components mainly consist of 6 Mars2H lenses (as shown in Fig.1), connectors, tripods, three-way pan/tilt, connecting wire, calibration rod (T-shaped and L-shaped calibration rods), NK- Cortex software, and reßective markers (Marker).

References Hu N, Wang A. Kinematics and dynamics analysis of lower limbs based on human motion data[C]//2020 Chinese Automation Congress (CAC). IEEE, 2020: 6727-6732.
Link https://ieeexplore.ieee.org/abstract/document/9327180/

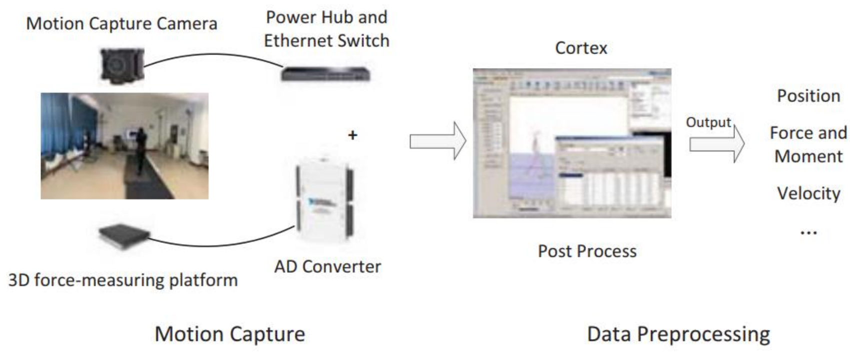
Lower Limb Rehabilitation Robot Control based on Human Gait Data and Plantar Reaction Force

Keywords

Human gait data; Plantar reaction force; Lower limb rehabilitation robot; Motion capture platform

Abstract

In this paper, to improve the safety and availability of rehabilitation training for patients, a control scheme for Lower limb rehabilitation robot (LLRR) based on human gait data and plantar reaction force is proposed. First, the real normal human gait data obtained by motion capture platform (MCP) is fed to the designed control system, and the plantar reaction force is fed to the LLRR after dynamic calculation. Then, a controller based on joint angle and angular velocity tracking error is designed to realize the trajectory tracking. Finally, for a robot simulation model, the effectiveness of the proposed method is confirmed based on the simulation results.



How NOKOV Contributes to the Research

One of the main concerns of these LLRR is to generate physiological gait trajectories with human motion characteristics, and achieve safe and effective rehabilitation training. Generally, the gait trajectories with good rehabilitation training results are generated by healthy subjects. There are a variety of motion capture techniques for acquiring gait trajectory in current, such as inertia, magnetic, and ultrasonic system [13], among them, the optical motion capture (OPC) is one of the most effective methods. The Nokov OPC equipment adopt the motion capture cameras with ten bits gray-scale depth and GrayScale image processing algorithm, can achieve the precision of millimeter [16], [17]. To realize batter control effectiveness, Xu proposed a torque control strategy based on real-time gait event detection [14], which could control torque and directly drive joint motion based on real-time gait information. However, this control strategy is proposed for the control of a bionic knee exoskeleton. Wang introduced a gait trajectory measurement and planning method [15]. By measuring and planning the gait trajectory, the ideal controller input of the lower limb rehabilitation robot is obtained, which is used to realize the humanoid movement of the lower limb rehabilitation robot, and improve the safety of rehabilitation training. Wang and Hu proposed a LLRR control system based on human gait comfort [16], [17], which can well realize the tracking of human gait trajectory.

References Ge Y, Dan Y, Wang A, et al. Lower limb rehabilitation robot control based on human gait data and plantar reaction force[C]//2020 International Conference on Advanced Mechatronic Systems (ICAMechS). IEEE, 2020: 286-289.
Link https://ieeexplore.ieee.org/abstract/document/9310077

Simulation of Limb Rehabilitation Robot Based on OpenSim

Keywords

Lower limb rehabilitation robot; Gait trajectory; OpenSim; Inverse kinematics; Forward dynamics

Abstract

Lower limb rehabilitation robots have been widely used in medical treatment in recent years. The safety of robot in rehabilita- tion training should be considered. In this paper, the method to analyze complicated inverse kinematics and forward dynamics of lower limb reha- bilitation robot is studied. Because of the mathematical model of lower limb is difficult to establish, the OpenSim software is used to simulate and analyze the human gait data which collected by the NOKOV optical motion capture system. According to the inverse kinematics simulation, the curve of each joint angle changing over time is obtained, and the reac- tion force acting on the ground is obtained through the forward dynamics simulation.

How NOKOV Contributes to the Research

In this paper, the NOKOV optical motion capture system is used to gain gait data. The cameras which can record each frame marker point movement sequence images are used to real-time motion capture. Because of the limited range of each camera lens, the 6 cameras can be crossed to produce an area. Markers which are captured by two lenses at the same time generate continuous trajectories. Besides, the motion capture system records the spatial coordinates of all markers at the rate of 60 frames per second and its capture accuracy can reach 1 mm. The collected human gait data can be simply processed and exported by the NOKOV system software. In this section, the 6 optical motion capture cameras are arranged in parallel in two columns [11]. The scene of motion capture and the marking points are shown in Fig. 1.

References Wang A., Lu J., Ge Y., Yu J., Zhang S. (2020) Simulation of Limb Rehabilitation Robot Based on OpenSim. In: Pan L., Liang J., Qu B. (eds) Bio-inspired Computing: Theories and Applications. BIC-TA 2019. Communications in Computer and Information Science, vol 1160. Springer, Singapore. https://doi.org/10.1007/978-981-15-3415-7_55
Link https://link.springer.com/chapter/10.1007%2F978-981-15-3415-7_55

Mechanical Compliance and Dynamic Load Isolation Design of Lower Limb Exoskeletonfor Locomotion Assistance

Keywords

Compliant joint; constant-force suspen-sion mechanism; exoskeleton; metabolic rate

Abstract

Improving the comfort and portability of exoskeleton structures for human locomotion assistance is challenging. Research shows that the misalignments between exoskeletons and human joints will lead to interference and undesired interaction forces in locomotion. Moreover, the weight and inertia of exoskeletons will lead to rapid changes in impact forces acting on the wearer. When the exoskeleton is tightly bound to the wearer's body, such forces are usually unavoidable. These issues not only reduce the comfort and portability of exoskeletons, but also increase the energy costs to wearers. To address these issues, we propose a novel lower limb exoskeleton with a constant-force suspension mechanism and self-adapting compliant joints. The constant-force suspension mechanism aims to isolate the impact force on the back of the wearer, while the self-adapting compliant joints aim to reduce the misalignments between the exoskeleton and the wearer. For the first time, a structure designed to isolate the impact force of exoskeletons is proposed. Moreover, compliant joints exhibiting comprehensive great performances in portability, flexibility, self-aligning, and weight-supporting ability have also been rarely reported. The experimental results demonstrate that the developed mechanisms can reduce the impact forces and misalignments in locomotion. Furthermore, the proposed exoskeleton can reduce the metabolic rate during walking at 5 km/h by 10.95 ± 4.40% and that during running at 9 km/h by 1.71 ± 4.54% compared with locomotion without the exoskeleton. These results confirm that the proposed designs can improve the performance of the exoskeleton in locomotion.

How NOKOV Contributes to the Research

The motion data under two conditions were measured and recorded by a motion capture system (NOKOV, China) with eight cameras. We deÞned a whole gait cycle as the motions between two consecutive right heel strikes. At these moments, the marker on the right heel reached its maximum anterior position. Thus, the motion data recorded by the motion capture system were segmented into gait cycles. Based on the data, we calculated the mean angles of the hip, knee, and ankle joints on the sagittal plane in these gait cycles ranging from 0% to 100% in the two conditions, as shown in Fig. 9(a). As the position of the markers might unavoidably move relative to the subject between the two conditions, the imperceptible differences may have arisen as a result of marker repositioning errors. Even so, these differences highlight the minimally restrictive nature of the exoskeleton.

References Li H, Sui D, Ju H, et al. Mechanical Compliance and Dynamic Load Isolation Design of Lower Limb Exoskeleton for Locomotion Assistance[J]. IEEE/ASME Transactions on Mechatronics, 2022.
Link https://ieeexplore.ieee.org/abstract/document/9802513

Human-Gait-Based Tracking Control for Lower Limb Exoskeleton Robot

Keywords

lower limb exoskeleton robot; human gait data; radial basis function network;

feed-forward control; motion capture

Abstract

Research shows that it is practical for the normal human movement mechanism to assist the patients with stroke in robot-assisted gait rehabilitation. In passive training, the effect of rehabilitation training for patients can be improved by imitating normal human walking. To make the lower limb exoskeleton robot (LLER) move like a normal human, a tracking control scheme based on human gait data is proposed in this paper. The real human gait data is obtained from healthy subjects using a three-dimensional motion capture platform (3DMCP). Furthermore, the normal human motion characteristics are adopted to enhance the scientificity and effectiveness of assistant rehabilitation training using LLER. An adaptive radial basis function network (ARBFN) controller based on feed-forward control is presented to improve the trajectory tracking accuracy and tracking performance of the control system, where the ARBFN controller is deployed to predict the uncertain model parameters. The feed-forward controller based on the tracking errors is used to compensate for the input torque of LLER. The effectiveness of the presented control scheme is confirmed by simulation results based on experimental data.

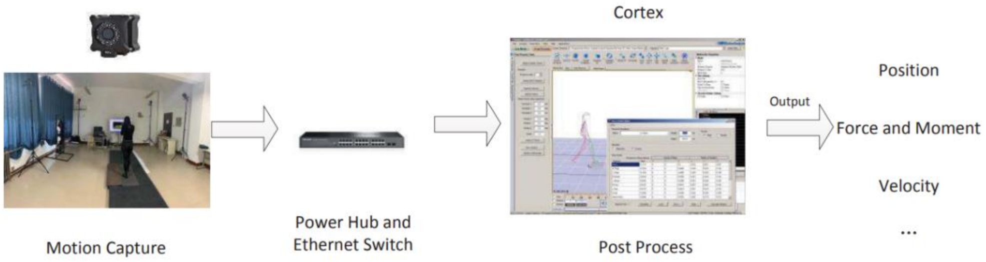


Fig. 1. Motion capture platform.

How NOKOV Contributes to the Research

Currently, a Nokov 3DMCP is utilized to obtain RHGD from healthy subjects. The 3DMCP comprises six high-performance infrared lenses (HPIL), motion capture soft- ware (Cortex), reßective markers, two calibration rods, data transmission equipment, etc. The motion capture platform is shown in Fig. 1. The HPIL is adopted to capture the spatial position of passive reflective markers, and these data are uploaded to the Cortex using data transmission equipment. The accuracy of RHGD processed by Cortex is up to sub-millimeter level, which benefits from the HPIL with the highest frequency of 240 Hz and 1.3 megapixels.

References Dan Y, Ge Y, Wang A, et al. Human-Gait-Based Tracking Control for Lower Limb Exoskeleton Robot[J]. Journal of Robotics and Mechatronics, 2022, 34(3): 615-621.
Link https://www.jstage.jst.go.jp/article/jrobomech/34/3/34_615/_article/-char/ja/

Serial–Parallel Mechanism and Controller Design of a Robotic Brace for Dynamic Trunk Support

Keywords

Dynamic trunk support; force control; robotic brace; serial–parallel manipulator;

Abstract

This article presents a robotic trunk support system that provides dynamic support and direct force/moment measurement, to assist trunk movement and train related core muscle groups. The proposed system has four degrees of freedom, three in the coronal plane and one in flexion/extension motion, which has a larger range than the existing robotic braces. The system was designed based on the serial–parallel mechanism. The serial module is responsible for the flexion/extension motion, and the parallel module is responsible for three degrees of freedom in the coronal plane. The kinematic modeling and singularity analysis of the parallel mechanism were discussed in detail. Then, the position control and force control of the serial control actuator were implemented, and the experiments were carried out to evaluate the performance of the controller. The effects on human body in force control were discussed and explained. A reduction in anterior muscles activation and an increase of dorsal muscles activation were exhibited when flexion torque was applied, while the trunk core muscle groups have opposite activation when extension torque was applied. The results indicate that the proposed robotic brace has potentials in the application to trunk core muscle groups training and corresponding rehabilitation.

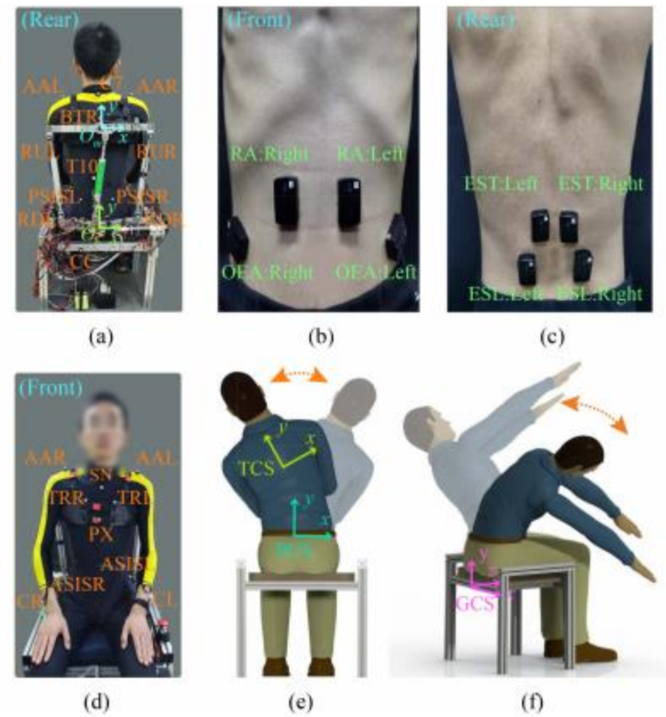


Fig. 6. (a) and (d) Placement of markers. (b) and (c) Placement of EMG electrodes. There are eight electrodes placed bilaterally on four muscle groups including EST, ESL, OEA, and RA. (e) and (f) Movement of lateral bending and the movement from right anterior flexion to left posterior extension, respectively.

How NOKOV Contributes to the Research

Kinematical Data Preprocessing: The motion capture camera system (MARS4H, NOKOV, China) was used to evaluate the performance of the RoboBDsys in terms of the accuracy of position at 100 Hz.

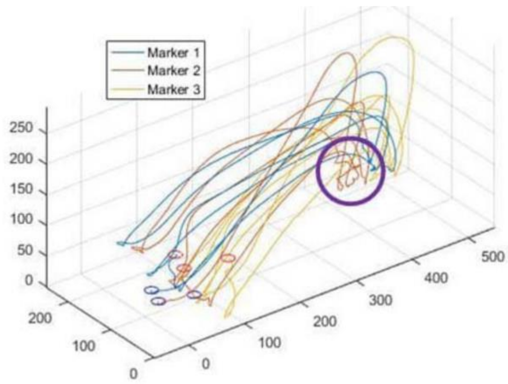
References Guo X, Zhou Z, Gao Y, et al. Serial–Parallel Mechanism and Controller Design of a Robotic Brace for Dynamic Trunk Support[J]. IEEE/ASME Transactions on Mechatronics, 2022.
Link https://ieeexplore.ieee.org/abstract/document/9747946

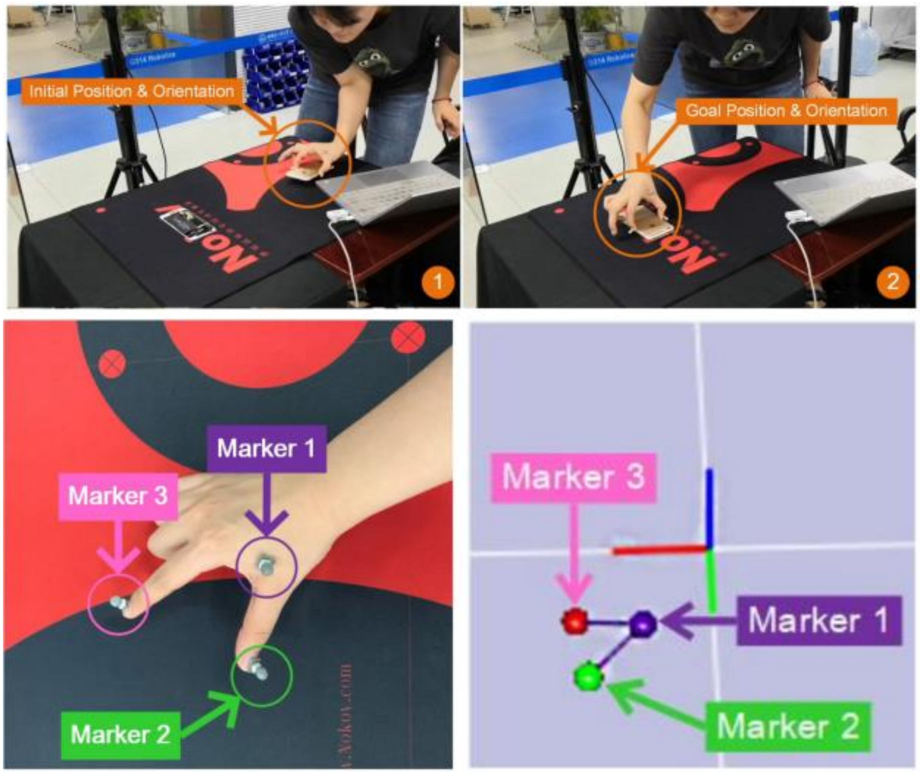
Part Ⅲ Robotic Arm

A Robot 3C Assembly Skill Learning Method by Intuitive Human Assembly Demonstration

Abstract

With the development of the Internet and computer technology, the demand for 3C products such as mobile phones has surged. At the same time, due to the continuous improvement of labor costs, it is urgent to automate the 3C assembly lines with industrial robots. The motivation of this paper is to propose an efÞcient off-line programming by demonstration method to automate 3C assembly lines. This process consists of two phases. In the Þrst phase, the optical motion capture device is used to capture the position and orientation information of human hands during assembly process. In the second phase, those information of a couple of demonstrations are learned to derive a robot control policy. To do so, the local outlier factor based anomalous point detection algorithm as well as the trajectory segmentation algorithm inspired by density-based spatial clustering is utilized in advance to pre- process the demonstration data. Then the human assembly skill represented by a probabilistic policy is learned from those data to drive the robot to accomplish the same assembly task under new environment. The Gaussian Mixture Model is utilized to pre-structure the policy. The offline programming by demonstration method efÞciently transfers human experience to the robot. Experimental results demonstrate the effectiveness of the method.





How NOKOV Contributes to the Research

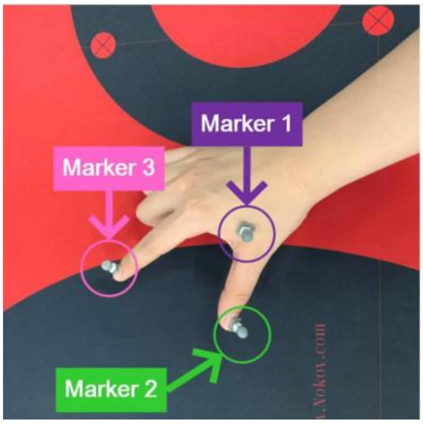
For the purpose of acquiring human demonstration data the optical motion capture platform from NOKOV Science and Technology Cooperation Ltd. [15], as shown in Fig.3, is selected to record the movement of reßective markers pasted on one hand of the operator at a 340fps sampling frequency. By doing so, the sub-millimeter positions of the operator's hand as well as Þngers are recorded through the infrared cameras when the operator executes the assembly process. In view of the quickness and complexity characteristics of the 3C assembly process, Better still, the optical motion capture platform does not interfere the normal assembly work of the operator. In addition, the optical motion capture platform is capable of working in normal industrial environments with- out too much space usage and dense equipment distribution. Afterwards, by a series of data pre-processing techniques, several smooth assembly motion trajectories are obtained from multiple human assembly demonstrations. Finally, a policy for the robot to regenerate assembly motion trajectory that can achieve the same assembly task under strange start and goal positions and orientation is derived by the policy learning algorithm.

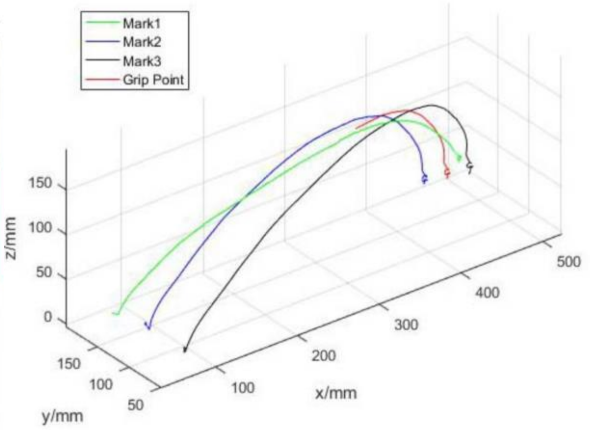
References Cao Z, Hu H, Yang X, et al. A robot 3C assembly skill learning method by intuitive human assembly demonstration[C]//2019 WRC Symposium on Advanced Robotics and Automation (WRC SARA). IEEE, 2019: 13-18.
Link https://ieeexplore.ieee.org/document/8931930

A Robot Programming by Demonstration Method for Precise Manipulation in 3C Assembly

Abstract

Industrial robots have been widely used in various production line but not in the 3C assembly line which is characterized by highly frequent change-over and still relies on labor heavily. To deal with this challenge, the Programming by Demonstration (PbD) method, which provides a simple and intuitive way for workers to transfer skills to the robot, will greatly reduces professional knowledge requirements for robot users. However, some practical factors in 3C assembly line, such as the mechanical diversities between the human body and the robot, make it difficult to apply PbD methods. Motivated by that, with a subtly designed demonstration data extraction platform and a posture mapping strategy, this article proposes a PbD method that transforms human assembly skill to the robot for 3C assembly tasks. Furthermore, by an iterative optimization method, the demonstration path is simplified to boost the assembly efficiency which counts for much in practice. A simulation and a 3C assembly experiment has demonstrated the effectiveness of the proposed method.





How NOKOV Contributes to the Research

A programming by demonstration (PbD) platform to trans- fer human 3C assembly skills to robots is proposed in this work, which consists of a demonstration data extraction platform (Fig. 3) and a robot assembly platform (Fig. 4). The demonstration data used in this work is obtained by an optical motion capture platform provided by Nokov Science & Technology Co., Ltd. [13] that tracks three reßective markers pasted on the operator's hand, as shown in Fig. 6. By doing so, intuitive human assembly actions are obtained in a natural and convenient way that sets no threshold for non-expert operators. Details of the demonstration process can be found in the supplemented video. Furthermore, the robot assembly platform is facilitated with a 3D structure light camera to estimate the initial position and orientation of the components and an Universal Robot 5kg (UR5) robot to carry out the assembly task. However, owing to the inevitable mechanical diversity between human hand and robot's end-effector, several physically different grippers coupled with quick-change mechanism are designed for a couple of 3C components. With the quick-change mechanism, the UR5 robot is capable of selecting the grippers automatically.

References Zhao Z, Hu H, Yang X, et al. A Robot Programming by Demonstration Method for Precise Manipulation in 3C Assembly[C]//2019 WRC Symposium on Advanced Robotics and Automation (WRC SARA). IEEE, 2019: 172-177.
Link https://ieeexplore.ieee.org/document/8931947

Official Website Case Link
https://www.nokov.com/en/support/case_studies_detail/robotic-arm-assembly-skills-learning.html

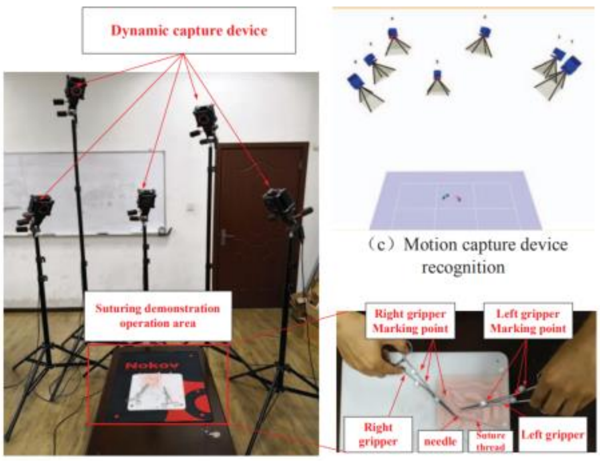
Learning from Demonstration: Dynamical Movement Primitives based Reusable Suturing Skill Modelling Method

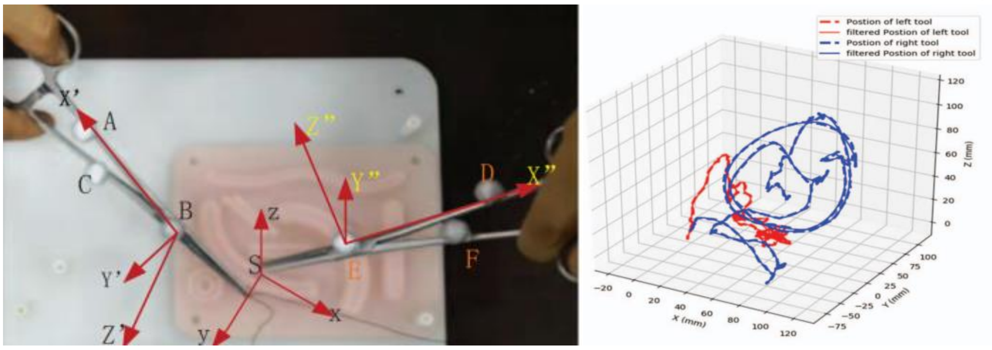
Keywords

Learn from demonstration; Suturing skill; Dynamical movement primitives; Modeling method

Abstract

Establishing a surgical skill model plays an important role for automatic robotic assisted surgery, besides that it is of great value to evaluate physicians' operational skills. In this paper, superficial tissue suture is selected as the modeling object, and suture skill learning and modeling research is conducted. In order to solve the problem of conventional models with poor migration ability for applications in new scenes, a demonstration-decomposition-modeling suture skill learning and modeling framework is proposed. The demonstration suture process is decomposed into sub-processes that repeats in various suture paradigms. The dynamic movement primitives (DMPs) method is introduced to uniformly model the suture trajectory of each sub-process. The superficial suture operation demonstration and acquisition platform is built, and the modeling ability of the proposed method and the adaptability to new scenes are preliminarily verified.





How NOKOV Contributes to the Research

The Nokov optical motion capture system is an optical three-dimensional motion capture system. In this experiment, 7 optical lenses were used to measure and track the suturing process. Six marker points were attached on the two surgical clamps. The 3D position of the marker points on the surgical forceps are collected, and the continuous motion trajectory (namely the spatial position and posture) of the surgical forceps can be calculated and recorded on the Nokov system in real time. By means of coordinate system transformation method, we can analyze the motion trajectory of the surgical forceps in the wound coordinate frame.

References Yang D, Lv Q, Liao G, et al. Learning from demonstration: dynamical movement primitives based reusable suturing skill modelling method[C]//2018 Chinese Automation Congress (CAC). IEEE, 2018: 4252-4257.
Link https://ieeexplore.ieee.org/abstract/document/8623781

Design and evaluation of a robotic apple harvester using optimized picking patterns

Keywords

Robotic apple harvester; Motion capture; Apple detection; Apple detachment

Abstract

A robotic apple harvester consisting of a mobile platform, a manipulator, an end-effector, a stereo camera, and a host computer was constructed and evaluated using two picking motions. The field tests showed all apple picking with success rates of 80.17% and 82.93% when using anthropomorphic and "horizontal pull with bending" motions, respectively. The main reasons for picking failure were depth misalignment, detachment failure, and blocked grasp. The "horizontal pull with bending" and anthropomorphic motions took 1.14 s and 3.13 s, respectively. The full picking cycle process using "horizontal pull with bending" motion was 12.53 ± 0.53 s, 4.64 s less than the average picking time when using anthropomorphic picking motion (17.17 ± 0.36 s). The picking process using anthropomorphic motion experienced a lower dynamic payload, meaning less effort would be required by the manipulator joints; however, fruit slipping decreased the overall success rate. The "horizontal pull with bending" picking motion had a superior picking cycle time and success rate. Notably, there were no stem-pulled or bruised apples during picking process using either motion. Based on this study, both picking motions have the potential to be applied in harvesting robots.

Fig. 8. NOKOV motion capture system.

How NOKOV Contributes to the Research

Through observing, it was found that workers widely adopt a picking motion that involves bending and pulling upwards. The NOKOV motion capture system (Beijing NOKOV Science & Technology Co., Ltd., China) was used to collect data on the movements of pickers' upper arms. As shown in Fig. 8, there were eight digital cameras with a 2048 × 1088 resolutions and ± 0.15 mm 3D accuracy positioned around the test area. Data were collected by tracking marked points and transferred to the host computer and processed in real-time to calculate the coordinates, velocity, and acceleration of the moving objects in space (Zhang et al., 2021b).

References Bu L, Chen C, Hu G, et al. Design and evaluation of a robotic apple harvester using optimized picking patterns[J]. Computers and Electronics in Agriculture, 2022, 198: 107092.
Link https://www.sciencedirect.com/science/article/abs/pii/S0168169922004094

Kinematics Optimization of a Novel Cable-Driven 7-Dof Redundant Manipulator

Keywords

Kinematics analysis; Spherical parallel mechanism; Redundant manipulator; LDWPSO;

Abstract

Redundant manipulators can accomplish complex tasks due to the redundant degree of freedom (DOF). At the same time, their kinematics calculations are complicated. In this study, a hybrid method is proposed to obtain the optimal kinematics solution for a 7-DOF redundant anthropomorphic manipulator. Kinematics analysis of the spherical parallel shoulder joint was performed by using a geometric method and coordinate transformation. Kinematics analysis of the redundant manipulator was performed by a geometric method with an optimizing arm angle. Linearly decreasing weight particle swarm optimization (LDWPSO) was used to optimize the arm angle to minimize the motion time of the manipulator. The kinematics calculation of the shoulder joint was verified by a combination of SolidWorks and MATLAB software. The kinematics calculation of the redundant manipulator was verified by MATLAB. The linear, circular and figure 8-shaped motion trajectories were used to evaluate the proposed method in the simulation. The simulation results showed that the motion time with optimization of the arm angle was only 16%–30% of that without optimization. Furthermore, the proposed method was evaluated through real manipulator experiments, and the experimental results were similar to those in the simulation.

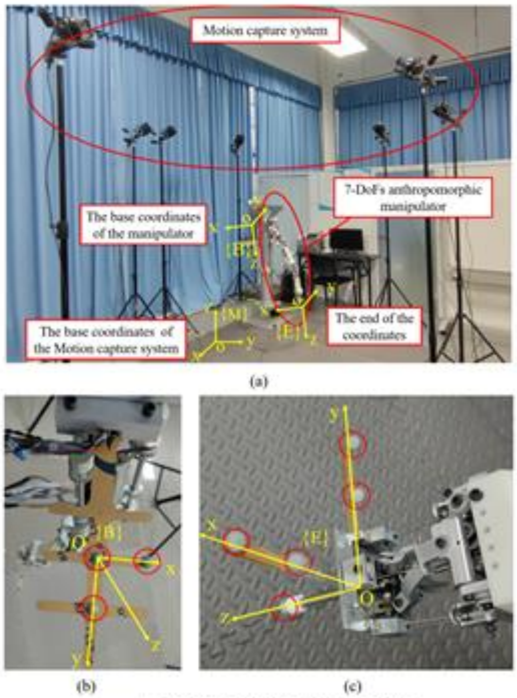


Fig. 22 Kinematics experiment on the manipulator

How NOKOV Contributes to the Research

> *This section describes an experiment performed to test the kinematics of the whole arm. As shown in Fig. 22, the experimental platform is built. A motion capture system is used to evaluated the manipulator. The motion capture system is composed of eight Mars1.3H infrared high-speed cameras of the NOKOV system, with a resolution of 2048*1088 and an accuracy of 0.02 mm.*

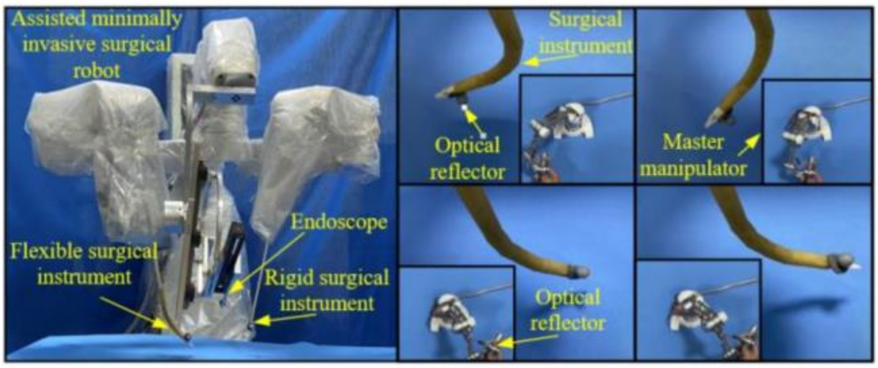
References Chen Y, Zhang X, Yanjiang H, et al. Kinematics Optimization of a Novel Cable-Driven 7-Dof Redundant Manipulator[J]. Available at SSRN 4116420.
Link https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4116420

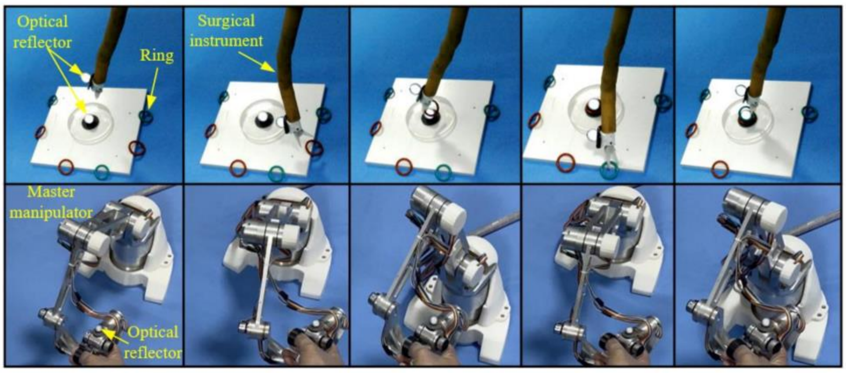
Part IV the Others

Kinematic Analysis of a Flexible Surgical Instrument for Robot-assisted Minimally Invasive Surgery

Abstract

Flexible surgical instruments can flexibly adjust their posture with a high degree of freedom, which makes them highly suitable for performing surgical tasks in narrow workspaces. However, redundant degrees of freedom increase their kinematic difficulty, which may cause redundant solutions, complex calculations, and low speeds. In this paper, a flexible surgical instrument is presented. The structural characteristics of this flexible instrument were explored in terms of force balance, it was concluded that the instrument had a constant curvature during bending. Based on this, the kinematics and inverse kinematics were solved via the geometric and Newton iteration methods, respectively. Our experiments showed that the proposed method for solving flexible instrument kinematics had high precision, a unique solution, and high speed; the instrument can be well controlled to perform refined operations. The proposed geometric method for solving the flexible instrument kinematics avoided the calculation of the Jacobian matrix, making it fast and capable of meeting the master-slave control requirement for real-time surgery. Furthermore, the proposed kinematics solution method is not limited by the mechanical structure, so it can be used for flexible instruments owning to its constant curvature bending.





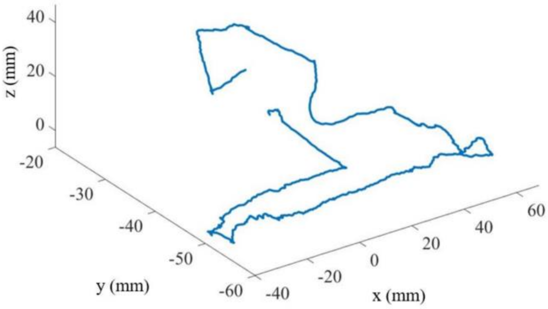


Figure 8. Trajectory of the flexible instrument mapped from the master manipulator

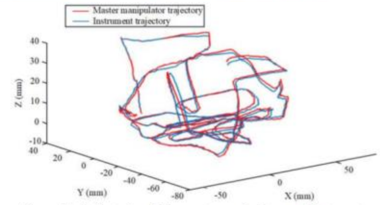


Figure 11. Trajectories of the master manipulator and instrument

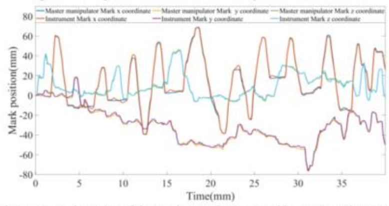


Figure 12. Trajectories of the master manipulator and instrument along the x, y, and z directions

How NOKOV Contributes to the Research

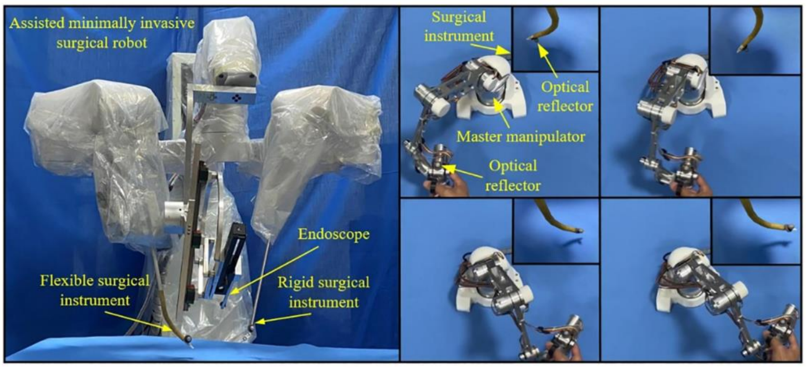
To validate the performance of the instrument under refined manipulation, it was controlled to grasp rings in target locations, as shown in Fig. 10, and a motion capture system (NOKOV Co., China) was used to follow the master and slave during operation. Optical reflectors were fixed to the end effectors of the master manipulator and instruments to collect movement information. Fig. 11 shows the movement trajectories of the master manipulator and the instrument. Fig. 12 shows the trajectories of the master manipulator and instrument along the x, y, and z directions. The RMSE of the expected and actual trajectory of the flexible surgical instrument in the x, y, and z directions were 0.498, 0.399, and 0.051, respectively. The experimental results show that the instrument can be well controlled to perform refined operations and under master-slave operation.

References Feng M, Ni Z, Fu Y, et al. Kinematic analysis of a flexible surgical instrument for robot-assisted minimally invasive surgery[C]//2021 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2021: 12229-12235.
Link https://ieeexplore.ieee.org/abstract/document/9561634/

Master Manipulator Optimisation for Robot Assisted Minimally Invasive Surgery

Abstract

In robot-assisted minimally invasive surgery, the surgeon controls a robot by operating a pair of master manipulators. Thus, the performance of a master manipulator directly affects the work of the surgeon physiologically and psychologically. In order to improve the operability and quality of operation, a structure optimisation method of master manipulator is proposed. This improves the comfort of the surgeon and can effectively avoid the problem of cutting off master–slave communication to adjust the position of the master manipulator owing to the small workspace.



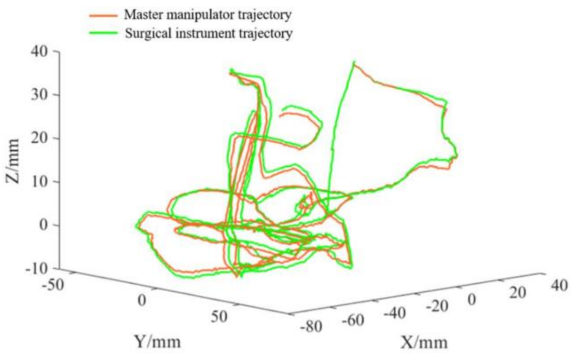


FIGURE 8 Trajectories of the end of the master manipulator and the surgical instrument

How NOKOV Contributes to the Research

The optimised structural dimensions were used to construct a prototype series-type master manipulator, as shown in Figure 4. To analyse the coverage by the master manipulator workspace of the human hand operation space, surgeons were asked to hold and move the end-effector of the manipulator in the operating posture. An optical reflector was fixed to the end-effector, and the motion capture system of China NOKOV company was used to collect the position of the optical reflector. The envelope of these positions was defined as the workspace. Figure 5 shows the master manipulator workspace and human hand operation space. The master manipulator workspace completely covered the human hand operation space, which can help avoid the problem of cutting off the master–slave communication to adjust the position of the master manipulator.

References Feng M, Ni Z X, Li A, et al. Master manipulator optimisation for robot assisted minimally invasive surgery[J]. The International Journal of Medical Robotics and Computer Assisted Surgery, 2021, 17(2): e2208.
Link https://onlinelibrary.wiley.com/doi/abs/10.1002/rcs.2208

Indoor Relative Positioning Method and Experiment Based on Inertial Measurement Information/Human motion model/UWB Combined System

Keywords

Indoor positioning; Inertial measurement information; Human motion model; UWB

Abstract

Navigation and positioning services are related to national security, economic development and social livelihood, they're playing a decisive and indispensable role in both military and civilian fields. Urbanization is accelerating and indoor sites are increasing. People spend more than 80% of their time living and working in the indoor environments (including large buildings, underground sites, mines, tunnels, etc.), How to achieve high-precision navigation and positioning in such a complex navigation environment? This is not only an urgent social problem but also a technical problem. Based on the introduction of indoor navigation background, an inertial measurement information/UWB combined indoor positioning method is proposed in this paper, to solve the problem of long-term positioning in a complex indoor environment, and the experimental researches have been performed. Firstly, based on the research of human motion model, the method extracts motion parameters related to navigation and establishes the mapping model between human motion parameters and navigation parameters in order to implement autonomous pedestrian navigation which is based on inertial measurement information/human motion model. Then, using the position information provided by UWB as the measurement, the Kalman filter based on inertial measurement information/ human motion model/UWB combined system is designed to integrate positioning information from the combined system of inertial measurement information/human motion model and UWB, so that it can provide long-term and high-precision relative navigation for indoor pedestrians. The paper develops a prototype of the inertial measurement information/human motion model/UWB combined system, which provides a physical platform for the experimental verification of the proposed method. What's more, it also optimizes and verifies the proposed method referring to experiments under the environment of NOKOV high-precision indoor 3D-motion

capture system by Beijing measurement technology co., LTD. There are bright application prospects that the method can be extended in single-soldier system, urban anti-terrorism operations and pedestrian positioning in the field of emergency rescue.

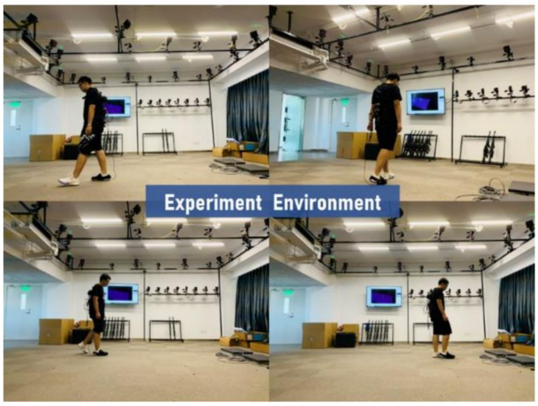


Fig. 4. Nokov 3D optical motion capture system.

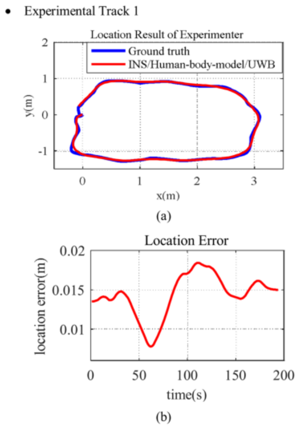


Fig. 5. (a) Location result of the indoor experimenter, (b) Location error.

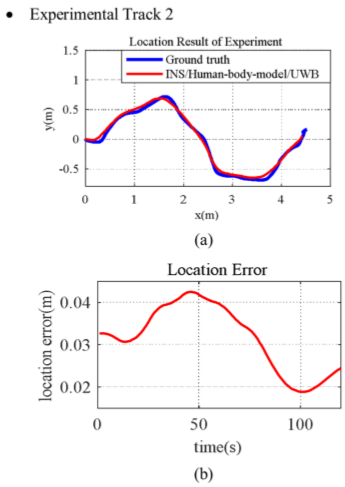


Fig. 6. (a) Location result of the indoor experimenter, (b) Location error.

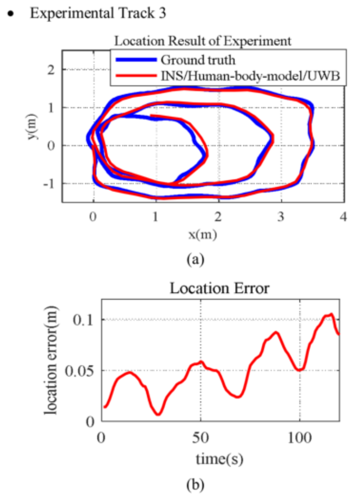


Fig. 7. (a) Location result of the indoor experimenter, (b) Location error.

How NOKOV Contributes to the Research

Nokov 3D optical motion capture system is mainly composed of infrared optical motion capture lens, operation, analysis and processing software and related accessories, which can capture and output the accurate three-dimensional data of the object to be measured. The accuracy of this motion capture system can reach sub-millimeter level, which meets the requirements of evaluating the positioning accuracy of the method proposed in this paper. The Nokov 3D optical motion capture system is shown as Fig. 4.

References Zhang Y, Wang N, Li M, et al. Indoor Relative Positioning Method and Experiment Based on Inertial Measurement Information/Human motion model/UWB Combined System[C]//2020 27th Saint Petersburg International Conference on Integrated Navigation Systems (ICINS). IEEE, 2020: 1-6.
Link https://ieeexplore.ieee.org/abstract/document/9134055

A General Framework of Knowledge-Based Coaching System with Application in Table Tennis Training

Keywords

Knowledge-based coaching system; Sequential decision problem; Table tennis training; Motion capture

Abstract

As the growth of people's awareness in health and Þtness, high-level sports exercise coaching resources become scarce comparing to the fast increasing demands. In traditional sports training, coaches are responsible for scheduling training sessions and giving instructions based on the performance of the trainee. This paper proposes a general knowledge-based coaching system (KBCS) for the purpose of automatic and intelligent sports training. Through systematically modeling the interactive training process between the coach and the trainee as a sequential decision problem, we show that the knowledge-based training controller can be properly designed to help the trainee to make effective progress towards the preset training goal. Partial implementation of KBCS in the table tennis training has been realized to demonstrate and verify the effectiveness of the proposed method.

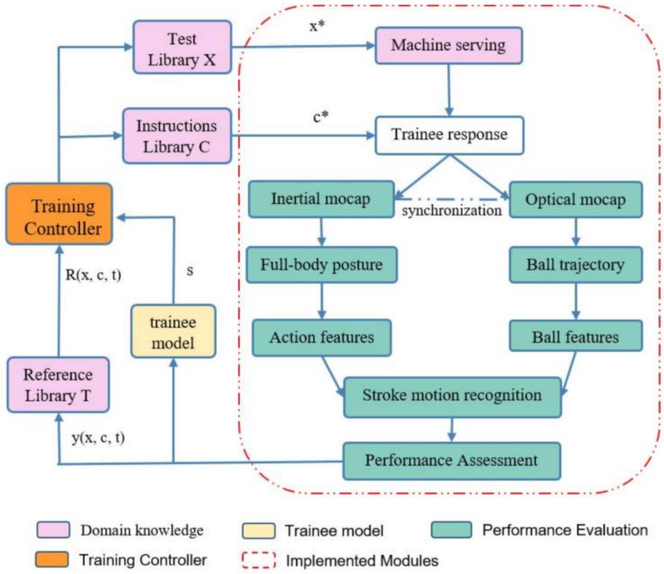


Fig. 4: KBCS prototype structure for table tennis

How NOKOV Contributes to the Research

According to the above design, an experimental platform is built as shown in Fig. 5. A NOKOV Motion Capture System was used to capture the trajectory of balls and the racket. The table tennis balls are covered with reßective material and the racket is attached reßective markers around the edge for better results. Besides, a NOITOM Perception Legacy suit is worn by the trainee for accurate posture recording. Four students are recruited and their data are analyzed.

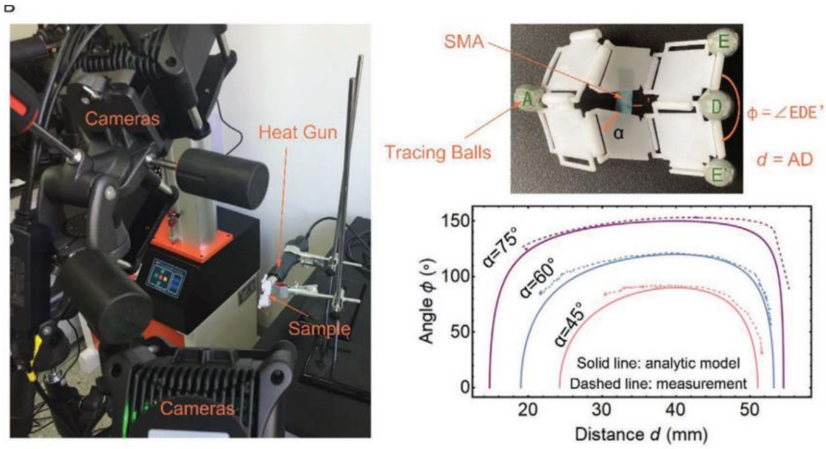
References Yan W, Ma H, Yang Z. A General Framework of Knowledge-Based Coaching System with Application in Table Tennis Training[C]//2020 39th Chinese Control Conference (CCC). IEEE, 2020: 2902-2907.

Link https://ieeexplore.ieee.org/abstract/document/9188412

Deployable-Structure-Based Artificial Muscles Generating Coded Forces

Abstract

Here mechanical metamaterials with shape memory alloys (SMA) are assembled to create a new kind of artificial muscle driven by response to temperature changes that generates pulling, pushing, and structurally coded and sequentially coded forces. The deformation and force response of a muscle unit can be geometrically tuned, and different forces are generated with two units arranged in parallel and in series. SMA sheets with different orientations controlling different units of a muscle chain can generate programmable force responses as a mixture of pulling and pushing forces. Combining structural coding with sequential coding, a wide range of force responses can be generated with a single muscle chain. It is shown that the proposed muscles can be applied in an arm-like mechanism to lift weights and to enable a car to cross a barrier. The principle explored in the work can be used to transform versatile origami- and kirigami-based structures into multifunctional actuators for many applications that can also be based on a variety of materials other than SMA.



How NOKOV Contributes to the Research

> *With the insertion of a SMA sheet into a section of the kiri- muscle, the section exhibits the expected deformation (Figure 1A) in response to the temperature changes. To measure the structural deformation, four tracing balls were attached at points A, D, E and E′ of the kiri-muscle and were tracked by a six-camera motion capture system (Figure 2B).*

References Yang N, Deng Y, Niu X. Deployable-Structure-Based Artificial Muscles Generating Coded Forces[J]. Advanced Materials Technologies, 2021, 6(9): 2100493.
Link https://onlinelibrary.wiley.com/doi/full/10.1002/admt.202100493

Achieving Reliable Underground Positioning With Visible Light

Keywords

Location algorithm; personnel positioning; underground positioning; visible light communication (VLC); visible light positioning (VLP);

Abstract

Visible light technology shows great potential in the underground mine positioning today. Most visible light-based underground positioning technology deploy the receiver, such as photodiodes (PDs), on the mine tunnel ground and consider the miner's lamp on the ceiling as the transmitter. This incurs the unreliable reception of visible light signals and the difficult implementation of VLP systems due to the complex underground mine environment, such as the receiver being obscured or trampled by objects (e.g., Minecarts and Ore). We present a reliable underground positioning algorithm with visible light considering the actual mine environment. The key innovation is that we design a novel reverse mechanism, i.e., utilizing the existing miner's headlamp as the transmitter for broadcasting the specific light beacon representing the mine's identity information, and the PDs deployed on the ceiling of the mine tunnel as the receiver for optical signal reception. We can infer the current locations of all miners using a series of base stations constructed by PDs. If some special mine environment limits the large-scale deployment of base stations and causes the positioning blind spots, the inertial navigation is combined to achieve all miners' real-time positioning. We overcome some technical challenges for this new mechanism and the underground mine environment, such as optimal frequency selection, robust frequency identification, and accurate base station positioning. We conduct extensive experiments on our algorithm in a simulated mine tunnel, and the experimental results verify that our algorithm exhibits good performance.

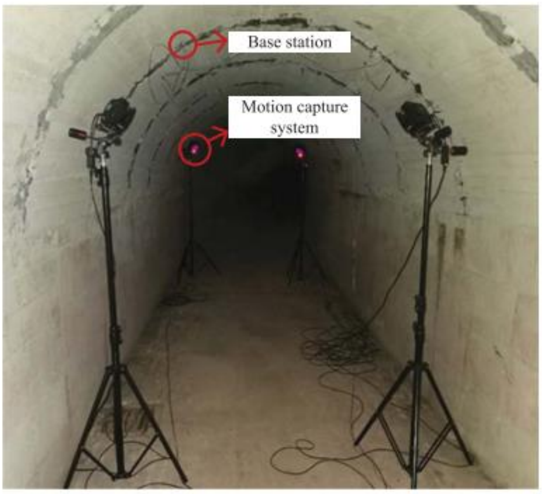


Fig. 21. Experimental scene.

How NOKOV Contributes to the Research

Motion Capture System: We use the motion capture system as the reference measurement system to obtain the real location of participants. The NOKOV motion capture system that we used consists of four optical motion capture lenses and some reßective markers. The optical motion capture lens (MASR1.3H) has an FOV of 56.3◦ × 43.7◦ and a sampling frequency of 240 Hz, and the reßective markers are reßective balls coated with special ßuorescent materials. This motion capture system can achieve subcentimeter-level indoor positioning accuracy in an area of 12 m × 12 m. During the experiment, we deploy the reßective marker on the modulated LED light; hence, the position of the reßective marker determined by the motion capture system is taken as the real location of participants.

References Pang M, Shen G, Yang X, et al. Achieving Reliable Underground Positioning With Visible Light[J]. IEEE Transactions on Instrumentation and Measurement, 2022, 71: 1-15.
Link https://ieeexplore.ieee.org/abstract/document/9740565

A Dynamic Resistive Force Model for Designing Mobile Robot in Granular Media

Keywords

Contact modeling; filed robots; methods and tools for robot system design;wheeled robots;

Abstract

Locomotion failure is the challenge for wheeled robots applied in granular media, which puts a high demand on the design of wheels. Due to a lack of a mechanical analysis method that can analyze the dynamic interaction between wheel and granular media, it is a challenge to seek design guidance for the wheel geometry. To this end, we introduce a Dynamic Resistive Force Model (DRFM) method suitable for 3D dynamic intrusion. In this method, Granular Resistive Force Theory (RFT) can be extended to 3D RFT smoothly by using granular parameters, and additional velocity terms can describe the effect of intrusion velocity on intrusion force. The relationship between wheel geometry and mechanical properties can be established by performing differential processing on the wheel surface and integrating the force generated by each micro-surface. On this basis, a complete set of solutions is proposed for the design of mobile robot wheels in granular media, and the screw-propelled wheel is taken as an example to optimize it. Theories, simulations, and experiments have all proved that the optimized wheel can produce greater thrust and lift than normal screw-propelled wheel when ensuring the stability of smooth propulsion. The proposed solution and the optimized screw-propelled wheel bring insights for designing mobile robots in granular media.

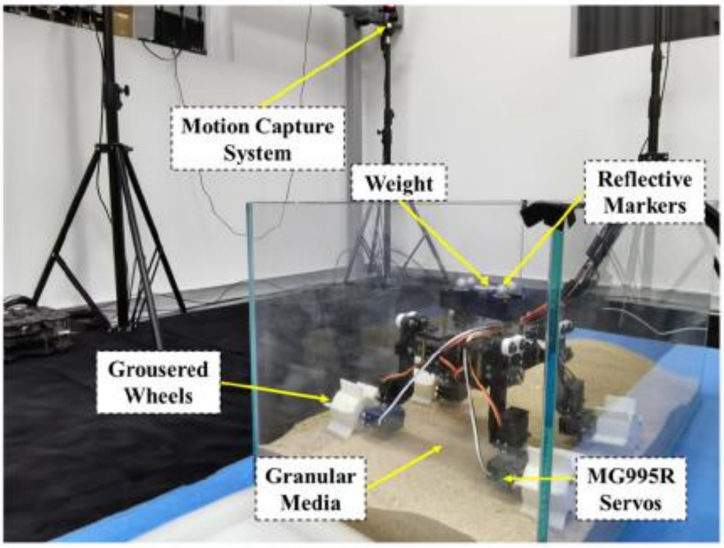


Fig. 1. **An overview of the robot motion experiment.** Robot equipped with grousered wheels is moving on sand media. The robot is driven by MG995R servos and its mass can be changed by weights. The motion data is captured by motion capture system through four reflective markers on the robot.

How NOKOV Contributes to the Research

Reßective markers were placed on the body of the robot, and kinematic data of the robot was captured by the NOKOV system. Eight NOKOV motion capture cameras were mounted around the bed, and the kinematic data were captured by reflective markers attached to the robot at a speed of 60 frames per second.

References Huang L, Zhu J, Yuan Y, et al. A dynamic resistive force model for designing mobile robot in granular media[J]. IEEE Robotics and Automation Letters, 2022, 7(2): 5357-5364.
Link https://ieeexplore.ieee.org/abstract/document/9729492

Continuous Occupancy Mapping in Dynamic Environments Using Particles

Keywords

Mapping; Aerial Systems: Perception and Autonomy; Collision Avoidance; Dynamic Environment;

Abstract

Dynamic occupancy maps were proposed in recent years to model the obstacles in dynamic environments. Among these maps, the particle-based map offers a solid theoretical basis and the ability to model complex-shaped obstacles. Current particle-based maps describe the occupancy status in discrete grid form and suffer from the grid size problem, namely: large grid size is unfavorable for path planning while small grid size lowers efficiency and causes gaps and inconsistencies. To tackle this problem, this paper generalizes the particle-based map into continuous space and builds an efficent 3D local map. A dual-structure subspace division paradigm, composed of a voxel subspace division and a novel pyramid-like subspace division, is proposed to propagate particles and update the map efficiently with the consideration of occlusions. The occupancy status of an arbitrary point can then be estimated with the cardinality expectation. To reduce the noise in modeling static and dynamic obstacles simultaneously, an initial velocity estimation approach and a mixture model are utilized. Experimental results show that our map can effectively and efficiently model both dynamic obstacles and static obstacles. Compared to the state-of-the-art grid-form particle-based map, our map enables continuous occupancy estimation and substantially improves the performance in different resolutions. We also deployed the map on a quadrotor to demonstrate the bright prospect of using this map in obstacle avoidance tasks of small-scale robotics systems.

How NOKOV Contributes to the Research

The velocity estimation experiments were conducted with the data collected in an indoor testing field with the Nokov motion capture system.

References Chen G, Dong W, Peng P, et al. Continuous Occupancy Mapping in Dynamic Environments Using Particles[J]. arXiv preprint arXiv:2202.06273, 2022.
Link https://arxiv.org/abs/2202.06273

CSI-Based Calibration Free Localization with Rotating Antenna for Coal Mine

Keywords

Indoor localization; Channel state information; Smartphone

Abstract

Accurate mine localization has always been an urgent demand. With the widespread emergence of cheap wireless devices in our life, channel state information (CSI) based indoor localization has attracted people's attention. In the existing CSI-based localization methods, fingerprint-based localization needs to build a huge database with poor robustness, and the methods based on angle of arrival (AOA) need specific antenna arrays and complex phase calibration. Because mobile devices such as smartphones only have one or two antennas, and the antennas inside the devices cannot form a receiving array, the conventional AOA estimation system cannot be deployed on such mobile devices. Therefore, we propose an AOA estimation method using rotating AP antennas. This method only needs one antenna at the receiving end to work and does not need to calibrate the phase. Firstly, the CSI phase of the rotating antenna is collected and the phase difference is calculated. Then, empirical mode decomposition (EMD) algorithm based on mutual information is used to remove the noise, and subcarrier selection is used to reduce the multipath effect in the data processing part. Finally, the AOA is estimated according to the relative position of the antenna. We conduct extensive experiments in mine and laboratory scenarios, and the median localization errors in mine and laboratory are 0.4 m and 0.6 m, the median angle errors are 4.2∘ and 5.2∘ respectively.

(a) Laboratory (b) Mine

Fig. 7. Experimental scenarios

How NOKOV Contributes to the Research

Eight nokov optical 3D motion capture cameras were used to measure the ground truth. We choose the laboratory and mine for the experiment, and the experimental scene is shown in the Fig. 7.

References Zhang T, Zhang K, Liu D, et al. CSI-Based Calibration Free Localization with Rotating Antenna for Coal Mine[C]//International Conference on Wireless Algorithms, Systems, and Applications. Springer, Cham, 2021: 263-274.
Link https://linkspringer.53yu.com/chapter/10.1007/978-3-030-85928-2_21

Deep Reinforcement Learning based Multi-target Coverage with Connectivity Guaranteed

Keywords

Multi-target coverage; multi-robot system; connectivity maintenance; deep reinforcement learning;

Abstract

Deriving a distributed, time-efficient, and connectivity guaranteed coverage policy in multi-target environment poses huge challenges for a multi-robot team with limited coverage and limited communication. In particular, the robot team needs to cover multiple targets while preserving connectivity. In this paper, a novel deep reinforcement learning based approach is proposed to take both multi-target coverage and connectivity preservation into account simultaneously, which consists of four parts: a hierarchical observation attention representation, an interaction attention representation, a two-stage policy learning, and a connectivity guaranteed policy filtering. The hierarchical observation attention representation is designed for each robot to extract latent features of the relations from its neighboring robots and the targets. To promote the cooperation behavior among the robots, the interaction attention representation is designed for each robot to aggregate information from its neighboring robots. Moreover, to speed up the training process and improve the performance of the learned policy, the two-stage policy learning is presented using two reward functions based on algebraic connectivity and coverage rate. Furthermore, the learned policy is filtered to strictly guarantee connectivity based on a model of connectivity maintenance. Finally, the effectiveness of the proposed method is validated by numerous simulations. Besides, our method is further deployed to an experimental platform based on quad-rotor unmanned aerial vehicles (UAVs) and omni- directional vehicles. The experiments illustrate the practicability of the proposed method.

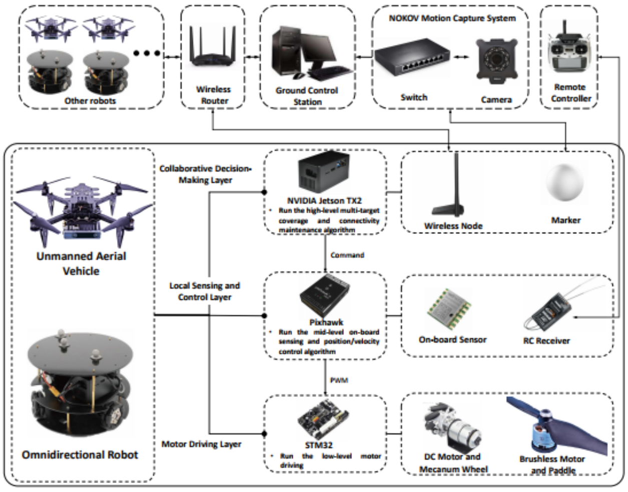


Fig. 6. Architecture of unmanned system consisting of quad-rotor UAV and omnidirectional vehicle.

How NOKOV Contributes to the Research

NOKOV motion capture system is used to calculate the positions and velocities of the mobile robots.

References Wu S, Pu Z, Qiu T, et al. Deep Reinforcement Learning based Multi-target Coverage with Connectivity Guaranteed[J]. IEEE Transactions on Industrial Informatics, 2022.
Link https://ieeexplore.ieee.org/abstract/document/9738445

Cost Function Determination for Human Lifting Motion via the Bilevel Optimization Technology

Keywords

inverse optimization control; bilevel optimization; direct collocation; particle swarm optimization; human lifting motion;

Abstract

Investigating the optimal control strategy involved in human lifting motion can provide meritorious insights on designing and controlling wearable robotic devices to release human low-back pain and fatigue. However, determining the latent cost function regarding this motion remains challenging due to the complexities of the human central nervous system. Recently, it has been discovered that the underlying cost function of a biological motion can be identified from an inverse optimization control (IOC) issue, which can be handled via the bilevel optimization technology. Inspired by this discovery, this work is dedicated to studying the underlying cost function of human lifting tasks through the bilevel optimization technology. To this end, a nested bilevel optimization approach is developed by integrating particle swarm optimization (PSO) with the direction collocation (DC) method. The upper level optimizer leverages particle swarm optimization to optimize weighting parameters among different predefined performance criteria in the cost function while minimizing the kinematic error between the experimental data and the result predicted by the lower level optimizer. The lower level optimizer implements the direction collocation method to predict human kinematic and dynamic information based on the human musculoskeletal model inserted into OpenSim. Following after a benchmark study, the developed method is evaluated by experimental tests on different subjects. The experimental results reveal that the proposed method is effective at finding the cost function of human lifting tasks. Thus, the proposed method could be regarded as a paramount alternative in the predictive simulation of human lifting motion.

How NOKOV Contributes to the Research

To verify the developed method on the IOC issue of human lifting motion, six healthy male subjects (age: 23 ± 2 years, mass: 62.5 ±4.52 kg, height: 1.71 ± 0.101 m) have been recruited to carry out a pack with 10 kg in our experimental study. The experimental kinematic data of each subject is obtained by using a motion capture system (Nokov, Beijing Metrology Technology Co., Ltd.) with 39 marker points. For more details about ways of sticking markers, the reader can refer to the operation guidance from OpenSim ofÞcial website (https://simtk-conßuence.stanford.edu:8443/display/OpenSim/Gait+2392+and+2354+Models). After gaining experimental kinematic data, the musculoskeletal model is scaled by the scaling tool in OpenSim to change the anthropometry of the model in order to match the speciÞc subject as far as possible. Note that joint kinematics and kinetics data (e.g. , joint angles and torques) are gained by inverse kinematics and inverse dynamics tools in OpenSim.

References Tang B, Peng Y, Luo J, et al. Cost Function Determination for Human Lifting Motion via the Bilevel Optimization Technology[J]. Frontiers in Bioengineering and Biotechnology, 2022, 10.
Link https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9163668/

Design and Control of TAWL—A Wheel-Legged Rover With Terrain-Adaptive Wheel Speed Allocation Capability

Keywords

Legged robot; planetary rover; terrainadaptive capability; wheel speed allocation; wheeled robot.

Abstract

This article presents the design, control, and implementation of a novel four-legged rover for planetary exploration. A novel active-passive coupled leg mechanism is proposed for the design of the planetary rover. Then, based on the design of the actuator and leg mechanism, the novel wheel-legged robotic system is developed. Furthermore, the kinematic model of the robot is established and then a kinematics-based control strategy is presented, incorporating roll-and-pitch control, contact force control, wheel speed allocation, and steering modules. Experiments are carried out on regular indoor terrain and irregular outdoor terrain. The variations of rover attitude angles and contact forces in regular terrain decrease by more than 90% and 60%, respectively. In the outdoor environment, rover attitude angles are regulated within 1o and variations of contact forces are reduced by more than half. In addition, the proposed control strategy decreases the slippage on hard unstructured terrain by almost half. Finally, the robustness and failure responses of the robot are investigated, which are also verified by simulations and experiments.

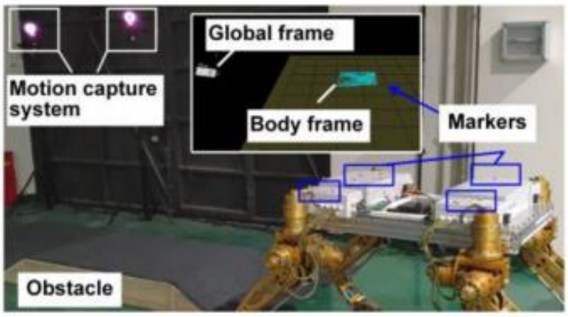


Fig. 15. Slippage experiments.

How NOKOV Contributes to the Research

Here, they are measured in real-time by the NOKOV visual motion capture system pictured in Fig. 15, which includes Þve cameras. Serval markers bonded on the body of the rover are used to establish the body frame in the world coordinate system.

References He J, Sun Y, Yang L, et al. Design and Control of TAWL—A Wheel-Legged Rover With Terrain-Adaptive Wheel Speed Allocation Capability[J]. IEEE/ASME Transactions on Mechatronics, 2022.
Link https://ieeexplore.ieee.org/abstract/document/9794482

MineGPS: Battery-Free Localization Base Station for Coal Mine Environment

Keywords

Coal mine;; robot self-positioning; battery-free,' base stations

Abstract

Rescue robot self-positioning is rescue. significant end, we propose a localization system with unique low-cost battery-free base stations for underground rescue robots, called MineGPS. The main idea is to design the battery-free base station with a unique arrangement sequence of reflective tags, and make robots identify each base station with computer vision-related technology to determine which base station it is near. In particular, inspired by Hamming code, we introduce a detection mechanism to correct the base station identification errors caused by dust covering in the mine. Finally, we present a robot localization algorithm by utilizing the location information of the base station. We implement MineGPS and evaluate its performance extensively. Results show that MineGPS can achieve the positioning accuracy with a median error of 15 cm. It is believed that MineGPS has a high potential to provide a low-cost and effective solution for the precise positioning of rescue robots in complex underground environments.

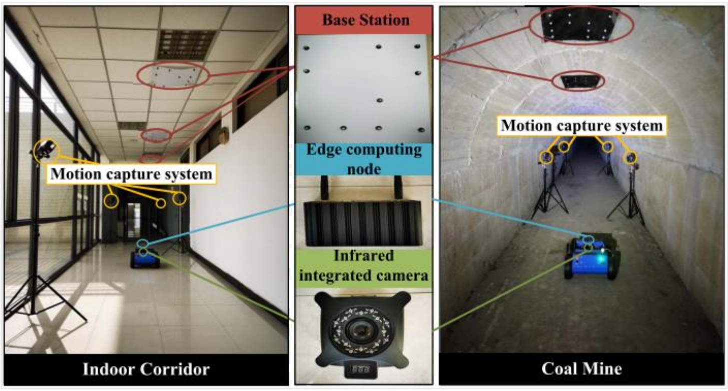


Fig. 8. Experimental scene.

References Yang X, Yu X, Zhang C, et al. MineGPS: Battery-free localization base station for coal mine environment[J]. IEEE Communications Letters, 2021, 25(8): 2579-2583.
Link https://ieeexplore.ieee.org/abstract/document/9433550

Model Predictive Control of a Novel Wheeled–Legged Planetary Rover for Trajectory Tracking

Keywords

mobile robot ; advanced intelligent control ; wheeled–legged; trajectory tracking; model predictive control ;

Abstract

Amid increasing demands for planetary exploration, wide-range autonomous exploration is still a great challenge for existing planetary rovers, which calls for new planetary rovers with novel locomotive mechanisms and corresponding control strategies. This paper proposes a novel wheeled–legged mechanism for the design of planetary rovers. The leg suspension utilizes a rigid–flexible coupling mechanism with a hybrid serial–parallel topology. First, the kinematic model is derived. Then, a control strategy for the wheeled–legged rover that includes a trajectory tracking module based on the model predictive control, the steering strategy, and the wheel speed allocation algorithm is proposed. After that, three groups of cosimulations with different trajectories and speeds, and experiments are carried out. Results of both the simulations and experiments validate the proposed control method.

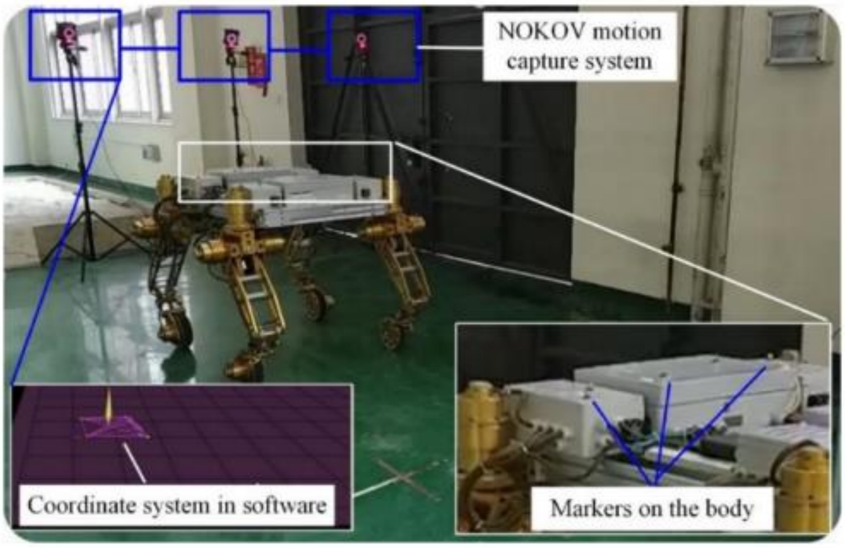


Figure 16. The experimental setup.

How NOKOV Contributes to the Research

> *To further verify the control strategy, an experimental setup based on the NOKOV vision motion capture system was established that consisted of six cameras, as shown in Figure 16.*

References He J, Sun Y, Yang L, et al. Model Predictive Control of a Novel Wheeled–Legged Planetary Rover for Trajectory Tracking[J]. Sensors, 2022, 22(11): 4164.
Link https://www.mdpi.com/1424-8220/22/11/4164

Monocular-Vision-Based Relative Pose Estimation of Noncooperative SpacecraftUsing Multicircular Features

Keywords

Monocular vision; multicircular features; noncooperative target spacecraft; nonlinear optimization method; pose estimation.

Abstract

Accurate relative pose (position and orientation) estimation for noncooperative target spacecraft is the basic module for on-orbit services, such as capture and repair. This article technically proposes a nonlinear optimization method based on monocular vision to estimate the relative pose for the solid-of-revolution-shaped nonco- operative spacecraft. Specifically, considering the multicir-cular features on the target, the parameters of the ellipses derived from the circles perspective projection are first obtained by the propounded ellipse detection algorithm. More- over, the constraint that the center of each circle falls on the center axis (normal direction) of the spacecraft is utilized to optimally solve the center position and the normal of the multicircles. In particular, the roll angle around the center axis is recovered through the geometric constraints of the solar panels, and the six-degree-of-freedom spacecraft pose estimation is then accomplished. Consequently, it is analyzed that the proposed optimization algorithm is able to provide a closed-form solution to ensure the accuracy of the relative pose and only requires limited computational resources. Finally, experimental results on the synthetic images and the physical scenes are conducted to evaluate the efficiency of the proposed approach.

How NOKOV Contributes to the Research

The noncooperative target spacecraft model is Shenzhou 12, and the Nokov motion capture system is used to obtain the ground truth pose of the noncooperative target relative to the camera.

References Long C, Hu Q. Monocular-Vision-Based Relative Pose Estimation of Noncooperative Spacecraft Using Multicircular Features[J]. IEEE/ASME Transactions on Mechatronics, 2022.
Link https://ieeexplore.ieee.org/abstract/document/9802504

Multi-Target Encirclement with Collision Avoidance via Deep Reinforcement Learning using Relational Graphs

Abstract

In this paper, we propose a novel decentralized method based on deep reinforcement learning using robot-level and target-level relational graphs, to solve the problem of multi-target encirclement with collision avoidance (MECA). Specifically, the robot-level relational graphs, composed of three heterogeneous relational graphs between each robot and other robots, targets and obstacles, are modeled and learned through using graph attention networks (GATs) for extracting different spatial relational representations. Moreover, for each target within the observation of each robot, a target-level relational graph is built with GAT to construct spatial relations from the robot. Furthermore, the movement of each target is modeled by the target-level relational graph and learned through supervised learning for predicting the trajectory of the target. In addition, a knowledge-embedded compound reward function is defined to solve the multi-objective problem in MECA, and guide the policy learning for deriving the behavior of MECA. An actor-critic training algorithm based on the centralized training and decentralized execution framework is adopted to train the policy network. Simulation and real-world experiment results demonstrate the effectiveness and generalization of our method.

How NOKOV Contributes to the Research

Aside from the simulations above, we also examine the trained policy in real-world experiments on an experimental platform based on omnidirectional robots. In the experimental platform, each robot is equipped with an onboard computer (Nvidia Jetson TX2) to improve the real-time performance of policy implement. Moreover, the positions and velocities of the robots are provided by the NOKOV motion capture system. The three snapshots of 6 robots encircling 2 targets in 2 obstacle environment are presented in Fig. 4. These actual results show the robots can successfully complete the MECA task, which demonstrates the effectiveness and practicability of the proposed method.

References Zhang T, Liu Z, Pu Z, et al. Multi-Target Encirclement with Collision Avoidance via Deep Reinforcement Learning using Relational Graphs[C]//2022 International Conference on Robotics and Automation (ICRA). IEEE, 2022: 8794-8800.
Link https://ieeexplore.ieee.org/abstract/document/9812151

Part V VR

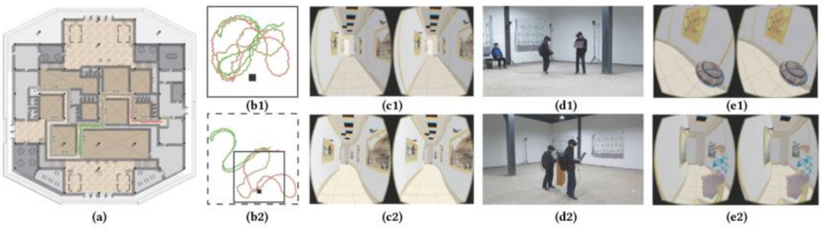
Redirected Smooth Mappings for Multi-user Real Walking in VR

Keywords

Virtual reality; Multi-user real walking; Multi-user physical interaction; Redirected smoothing mapping; Automatic collision avoidance

Abstract

We propose a novel technique to provide multiuser real walking experiences with physical interactions in virtual reality (VR) applications. In our system, multiple users walk freely while navigating a large virtual environment within a smaller physical workspace. These users can interact with other real users or physical props in the same physical locations. The key of our method is a redirected smooth mapping that incorporates the redirected walking technique to warp the input virtual scene with small bends and low distance distortion. Users possess a wide field of view to explore the mapped virtual environment while being redirected in the real workspace. To keep multiple users away from the overlaps of the mapped virtual scenes, we present an automatic collision avoidance technique based on dynamic virtual avatars. These avatars naturally appear, move, and disappear, producing as little influence as possible on users' walking experiences. We evaluate our multiuser real walking system through formative user studies, and demonstrate the capability and practicability of our technique in two multiuser applications.



How NOKOV Contributes to the Research

> *Tracking System. As shown in Figures 1 and 8, our multiuser real walking and interaction experiments run in a 10m × 10m physical room with 12 Nokov motion capture cameras (http://www. nokov.com/). An iron pillar (Figure 8(b)) in the room is treated as an interior obstacle (the black box in Figure 8(a)) that is avoided by f(V). Since users are redirected in f(V), they can walk freely without hitting the iron pillar. The average position of three markers, which are placed on top of a user's head, determines the user's position.*

References Dong Z C, Fu X M, Yang Z, et al. Redirected smooth mappings for multiuser real walking in virtual reality[J]. ACM Transactions on Graphics (TOG), 2019, 38(5): 1-17. Link https://dl.acm.org/doi/abs/10.1145/3345554

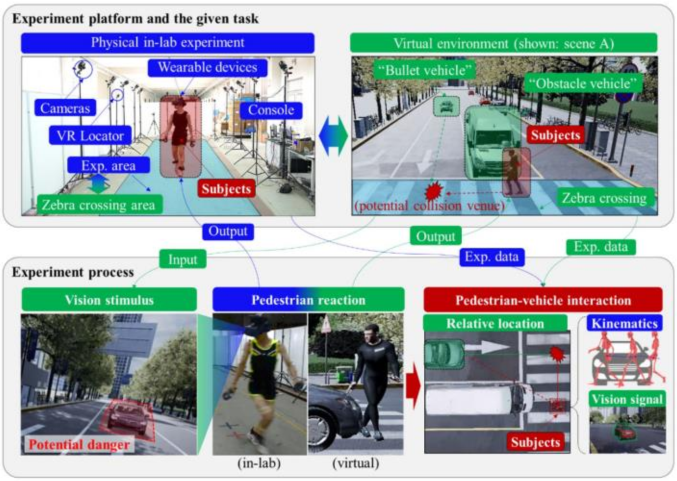
Safety Envelope of Pedestrians upon Motor Vehicle Conflicts Identified via Active Avoidance Behaviour

Keywords

Virtual reality; Multi-user real walking; Multi-user physical interaction; Redirected smoothing mapping; Automatic collision avoidance

Abstract

Human reaction plays a key role in improved protection upon emergent traffic situations with motor vehicles. Understanding the underlying behaviour mechanisms can combine active sensing system on feature caption and passive devices on injury mitigation for automated vehicles. The study aims to identify the distance-based safety boundary ("safety envelope") of vehicle–pedestrian conflicts via pedestrian active avoidance behaviour recorded in well-controlled, immersive virtual reality-based emergent traffic scenarios. Via physiological signal measurement and kinematics reconstruction of the complete sequence, we discovered the general perception-decision-action mechanisms under given external stimulus, and the resultant certain level of natural harm-avoidance action. Using vision as the main information source, 70% pedestrians managed to avoid the collision by adapting walking speeds and directions, consuming overall less "decision" time (0.17–0.24 s vs. 0.41 s) than the collision cases, after that, pedestrians need enough "execution" time (1.52–1.84 s) to take avoidance action. Safety envelopes were generated by combining the simultaneous interactions between the pedestrian and the vehicle. The present investigation on emergent reaction dynamics clears a way for realistic modelling of biomechanical behaviour, and preliminarily demonstrates the feasibility of incorporating in vivo pedestrian behaviour into engineering design which can facilitate improved, interactive on-board devices towards global optimal safety.



How NOKOV Contributes to the Research

> *Kinematics capture system. The kinematic capture system (No. Mars 2H; Beijing Nokov Science & Technology Co., Ltd) recorded the key motion information of subjects during the experiments. Setup of the kinetic capture system consists of 12 cameras, 54 on-body markers and a software module. The cameras (sampling frequency: 100 Hz) were fixed on the edge of the subjects' movement range by tripods. Motion of the subject throughout the whole event was recorded using 54 markers adhered externally to the skin on body. Algorithm processing of the kinematic images yielded signals of the quantified whole-body kinematics. Feature velocity of the pedestrian was extracted at the centre of the pelvis.*

References Nie, B., Li, Q., Gan, S. et al. Safety envelope of pedestrians upon motor vehicle conflicts identified via active avoidance behaviour. Sci Rep 11, 3996 (2021). https://doi.org/10.1038/s41598-021-82331-z
Link https://www.nature.com/articles/s41598-021-82331-z

Kinetic and Kinematic Features of Pedestrian Avoidance Behavior in Motor Vehicle Conflicts

Keywords

Pedestrian safety; Active behavior; Kinematics; Biomechanics; Integrated safety; Volunteer testing

Abstract

The active behaviors of pedestrians, such as avoidance motions, affect the resultant injury risk in vehicle–pedestrian collisions. However, the biomechanical features of these behaviors remain unquantified, leading to a gap in the development of biofidelic research tools and tailored protection for pedestrians in real-world traffic scenarios. In this study, we prompted subjects ("pedestrians") to exhibit natural avoidance behaviors in well-controlled near-real traffic conflict scenarios using a previously developed virtual reality (VR)-based experimental platform. We quantified the pedestrian – vehicle interaction processes in the pre-crash phase and extracted the pedestrian postures immediately before collision with the vehicle; these were termed the "pre-crash postures." We recorded the kinetic and kinematic features of the pedestrian avoidance responses—including the relative locations of the vehicle and pedestrian, pedestrian movement velocity and acceleration, pedestrian posture parameters (joint positions and angles), and pedestrian muscle activation levels—using a motion capture system and physiological signal system. The velocities in the avoidance behaviors were significantly different from those in a normal gait ($p < 0.01$). Based on the extracted natural reaction features of the pedestrians, this study provides data to support the analysis of pedestrian injury risk, development of biofidelic human body models (HBM), and design of advanced on-vehicle active safety systems.

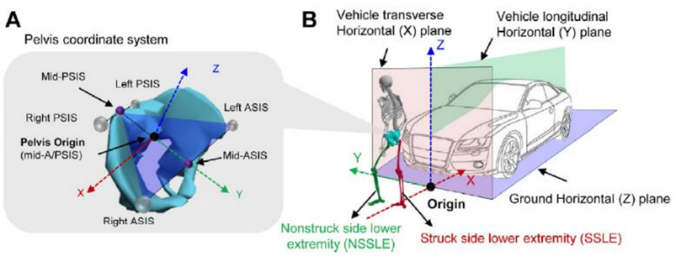
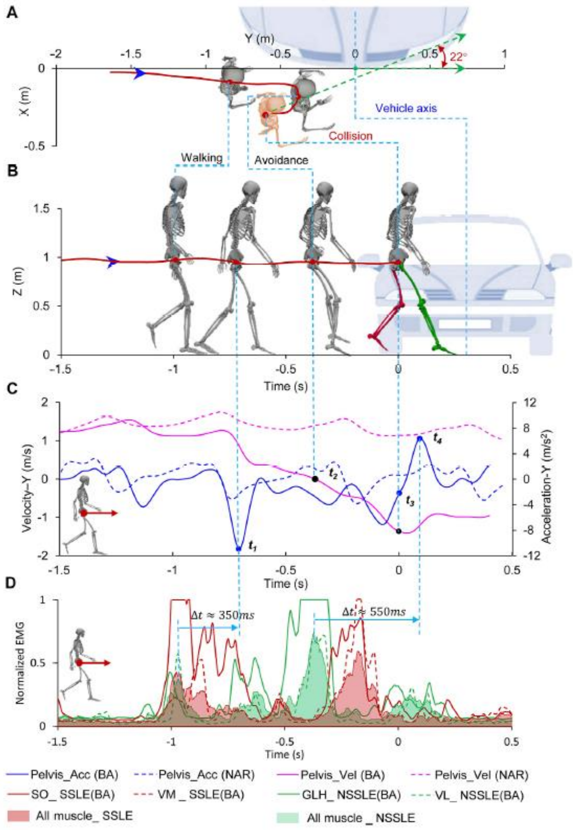


FIGURE 1 | Illustration of the locations of the coordinate system; **(A)** pedestrian local coordinate system, **(B)** vehicle coordinate system.



How NOKOV Contributes to the Research

The pedestrian kinetic and kinematic features include the relative locations of the vehicle and pedestrian, the pedestrian's movement velocity and acceleration, their posture (joint positions and angles), and their muscle activation levels. The data were recorded and extracted using the 12 cameras (100 Hz) of the motion capture system (No. Mars 2H; Beijing Nokov Science and Technology Co., Ltd.) by tracking 54 markers. In addition, 11 joints were used to describe the pedestrian posture (Arnold et al., 2010) (Supplementary Figure S1). The pedestrian kinematics were inversed using OpenSim and the "Full Body Model" (Rajagopal et al., 2016).

References Li Q, Shang S, Pei X, et al. Kinetic and Kinematic Features of Pedestrian Avoidance Behavior in Motor Vehicle Conflicts[J]. Frontiers in Bioengineering and Biotechnology, 2021, 9.

Link https://www.frontiersin.org/articles/10.3389/fbioe.2021.783003/full

Iterative Pose Estimation for a Planar Object Using Virtual Sphere

Keywords

Planar object; pose ambiguity; optimization Algorithm; local minimum; singular value decomposition;

Abstract

This paper proposed an iterative pose estimation for the planar object to deal with the pose ambiguity in the Perspective n Points (PnP) problem. SpeciÞcally, by utilizing the unit virtual sphere, the PnP pose estimation problem can be performed as a minimization of the error function with three independent transitional parameters, referred to as the coupling position. Then, Levenberg-Marquardt (LM) optimiza-tion algorithm is applied to acquire the coupling position of the Þrst local minimum. Furthermore, the coupling position is represented as the two Euler angles and the vector length, which are combined with the planar points to compute the second local minimum approximation as the initialization of the second LM algorithm. Consequently, once the global coupling position in the two local minimum is decided by the lower error, the orientation and position are directly decoupled by using the singular value decomposition (SVD). It is shown that the designed pose estimation is able to achieve prescribed performance for locating and distinguishing two local minimum, and meanwhile guarantee the superior computation behavior under the pose ambiguity for the planar object. Finally, numerical simulation and physical experiment are conducted to validate the effectiveness of the proposed method, compared to the state-of-the-art PnP methods.

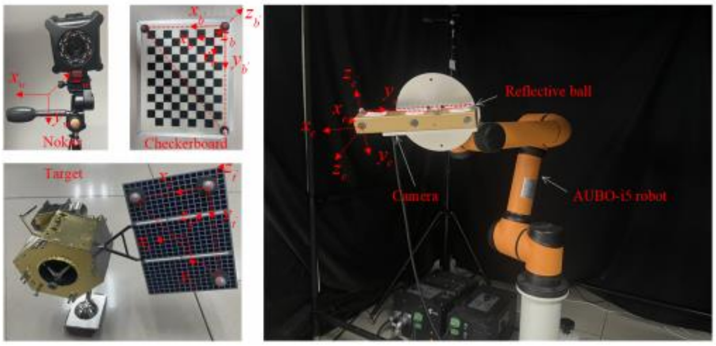


Fig. 10. The composition of the ground experimental system.

How NOKOV Contributes to the Research

To verify the effectiveness of the proposed approach, the ground experimental system is designed, shown in Fig. 10. The experimental system is mainly composed of the Bumblebee camera, the AUBO-i5 robot, the FY 4 target model, the checkerboard, and the Nokov tracker system, wherein seven reference frames are all introduced in Table I. The camera model that is mounted on the end of the robotic arm is applied to acquire the target pictures, while the Nokov tracker system is regarded as the ground truth data.

References Jiang C, Hu Q. Iterative Pose Estimation for a Planar Object Using Virtual Sphere[J]. IEEE Transactions on Aerospace and Electronic Systems, 2022.
Link https://ieeexplore.ieee.org/abstract/document/9684975

Part VI Psychology

The influence of Prior Intention on Joint Action: an fNIRS-based Hyperscanning Study

Keywords

Prior intention; Joint action, Premotor and supplementary motor cortex, Temporo-parietal junction; Hyperscanning

Abstract

Motor performances of the same action are affected by prior intentions to move unintentionally, cooperatively or competitively. Here, a back-and-forth movement task combined with a motion capture system and functional near-infrared spectroscopy (fNIRS)-based hyperscanning technology was utilized to record both the behavioral and neural data of 18 dyads of participants acting in pairs [joint conditions: no-intention, cooperative (Coop) and competitive (Comp)] or alone (single conditions: self-paced and fast-speed). The results revealed that Coop or Comp intentions in the joint conditions significantly sped up motor performance compared with similar single conditions, e.g. shorter movement times (MTs) in the Coop/Comp condition than the self-paced/fast-speed condition. Hemodynamic response analysis demonstrated that stronger activities for all joint conditions than the single conditions in the premotor and the supplementary motor cortex (Brodmann area 6) were independent of variations of MTs, indicating that they might reflect more complex aspects of action planning rather than simple execution-based processes. The comparisons of joint conditions across distinct prior intentions before acting yielded significant results for both behavioral and neural measures, with the highest activation of the temporo-parietal junction (TPJ) and the shortest MTs in the Comp condition considered to be implications for the top-down influence of prior intentions on joint performance.

How NOKOV Contributes to the Research

A Nokov Optical 3D Motion Capture System (http://www. nokov.com/en) was used to obtain movement data of two motion capture markers attached to the top of the rod at a sampling rate of 100 Hz, the coordination system was established at the calibration phase by putting a calibration tool at the experimental table. Movement data were preprocessed using Cortex 6.0 to acquire spatial coordinates for each marker, which includes the displacements of the markers in the x–y–z axes over time. And the x–y–z axes represent the vertical axis (x), the longitudinal axis (y) and the horizontal axis (z), respectly

References Chen Y, Zhang Q, Yuan S, et al. The influence of prior intention on joint action: an fNIRS-based hyperscanning study[J]. Social Cognitive and Affective Neuroscience, 2020, 15(12): 1340-1349.
Link https://academic.oup.com/scan/article/15/12/1340/5995789?login=true

Collective fission behavior in swarming systems with density-based interaction

Keywords

Swarming systems; Robotic swarm; Density field interaction; Collective fission behavior; Spontaneous split

Abstract

In this paper we revisit the self-organized collective behavior of swarms with density field interaction that is inspired from the model of smoothed particle hydrodynamics. For a homogeneous swarming system a novel collective fission behavior is seen to emerge where equal to or more than two sub-clusters spontaneously come from a single connected cluster. The focus of this study is on the analysis of collective fission behavior in trigger conditions, function manners and dynamic characteristics. For the first time, we are able to predict the stability of a single connected cluster, the trigger conditions of collective fission behavior, the number of sub-clusters and the group size of each sub-cluster. The analysis results also show that the collective fission behavior is irreversible by changing the control parameters and the group size. However, it is reversible when the sensing range is enlarged to encompass all sub-clusters. These characteristics are evaluated in simulations as well as on the real swarm robotic system. The study of collective fission behavior provides an elegant insight for how self-organized segregation emerges in biological swarms and artificial systems.

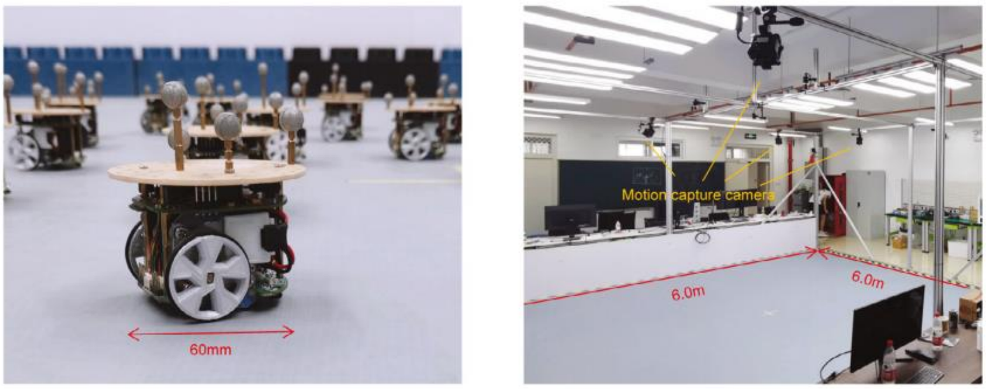


Fig. 8. SwarmBang robot and the overhead tracking system.

How NOKOV Contributes to the Research

> *Firstly, each robot needs to obtain the heading and position information of its local neighbors, which means the robot should have a localized sensing ability. To achieve this, we use the overhead tracking system, which can estimate the headings and positions of all robots in a global reference frame by employing a motion capture system manufactured by NOKOV. The information of headings and positions that contains all robots then is broadcasted to the working robots. For each working robot, it only decodes the information of positions and headings of its neighbors, such that the distributed computation is approximated.*

References Zhang S, Lei X, Zheng Z, et al. Collective fission behavior in swarming systems with density-based interaction[J]. Physica A: Statistical Mechanics and its Applications, 2022, 603: 127723.

Link https://www.sciencedirect.com/science/article/abs/pii/S0378437122004794

NOKOV Motion Capture System

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