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Peidong Liang

Fujian (Quanzhou) - HIT Research Institute of Engineering & Technology

Fengshun Liang

Fujian (Quanzhou) - HIT Research Institute of Engineering & Technology

Lizhi Gu (✉ gulizhi888@163.com)

Quanzhou University of Information Engineering

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Logic Motion Algorithm and Design of Flexible Limb of Gecko-imitating Robot

Liang Peidong^{1,a}, Liang Fengshun^{1,b}, Gu Lizhi^{2,c,*}

¹ Fujian (Quanzhou) - HIT Research Institute of Engineering & Technology, Building 9, Quanzhou Software Park, Fengze District, Fujian, China, 362000

² Key Laboratory of Virtual Manufacturing Technology of Fujian Universities, Quanzhou Mechanical Design, Manufacturing and Automation Studio, Quanzhou University of Information Engineering, No. 249, Bodong Road, Fengze District, Quanzhou, Fujian, China, 362000

*Corresponding Author, gulizhi888@163.com

Abstract:

The transmission tower climbing robot runs up and down along the tower tri-steel skeleton, and is supposed to stay in the required position firmly, transporting and installing the safety cable at the appropriate tower end for provision of the basic life safety guarantee for the operator during climbing and operating in maintenance. This paper puts forward and designs a set of robot and intelligent control with the hardware system of homing and pseudo-target excluding algorithms. In Euclidean n dimension space with the real number, definitions and constructions of the robot climbing state sequence number set are down with the norm sequence number set of the two adjacent rotary center distance of the handles on the same side of the skeleton, machine vision, and W- type sensor layout of discrete - continuous integration, efficiently homing the real goals and reliably identifying the pseudo target. According to the three point support - one point fetching, design of flexible appendage logical sequence were built up, not only guarantee the biomimetic gecko type climbing, and ensure the reliable grip of the robot hand with respect to to help handle. Together with the hardware design, the robot can work safely and reliably and transport the safety cable to the tower end. Because of the non-uniformity of the arrangement of the handle along the skeleton, the most critical problem to be solved in the climbing process is the robot's searching and reliable grasping.

Keywords: Safety rigging; Flexible limb; Gecko-like climbing robot; Pseudo-target elimination algorithm; Norm sequence number set

1. Introduction

Robot climbing and its application have always been the focus of experts, scholars and industrial engineers for several decades. The theory and technology of vertical-climbing robots are intrinsic and put into wide use, which has become the focus of research and application of industrial robots.

The design and use of safety cable has gone through two development stages: trial facility, generalization and specialization. In the climbing or moving robot field, several achievements have been gained. Jaesung Oh et al. [1, 2] put forward autonomous laser toning system based on vision recognition and robot manipulator, and online path planning. Yanwei Liu et al. [3] developed a track-type inverted climbing robot called SpinyCrawler, using a spiny track with an opposed gripping mechanism with the ability of generating considerable adhesion to achieve stable inverted climbing. Kapoutsis, A. C. et al. [4] created Plug-n-play Algorithm for Multi-robot applications. Liu Yanwei et al. [5] aimed the application requirements of crawling on the rough wall and ceiling, and proposed a wall-crawling robot with imitating of an inchworm. The robot adopted the movement mode similar to that of the inchworm, with its two feet attached to the wall alternately, and completes the transition movement of forward, backward and wall through the body flexion and extension. Fumin Gao et al. [6] presented a new climbing-wall detection robot mechanism consisting of two climbing modules. The two climbing modules were connected by anti-overturning mechanism to provide a capacity of anti-overturning during overcoming obstacle with a detection mechanism is installed at the bottom of the robot. Song, Yalun et al. [7]

provided a mechatronic approach for double robots in deburring of die casting. Munzer, Thibaut et al. [8] developed preference learning on the execution of collaborative human-robot tasks. Virgili-Llop, Josep et al. [9] carried out a convex-programming-based guidance algorithm to capture a tumbling object. Tang Shiyang et al. [10] analyzed the case of aerial work accidents in the power grid industry and proposed a protection plan for the first person to work on the tower, and gives a preliminary design of the installation assistant robot for operation on the tower. Ashkvari, Mahyar et al. [11,12] designed a 2-DOF ankle joint actuation mechanism for a humanoid robot, and for motor-tendon actuator for a soft starfish-like robot, respectively. Jiang Ru-hao et al. [13] analyzed the mechanical structure and freedom of the space four-legged crawling robot, studied the changes of the center displacement of the spherical shell, the displacement of the moving sub-line and the angular displacement of the rotating sub-line with time, and planned the crawling gait of the robot. Villagrossi, E. et al. [14] used single-point laser sensor in flexible robot-based cast iron deburring cell. Zhuang Hong-jun et al. [15] proposed an embedded vision system of power tower climbing robot based on FPGA, which combined with embedded image processing technology. Eslami, Mostafa et al. [16] Presented a model of biped robot for Real-time Trajectory control. The current research aims at safety cable of the gecko climbing robot which plays an fatal role in the basic life support of the operator. Wang Yang et al. [17] designed climbing and locking parts of a robot, based on the climbing statics analysis of the major parameters with respect to corresponding two key mechanisms, as well as the climbing control strategy. Li Huaqiang et al. [18] expounded the utility of the climbing inspection robot, analyzed its technical scheme and optimization, in order to improve the function of the climbing inspection robot, reduced the difficulty of the inspection work, and promoted the development of the national power grid. ZHAO Peng et al. [19] designed a kind of climbing robot which could crawl on rigid long poles or flexible ropes, so as to replace human beings for climbing. And the robot compaction mechanism by adjusting the pre-tightening force of the spring to make robot roller could produce certain pressure to rope or pole to generate enough friction, ensuring the robot to crawl on the rope. Zhao Zhangyan et al. [20] designed a magnetic adsorption metal climbing robot with strong obstacle resistance in order to meet the detection requirements of dangerous parts of large cranes. The robot could carry high-definition image transmission equipment, robotic arms and other metal detection equipment with a unique magnetic adsorption component. Jiang Li et al. [21] proposed, based on the self-designed biped climbing robot, named Climbot, an energy-optimal motion planning method, which considered the kinematics and dynamics constraints simultaneously, and described a mathematical model with energy consumption for climbing robot. Li, Shuai et al. [22] proposed a motion planning algorithm with probabilistic guarantees for limbed robots with stochastic gripping forces. And the planners based on deterministic models with a worst-case uncertainty could be conservative and inflexible to consider the stochastic behavior of the contact, especially when a gripper is installed. Shirai, Yuki et al. [23] presented a motion planning algorithm with probabilistic guarantees for limbed robots with stochastic gripping forces, with Planners based on deterministic models with a worst-case uncertainty being conservative and inflexible to consider the stochastic behavior of the contact, especially when a gripper was installed. Mazzolai, Barbara et al. [24] analysed the works in which both biological and engineering aspects have been investigated, and highlighted the key elements of plants that have been milestones in the pioneering field of growing robots. Brown, Jason M. et al. [25] examined how cockroaches vary their behavior as slope was changed from horizontal to vertical, with special care to examine individual leg forces when possible. Gallentine, James et al. [26] presented new plant-inspired robotic tendril-bearing and intertwining stem hardware and corresponding novel attachment strategies for thin continuum robots. Mao, Liheng et al. [27] investigated the gait planning task for a six-legged robot climbing stairs, and developed a novel robot-terrain interference model, which can be efficiently established online using a terrain map. Gallentine, James et al. [28] proposed new plant-inspired robotic tendril-bearing and intertwining stem hardware and corresponding novel attachment strategies for thin continuum robots. Amirhosseini, Hessameddin et al. [29] presented the development of a small and lightweight differential hexapedal microrobot, inspired by cockroach locomotion mechanism with detailed design, prototyping and performance evaluation. Chen, Youxu et al. [30] proposed a novel pneumatic soft actuator, which can perform bending in different directions under positive or negative air pressure with the actuators composed of multiple airbags designed. Fukui, Rui et al. [31] presented a ceiling-mounted mobile robot, HanGrawler, with high-speed mobility and the ability to freely select and adjust its route under a ceiling plate. The HanGrawler hangs from the holes of a perforated metal ceiling plate using newly developed mechanically constrained hanging mechanisms mounted on crawler-type traveling equipment. Hirasawa, Junji [32] described about improvements in the mobility of a stair climbable mobile robot on a step-field standardized by the

National Institute of Standards and Technology being a simulated artificial rough terrain used for testing rescue robots. Chen, Ningning et al.[33] established a theoretical model of the rotation flow, containing two important parameters and verified it experimentally, with application of the computational fluid dynamics (CFD) method to illustrate the secondary flow relative to the blades, revealing that it gave rise to a nonlinear velocity distribution. Cil, Zeynel Abidin et al. [34] investigated the mixed-model assembly line balancing (MMALB) problem with the collaboration between human workers and robots, developed a mixed-integer linear programming (MILP) model to tackle the small-size problems optimally to minimize the sum of cycle times of models, with implementation of bee algorithm (BA) and artificial bee colony (ABC) algorithm. Serebrennyi, V. V. et al. [35] discussed the dynamics of a newly developed mobile robot with a vertical movement mechanism on magnetic caterpillar movers, and based on analysis of the current solutions in the field of vertical movement robots, proposed an original kinematic scheme of the movement of the vertical movement mechanism that allows implementing a number of critical advantages compared to current schemes. Chen, Yufeng et al.[36] presented a novel adhesion method that leverages capillary and lubrication effects to achieve simultaneous adhesion and sliding with design of a 47 mg adhesion pad and installation of it on a 1.4 g insect-scale quadrupedal robot to demonstrate locomotion on inverted and inclined surfaces. Seo, Myoungjae et al.[37] proposed a novel mechanical design of a cable-driven parallel robot (CDPR), called a dual ascender robot (DAR), which consists of two ascenders and two structures for rope-measuring sensors. Choi, Kisuk et al.[38] proposed the modeling methodology and its experimental verification that could maximize the lifting shear force of the electroadhesive device to reach well over the human-finger grip force, say, ca. 8.9 kPa, which has not been achieved yet in this device system. Bogue, Robert. [39] aimed to provide technical details of humanoid robot developments from the 1970s to the present day and to consider their potential applications and prospects with Design/methodology/approach Following an introduction, this first identifies the motivations for developing humanoid robots. Soffiatti, Patricia et al.[40] explored the functional traits of the climbing cactus *Selenicereus setaceus* (Cactaceae) from the Atlantic forest of Brazil and discuss the potential of these traits for robotics applications. Fan, Jizhuang et al.[41] developed a novel style of a permanent-magnetic adsorption mechanism using an electromagnetic method and internal force compensation principle. Feng, Xiaobing et al.[42] analyzed the application of spherical tank welding robot and studied the fusion welding forming model based on BP neural network with the preview of the key technology trend in the future. Feng, Xiaobing et al.[43] studies the application of wall-climbing robots in ship automatic welding, which has an important role in the research of ship-welding technology. Wu, Xuewei et al.[44] introduced an aircraft skin inspection robot which sticks to the surface of an aircraft by suction adhesion with the purpose of operating adsorption force is to ensure a smooth and fast movement of the robot. Xu, Fengyu et al.[45] addressed the implementation mechanism required and revealed a method of extracting the characteristic parameter with devised rough wall was devised then simulated 3D profiles of rough walls for the discriminant conditions necessary for the claws to stably grasp the wall. Liu, Jinfu et al. [46] Aimed at task requirements on multiple walls and based on the above three bionic structures, a wall-climbing robot with the composed mode of "grabbing+adhesion+adsorption" is presented via the law of mechanism configuration synthesis. Chavdarov, Ivan et al.[47] investigated the possibilities of climbing higher obstacles while maintaining the overall dimensions of a walking robot through design improvements and experiments. Yoo, Sungkeun et al.[48] proposed a novel multi-wound differential pulley winch (MWDPW) component for assisting the ascending/descending operations of a wall climbing robot. The robotic platform enabling rope access in dangerous environments (ROPE RIDE) climbs vertical walls using a rope and embedded winch. Masoud, Hassan Ito, Kazuyuki et al. [49,50] developed a soft climbing robot made of silicone. Octopus-like behaviour is realized by a simple mechanism utilizing the dynamics of the soft body, and the robot can grasp various objects of unknown shape. Austin, Max P. et al. [51] outlined some of the specific motion planning challenges faced when attempting to plan for legged systems with dynamic gaits, with specific instances of these demonstrated by the dynamic climbing platform TAILS. Wardana, A. A. et al.[52] proposed the design of a single-wheeled robot capable of climbing stairs. The robot is equipped with the proposed climbing mechanism, which enables it to climb stairs. Sun, Jingyuan et al. [53] proposed a control framework to tackle the hybrid locomotion problem of wheeled-legged robots. It comes as a hierarchical structure with three layers: hybrid foot placement planning, Centre of Mass (CoM) trajectory optimization and whole-body control. Zhou, Qiang et al.[54] proposed a convolutional neural network-based positioning scheme comprised of a global bounding box detector and local wheel detector.

The current study puts forward and designs a set of robot and intelligent control with the hardware system of homing culling algorithm, and the pseudo target defined in Euclidean n D space

with

Fig. 1 A gecko in climbing

Fig.2 Climbing robot with bionic gecko

the real number and climbing state sequence number set, and applied on the same side two adjacent rotary center of the handle is apart from the norm of the sequence number set, efficiently and reliably identify false target and real goal, make robots catch hand based on reliable mathematical climbing, climbing, not only ensure the biomimetic gecko type and ensure the robot hand refers to help handle the reliable grip, along with the hardware design, to ensure the safety of the robot working reliable.

2. Analysis and Expression of the Climbing Logic

2.1 Function Analysis

The functions of the robot limbs mainly include

- (1) Climb up, down and stay in the desired position along the skeleton handle of the tower;
- (2) The working handle in the direction of detection and searching, namely the target handle;
- (3) Flexible limb length. By changing the length of forelimb or hind limb, the center of the target handle and the center of the palm and finger can be conformed;
- (4) Grasp handles;
- (5) To provide and transmit power and movement to make the vehicle run;
- (6) Support bearing device to realize carrying capacity.

2.2 Expression of Logical Action Sequence

Climbing physical model and kinematic model

Fig. 3 Climbing physical model and kinematic model

31 Vehicle chassis;32 Stepping motor (2);33 Stepping motor (1);34 Posterior limb (1);35 Hind limb (1);36 Forelimbs (1);37 Anterior limb (1)

Driven by a stepping motor, the front and rear limbs rotate counterclockwise ($180^\circ - 2\beta$) from a relative horizontal Angle to handle 1 and handle 2, respectively, to push the vehicle chassis to move $L/2$ forward, or forward:

$$M = L/2 = 2q \cos \beta$$

In the XOZ plane, the displacement and velocity of any point on the vehicle are

$$\begin{cases} x = q \sin wt \\ z = -q \cos wt \end{cases} \quad (1)$$

$$\begin{cases} \dot{x} = -wq \cos wt \\ \dot{z} = wq \sin wt \end{cases} \quad (2)$$

Meanwhile, the acceleration is

$$\begin{cases} \ddot{x} = -w^2 q \sin wt \\ \ddot{z} = -w^2 q \cos wt \end{cases} \quad (3)$$

Crawling route

Based on gecko crawling bionics, a "3-1 climbing mode" is formed -- 3 points of positioning support and 1 point of power transmission to realize forward movement. Accordingly, under the given working conditions in Fig. 1, the movement mode in Fig. 3 is adopted to realize gecko climbing. The specific model is as follows:

Press gecko limbs -- forelimb 2 arms, hind limb 2 legs and feet, respectively defined as arms 1, arms 2, legs and feet 1 and feet 2. The handrails corresponding to moments are handle2, Handle4, handle1 and Handle3, which are called points 2, 4, 1 and 3 respectively. Its working state is point 1, 2 and 3 in the state of holding the handrail, and arm 2 in the state of stretching forward in space, forming a (1,2,3) -4 pattern. In the next instantaneous state, points 2, 3 and 4 are in the state of holding the handrail, while arm 1 extends forward in space, forming a pattern of (2,3,4) -1. Follow the loop to achieve a forward climb. This is known as the three-point grab-and-one-point forward

stretch mode. The progressive pattern sequence of Formula 3-1 can be expressed as

3. The Flexible Limb and Design

Fig. 4 Schematic of a flexible limb

Its core composition is a screw nut mechanism. Driven by a stepper motor, the middle sleeve with an end key drives the nut to turn, and the nut's outer cylinder undertakes bearing and turns relative to the shell. The rotating nut pushes the lead screw in a straight line. When the motor rotation is changed, so is the lead screw.

3.1 W—type Design of the Discrete - continuous Sensing Region

Fig. 5 W-type distribution of sensing elements in the induction zone

41 Induction zone grid division; 42 Sensing element

In the $w \times m$ region, it is divided into a sufficient number of small cell slices with a certain length and width 41, and a sensitive element 42 is set on each cell slice. Ensure

$$W > b$$

where, b is the minimum center distance of two adjacent irregularly distributed handles on the same side. take

$$W = b + 60$$

When the small cell slices are divided on the length of W , if the sensing element is arranged with length n and the center of the sensing element is designated as the extraction location, then the detection density is

$$D_s = w/t \quad (4)$$

Since the length of each sensing element n is greater than the length of the segmented thin section k , the cylindrical bus of the target handle in front can be detected in the entire $w \times m$ region, and the geometric center of each sensitive element in contact with the cylindrical bus is regarded as the position of the contact point of the handle bus, as shown in Figure 6.

3.2 Grasping Palm Design

(a)

(b)

Fig. 6 Coincidence and irregular handle spacing between handle center and grip center
(a) two centers; (b) irregular handles

Fig. 7 Grasping and releasing of palm fingers

70 help handle; 71 limb sensing area; 711 wedge lock; 712 gear; Palm sensing element; 72.721 transmission rack; 73 stepper motor; Rack guide device; 74 a shaft; 75 vehicle chassis; 76 finger sensitive element; 77 open state

When the handgrip is designed, the grip force should be uniform and have automatic compensation function, so as to eliminate the limited distribution and certain error of the sensing element in the process of detection and seeking.

(a) Composition and layout of palm fingers

It is composed of palm 72, finger 77, palm and finger sensitive elements, rotating shaft 74, stepper motor 73, etc., as shown in Figure 7

(b) Palm design

A part of the retractable forelimb, the working face is made into a part of the cylinder, the diameter can be chosen as the diameter of the handle, but the tolerance is positive deviation

$$d_{p+\Delta}^{+(\Delta+\Delta T)}$$

$$d_p = d_h$$

To adapt to the handle cylinder working face.

(c) means design

Finger shape as a pawl, its working face diameter slightly larger than the handle diameter

$$d_f = d_h + \delta$$

$\delta = 1.5 \sim 2 \text{mm}$.

One end of the finger is fixedly connected with the shaft sleeve, and the bearing is matched with the shaft to rotate in two directions under the driving of the stepping motor, and the angular stroke is rotated to ensure that the limbs work reliably without interference during searching and when grasping.

(d) Layout and mechanical design of sensing elements

There are at least two sensors on palm region, three sensors on the finger region. If the press on the palm and fingers is

$$p \pm \Delta p$$

The real press on the sensor i is

$$P_i > p$$

Then the infinitesimal adjustment will be down to the direction of leaving the sensor, so as uniform the presses on the palm and fingers, as well as eliminating the error raised during the homing.

Fig. 8 Climbing logic movement sequence of gecko-bionic robot

(a) skeleton of the power transmission tower; (b) logical movement sequence

4. Representation of Climbing Movement Mode and Logical Action Sequence of the Robot

4.1 Climbing Gesture

In the Euclidean n-dimensional space with real number domain, the spatial position of the handle on the tower skeleton, the robot's homing and decertifying targets, and the climbing attitude will be defined.

Based on the bionics of the gecko, the four limbs are supposed as the anterior limb1(arm1), anterior limb2(arm2),posterior limb1(leg1), and posterior limb2(leg2).See Fig.2. In a moment, the state of the robot in climbing will be

$$S=\{s_1, s_2, \dots s_i, \dots s_n\} \quad (5)$$

where s_i —— the i -th climbing sequency, may even be depicted in the following

$$s_i=\{i, \text{gesture}_k, \text{fix} (n_1, n_2, n_3), \text{drive} (\text{limb}_j)\}, \quad i=1,2,\dots;l; \quad (6)$$

L ——number of climbing steps, it is so defined as the climbing step with respect to the forward guide with one step. L may have the same value as with n .

gesture_k —— climbing direction. up climbing , when $k=1$; down climbing-clarification, when $k=2$;

gesture_k

$\text{fix} (n_1, n_2, n_3)$ ——code of grasping limb, 3;

$\text{drive} (\text{limb}_j)$ ——forward guidecode, 1;

Defined respectively by (arm1,arm2,leg1,leg2).

4.2 Movement State Sequential Set and Expression

When a limb, say arm1, becomes the drive that makes the carrier forward, then the expression Drive(limb1) is used for clarification from other limbs. The four limbs in drive will be formulated in terms of

$$\text{drive}(\text{limb}_j) = \begin{cases} \text{arm}_1, j = 1 \\ \text{arm}_2, j = 2 \\ \text{leg}_1, j = 3 \\ \text{leg}_2, j = 4 \end{cases} \quad (7)$$

The handles corresponding to the moment are handle2, handle4, handle1 and handle3, which are called working state points 2, 4, 1 and 3 respectively, as shown in Figure 4. Set in the original position, the climbing robot limbs are defined by Equation (3). Its working state is that points 1, 2, 3 and 4 are all in the grip state and ready to crawl forward, namely attitude A. The first step of crawling forward is corresponding to attitude B. The limbs are rotated forward with the center of the handle as the center of rotation respectively forward 180° - $\beta(\text{drive}(\text{limb}_3) = \text{leg}_1), \text{drive}(\text{limb}_4) = \text{leg}_2)$. In the second step, arm 1 takes hinge 1 as the center of rotation, leans forward and grabs the handle of target 1 (see "Searching and Removing False target Algorithm" for process details). In this process, working points 3,4 and 2 are still in the grip state, see state C, form (2, 3, 4-1); Arm 2 extends forward in space centering on hinge 3 and grabs target 1 handle. During this process, work points 1,2 and 4 are in a grip state ($\text{drive}(\text{limb}_j) = \text{arm}_2$), forming a (1,2,4) -3 pattern, see attitude D. In the next instantaneous state, the working state is point (1,3,4), which is in the state of holding the handrail, while the leg-foot 1 extends forward in space and grabs the handle of the original arm 1, forming a pattern of (1,3,4) -2. See State E. In the following action, the working state points (1,2,3) are in the state of holding the handrail, while the second leg extends forward in the space and grabs the handle of the original second arm,

forming a pattern of (1,2,3,) -4. See state F. At this point, you go in a loop, going L/2.

This is known as the three-point grab-and-one-point forward stretch mode. Then crawl into the next loop. The progressive 3-1 pattern sequence can be expressed as gecko climbing mode:

$$\{ (1,2,3,4) , ((1, 2, 3, 4) -2, 4) , ((2,3,4) -1) , ((1,2,4) -3) , ((1,3,4) -2) , (1, 2, 3) -4, (1,2,3,4) , ((1, 2, 3, 4) -2, 4) , ((2,3,4) -1) , \} \quad (8)$$

The backward climbing is equivalent to the forelimb modification, while the forelimb modification is similar to the forward circulation mode and has a symmetrical form with Formula (8), so it is no longer redundantly expressed.

5. Homing and Pseudo Target Eliminating Algorithm

5.1 Homing by Sensing Technology and Machine Vision

5.1.1 Homing by the sensor technology

Fig.9 Homing and grasping of the robot with flexible limb

51 Initial position of metacarpal finger; 52 Sensing element; 53 Palm grasp position; 54 hand shank; 55 sensors; 56 stepper motor; Carrier car chassis; 57.58 screw; 59 CCD

The algorithm is as follows:

First, set the target handle within the sector swept by the flexible limb:

In the area swept by the limb, the target handle must be included, that is, the length of the sensing area should cover the target handle, as shown in Figure 5.

The sensing elements are distributed as follows

Since each sensor length, n , is designed greater than the fine district piece length k , in some part of the entire domain of the $w \times m$ area the generatrix of the handle in front can be touched and detected, and each contact with the cylinder is supposed to be the geometric center of the sensitive element, thus ensuring the capture of one target with the location of the handle, as shown in Figure 6.

The i -th sensor in the "W" distribution of the sensing area touches the cylinder side of the handle, generating the spatial coordinate position:

$$O_t' (x_o', y_o', z_o') \quad (9)$$

And the center coordinate of the palm grasping the handle, O_p , is

$$O_p (x_p, y_p, z_p) \quad (10)$$

In the unified coordinate syste, we have

$$z_o' = z_p = z = C$$

Then the spatial two points may be transformed into planetary problem, with the distance of the two points

$$H = \sqrt{(x_o' - x_p)^2 + (y_o' - y_p)^2 + (z_o' - z_p)^2} = \sqrt{(x_o' - x_p)^2 + (y_o' - y_p)^2} \quad (11)$$

The transformation between the touch generatrix of the handle and the center of the handle will be, see Fig.7

$$\begin{cases} x_o = x_o' - r_o \cos \gamma \\ y_o = y_o' - r_o \sin \gamma \end{cases} \quad (12)$$

So, the center coordinate of the handle may be obtained.

5.1.2 Homing by the machine vision

Fig.10 The homing by the machine vision

As shown in Figure 6, when using machine vision, after the robot climbs one step, the target handle enters the visual field. At the same time, the visual system prompts the target center coordinates to the control system, and compares the coordinate range with the induction region on the flexible arm. When the machine vision prompts the target handle to be within the coordinate range of the induction zone, the length of the flexible arm remains unchanged and the rotary motion continues; When the machine vision prompts the target handle to exceed the coordinate range of the induction area (in the far direction), the control system indicates the extension of the flexible arm. Meanwhile, the screw mechanism exerts to lengthen the flexible arm so that the target are made within the sector of the flexible arm in rotary motion.

$$\Delta H = (J \times B \times \theta) \cdot p \quad (13)$$

where J ——number of the teeth of the rotor in the stepping motor

B —— operating meter

θ ——stepping angle in run

p ——lead of the screw.

The homing will be firmly down by combination of the two methods.

5.2 Pseudo Target Elimination Algorithm

Due to the structural form of the tower frame, the distribution of handles on the same side of the triangle steel is irregular, that is, the distance b between the two adjacent handles is far less than the spacing of regular arrangement, as shown in Figures 3 and 5. In this case, in the "climb up" mode, two adjacent handles that are not arranged in a regular pattern, the nearer one cannot be used and becomes the "pseudo target" or "pseudo target", while the farther one is the handle to be used and becomes the "real target".

Therefore, the false targets must be eliminated, and the corresponding algorithm is as follows:

In the Euclidean N-dimensional space with the real number domain, the center positions of the same side handles are composed into a set $\{C_i\}$, and then the number set is composed of the distance norm sequence between the rotation centers of any adjacent handles on the same side, and is put into the database. The distance norm of any two adjacent handles is:

$$|d_{i,i-1}| = \left((C_{xi} - C_{xi-1})^2 + (C_{yi} - C_{yi-1})^2 + (C_{zi} - C_{zi-1})^2 \right)^{\frac{1}{2}} \quad (14)$$

then becomes a set of distance norm sequence $\{d_{i,i-1}\} = \{C_i - C_{i-1}\}$

That is

$$\{C_2 - C_1, C_3 - C_2, \dots, C_i - C_{i-1}, \dots, C_{n-1} - C_{n-2}, C_n - C_{n-1}\}, i=1, 2, \dots, n. \quad (15)$$

So, the constituent elements of the distance norm sequence set are

$$\{d_{2-1}, d_{3-2}, \dots, d_{i,i-1}, \dots, d_{n-2,n-1}, d_{n,n-1}\} \quad (16)$$

Take the minimum value and second minimum value of the elements:

$$S_{b1} = \min_{1 \leq i \leq n} \{d_{i,i-1}\}; S_{b2} = \min_{1 \leq i \leq n} \{d_{i,i-1}\}, S_{b2} \neq S_{b1} \quad (17)$$

Now take the position of the first handle, $C_1 (x_1, y_1, z_1)$ and the second minimum value of the elements the distance norm sequence set, S_{b2} , as the basic parameters of the climbing robot, then the general spatial locus of the flexible arm may be obtained

$$(x - x_{C1})^2 + (y - y_{C1})^2 = R^2 \quad (18)$$

And specific locus of the touch point of the sensor on the flexible arm corresponding onto the handle, and specific locus of palm center, both swept in space, respectively, may be depicted in terms of

$$(x - x_{C1})^2 + (y - y_{C1})^2 = R_1^2 \quad (19)$$

$$(x - x_{C1})^2 + (y - y_{C1})^2 = R_2^2 \quad (20)$$

where, R_1 and R_2 are respectively the radii between the track of the contact point between the sensor and the handle and the track of the palm grasping center relative to the common instantaneous center C_s , as shown in Fig. 7.

As shown in Fig. 6 and Fig. 8, the distribution of the same side handles is non-uniform. Under normal circumstances, the distance between any two adjacent handles is with a certain value. However, at the turning point of the tower frame, the distance between the two adjacent handles would be $b = 200\text{mm}$, which is much smaller than the normal distance of $P = (450-500) \times 2\text{mm}$. At this time, the robot should grasp a farther handle. In this way, the nearer handle in the above mentioned becomes a false

target and must be eliminated in the control process. The algorithm adopted is to use equations (15), (16) and (17) to find the minimum element of the distance norm sequence set, S_{b1} , at the same time, judge

$$S_{b1} \leq \Delta \quad (21)$$

where Δ is the distance between the two irregular adjacent handles, which is much smaller than that of the two regular adjacent handles (900mm-1000mm).

If Equation (21) is true, then the coordinates of the two handles forming S_{b1} will be

$$\begin{aligned} C(S_{b1})_1 &= C_\lambda, \\ C(S_{b1})_2 &= C_{\lambda-1}, \quad \lambda=1, 2, \dots, n \end{aligned}$$

Therefore, it can be determined that the farther handle is the real target, and the nearer handle is the pseudo target.

If the next target is settled then the movement of the palm center approaches linearly the center of the handle and to make the two overlap, by way of Equation(13).

6. Conclusion

A set of climbing robot with intelligent control realizing homing and pseudo-target eliminating algorithm was put forward in Euclidean n D space with real number, and catch climbing state sequence set was proposed and applied on the same side two adjacent rotary centers of the handles of the tower skeleton apart from the norm of the sequence number set. Taking the gecko climbing as the bionic object, the series of grasping and climbing states of the climbing robot is defined and constructed in the Euclidean n-dimensional space with real number domain, and the corresponding handle, limb state, grasping and guiding model are defined with the so-called "three-point grasping and one-point forward stretching driving model":

$$\{(1,2,3,4), (1,2,3,4) - 2,4), ((2,3,4) - 1), ((1,2,4) - 3), ((1,3,4) - 2), ((1,2,3) - 4), (1,2,3,4) - 2,4), ((2,3,4) - 1) \dots\}$$

Number theory and database technology have been employed to define, store and access the norm of center position distance of any two adjacent handles on the same side, the norm sequence number set, the minimum norm and the secondary minimum norm, so that the climbing and homing of robot, the elimination of false targets and the intelligent control are based on reliable mathematics.

Third, using the two technology methods of sensing and machine vision, through the machine vision guidance and flexible arm design, the limbs sweep the sector, the sensing elements arranged in the induction area "W" style, the discrete induction detection is continuous and seamless, to ensure the limb sensing area and the target cylinder bus effective contact, to achieve the search; The precise location of the center position of the handle is obtained by the coordinate transformation algorithm on the cylindrical bus.

The norm sequence number set of the center distance of any two adjacent handles on the same side of the skeleton has been originated and used effectively in discrimination of false targets and real targets, raised by regular and irregular arrangement of handles on the same side.

Pressure equalization algorithm has been created and adopted in grasping handles, laying no less than 5 distributed sensing elements on the working face of palm-finger, adjusting the pressure between palm-finger adaptively according to the pressure deviation, ensuring the center of palm-finger is coexisting with the center of palm-finger, and grasping the handle reliably.

In the Euclidean n D space with real number, the tower climbing robots catch hold climbing state sequence number set has been defined and the corresponding database constructed. Combined with the gecko help handle creepy robot limbs, symmetrical design in "climbing down" mode of algorithms, both homing or eliminating pseudo targets, only set the related sequence database

elements in reverse, the fore limbs replace the hind legs, then a full set of algorithms and corresponding database in "climbing up" mode can fully be used, to simplify the program, the robot structure, improving the reliability of the system.

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Author description: Liang Peidong, male, (1984.12 -) , PhD in Engineering, engineering director of Fujian (Quanzhou) HIT Research Institute of Engineering & technology, and robot technology minister, excellent mechanical and electrical engineering of Harbin Institute of Technology, PhD, imperial college London visit, Ph.D., introduction of high-level talent, class C in Fujian Province quanzhou high-level talents third level talents. It is mainly engaged in industrial robot technology, intelligent robot technology, multi-sensor information fusion and intelligent detection. He has been in charge of or participated in, more than 30 projects, including National Natural Science Foundation, National "863" Program, National Major Special Projects, National Key Research and Development Program, National Key Laboratory Independent Projects and open projects, etc. He has published nearly 20 international academic papers, including 6 by SCI, 12 by EI, 1 by top international conference on Robotics, and 1 by THE IEEE CYBER2015 International Conference as the best paper.

Corresponding author: Gu Lizhi, male, (1956.11-), PhD in Engineering, Professor of Mechanical Manufacturing, Quanzhou University of Information Engineering, Huaqiao University, Doctor of Engineering, doctoral graduate tutor, National Outstanding Teacher. Director of key Laboratory of Virtual Manufacturing Technology in Fujian Universities, Premium Talent of Equipment Manufacturing in West Taiwan Street Industrial Agglomeration Area, evaluation expert of National Innovation Fund, and expert of provincial and municipal project evaluation and warehousing. Research interests: digital design and manufacturing, vibration metal cutting and advanced manufacturing technology, research on specific mechanisms and robots. He has published more than 400 papers, edited and reviewed 8 works, authorized more than 30 National Invention Patents, and won 4 Provincial Science and Technology Progress awards.