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Human-Tracking Strategies for a Six-legged Rescue Robot Based on Distance and View

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Abstract: Human tracking is an important issue for intelligent robotic control and can be used in many scenarios, such as robotic services and human-robot cooperation. Most of current human-tracking methods are targeted for mobile/tracked robots, but few of them can be used for legged robots. Two novel human-tracking strategies, view priority strategy and distance priority strategy, are proposed specially for legged robots, which enable them to track humans in various complex terrains. View priority strategy focuses on keeping humans in its view angle arrange with priority, while its counterpart, distance priority strategy, focuses on keeping human at a reasonable distance with priority. To evaluate these strategies, two indexes(average and minimum tracking capability) are defined. With the help of these indexes, the view priority strategy shows advantages compared with distance priority strategy. The optimization is done in terms of these indexes, which let the robot has maximum tracking capability. The simulation results show that the robot can track humans with different curves like square, circular, sine and screw paths. Two novel control strategies are proposed which specially concerning legged robot characteristics to solve human tracking problems more efficiently in rescue circumstances.

Keywords: human-tracking, legged robot, intelligent control algorithm

1 Introduction

Legged robots have been widely used in many applications with complex uneven terrains, e.g. the rescue tasks for earthquake, exploration in other planets and so on. Compared with wheeled or tracked robots, the main different feature is that they apply discrete footholds on the ground for locomotion. For rescue tasks, they often need to carry sensors(e.g., camera, laser and sonar) for environment monitoring and tools (e.g., arm and hand) for manipulations (e.g., clear obstacles, open doors and fix leaking pipes). In these scenarios, the payload capability becomes an important design requirement and should be taken into consideration.

In last a few years, many six-legged robots have been developed, here lists some most famous prototypes. Ambler developed by KROTKOV, et al[1], targeted missions of exploration in other planets. Athelete developed by WILCOX, et al[2], was designed to help NASA to handle cargos in the moon. COMET developed by OHROKU, et al[3], was designed for demining tasks. DLR Crawler developed by GÖRNER, et al[4], mainly focused on evaluation of gaits and control. Plustech developed by PAAKKUNAINEN, et al[5], was used to cutting woods in forest. RHex developed by HAYNES, et al[6], was designed for traversing in many kinds of complex terrains. These robots are different in terms of leg number, mechanism type, degree-of-freedom, weight, size, payload, speed, stability, algorithm and applications. Due to the complex unstructured environment in rescue scenario, robots carrying a lot of sensors and tools often use static stable gait. Basically speaking, with more legs, the robot stability is better, but its mechanical structure is more complex. Considering this, recently a novel six-legged rescue robot with parallel mechanism leg has been developed[7–9]. Its main features include heavy payload, static stability, and uneven terrain adaption.

To deploy the robot into the disaster field, the very first thing to do is to put it to some place near the target position by truck. Then the robot should walk into the situation center by tracking an operator. After that, the operator can control the robot as a tool to fulfill tasks like manipulating devices, cutting metals, turning valves and so on. The control command can be sent through wireless network. This paper mainly focuses on the tracking methodology, and compares the different tracking strategies.

To detect and locate a human, sensors like GPS, laser scanner, infrared light, sonar, inertial sensor and camera must be installed. Some of them can be used independently, while others must be used corporately to generate human position signals. Common sensors used in tracking tasks are as follows:

(1) The GPS can provide the location of an outdoor human, but the accuracy is only about 1–3 m depending on atmospheric effects and receiver quality. In most indoor

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cases, laser scanners are used[10–15], which are not sensitive to illumination changes in the environment. The sonars are also used in several related studies[16–20]. Among them, the ultrasonic rangefinder can provide 1cm resolution within several meter range. Another advantage is that it can be used in the smoky environment. Tracking methodology by inertial sensors was proposed by YUAN, et al[21], and its accuracy is within 1%–2% of the total walking distance. Many researchers[22–27] used binocular cameras to get and process the human positions. However, its performance was affected a lot by environmental conditions including changes in illumination. Infrared lights were used by HESCH, et al[28]. It can measure the depth information using an infrared light sender and a monochrome CMOS receiver. It can be used even in very gentle light, and additionally, it can be used to detect the human profile using a RGB camera. It has a multi-array microphone to receive the human voice. It is a promising way to achieve human detection in tracking applications.

(2) To enhance the tracking performance, sensors can be used corporately. In literature, camera and inertial sensor[29], camera and laser scanner[30–31], sonar and laser scanner[32], camera and voice recognition sensor[33] are used together to generate dependable human position information.

After the human is detected and located, the human-tracking algorithms should be applied. Considering specific rescue applications, mature human-robot interaction technologies like tracking human faces can't be used thus not studied in this paper. Instead, only human path tracking methodology is considered here: Using posture feedback, a PI controller was used by DANG, et al[34]; based on image feedback, some visual servo methods, e.g., curve tracking[35], optimal control[36] and position error model using state feedback were proposed. Using laser rangefinder feedback, a human leg tracking method was proposed. Some human tracking strategies, e.g., pursuing a person, keeping a distance with a person, body orientation correction were used by SONG, et al[26].

Unfortunately, most of existing human-tracking algorithms were designed for the wheeled robot. Few studies for legged robots can be found. Some famous legged robots have tracking function, e.g., BigDog can track soldiers in wild environment, but no detail of its algorithm has been revealed.

The main difference of the human-tracking methods between the wheeled and legged robots lies that legged robots can only walk step by step in a discrete way, while the wheeled robots can start or stop at any time thus move in a continuous way. For legged robots, it is very difficult to change their walking speed very in only one step. This makes the gait planning for human-tracking tasks more difficult. Given the human location, the human-tracking algorithm can be decomposed to 2 parts: how to plan the walk path and how to generate an appropriate gait. Considering these two challenging issues, we proposed a new human-tracking approach specially for legged-robots in this article. The main contributions of the paper are as follows.

(1) Two key issues affecting the human-tracking for the legged robot are pointed out, which have never been referred to in previous literatures.

(2) Analogizing similar behaviors of human beings and other creatures, two tracking strategies are proposed: the view priority strategy and the distance priority strategy.

(3) Two evaluating indexes are defined to evaluate the tracking effects of the strategies. In addition, the strategies are optimized based on these indexes to achieve better tracking performance.

(4) Several typical human-tracking simulations are performed in MATLAB environment, and the results can well validate our methods.

(5) This research supplements relevant human-tracking study for legged robots.

The paper is organized as follows. Section 2 introduces the prototype of our rescue robot which is a six-legged walking robot using parallel mechanism. The main difficulties of human-tracking issue are described and analyzed in section 3. Section 4 gives detailed contents of 2 kinds of tracking strategies, and Section 5 provides the implementations of these 2 strategies respectively. The strategy evaluating indexes are defined in section 6, the strategies are evaluated, and the optimization is also given. Section 7 shows the simulation results with different kinds of human path like square, circular, sine and screw paths, in MATLAB software. Section 8 gives the conclusion and future plans.

2 Six-legged Rescue Robot

The six legged rescue robot prototype is shown in Fig. 1. Compared with other legged-robots, the main different part was that its legs applied parallel mechanisms, which were three-link parallel mechanisms. Each leg was driven by 3 motors hence it had 3 active degree-of-freedoms(DOFs). From the mechanism point of view, the whole system was also a parallel mechanism: the robot body was the end-effector, the ground was the base, and each leg was a limb. Thus the robot body could be treated as a redundant-driven six-DOF walking and manipulating platform. This parallel-parallel design can improve the payload capability significantly. It also meant that the driven torque requirement on the motor was reduced. In our prototype, the maximum payload could be as much as 500 kg(not considered its own weight, which was about 240 kg), while the power rate of the driven motor was relatively low: 400 W each. The extra manipulator could be installed over or under the body. The legs themselves could also be used as a manipulator.

Another feature was that the robot foot was designed as a circle shape which was connected to the leg using a spherical joint with several springs. The rotational range of the spherical joint was about ±35° which was enough for most kinds of terrains.

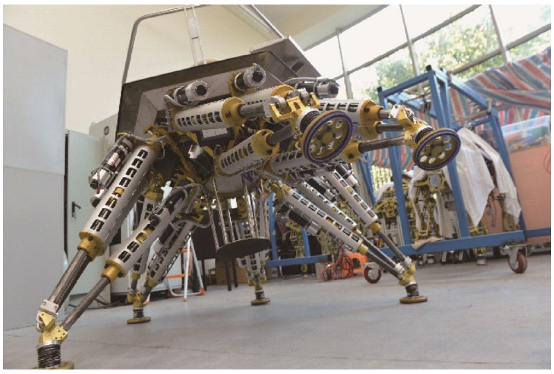


Fig. 1. Prototype of six legged rescue robot

The robot was isotropic along all six leg directions. It also could turn around the body center. Compared with non-isotropic walking robots, it is more flexible for the path planning. With 500 kg payload on its back, the walking speed of the robot was about 0.25(m/s) and the turning speed was about 10((°)/s).

The tracking gait consisted of 2 parts: the turning part and the walking part as shown in Figs. 2 and 3. When the robot was required to turn, it could rotate around its center with an arbitrary angle from 0° to 30° per step. The walking part included 3 periods: the accelerating period, the constant walking period and the decelerating period. The walking gait was static stable 3-3 gait. Each time the robot first lifted up 3 non-adjacent legs and moved them forward with a certain distance and meanwhile the robot body moved forward with half of that distance. Then the robot would move its the other 3 legs and its body in the same way. When the robot was walking, first it took 1 step to accelerate its body, then it could move with constant speed for arbitrary steps, finally it took additional 1 step to decelerate its body to stable. Fig. 3 shows the whole walking process and in the figure the robot moves forward for 5 steps: 1 accelerating, 3 constant speed and 1 decelerating step.

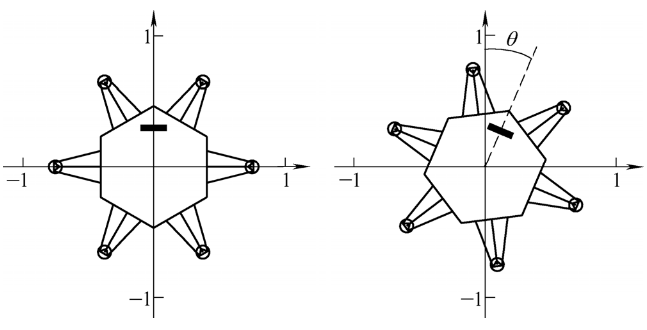


Fig. 2. Turning gait

3 Human-tracking Issue

The human tracking stategy for our robot was bio-inspired, and similar like human beings and other creatures, a three dimensional vision system was mounted on the robot. The system had a limited view range, which was a fan-shaped area whose center was located at the vision sensor's origin. In order to ensure the legged robot can track a target human successfully, two essential conditions must be satisfied. One is the human must be in the field of view(FOV) of the robot, because if the human is beyond the robot's view, the robot will never be able to get the human's position information and can't to track the target any more. The other condition is that the distance between the human and the robot should be within a limited range, which will avoid the human from waking out of the FOV of the robot easily. The valid distance between the human and the legged robot was not a specific value, but a range that was related to the step length of the robot. The human-tracking algorithm was not to track a specific location of the human, but to track an target area in which the human was located. What's more, the legged robot's walking cycle was longer than those of human beings, so the algorithm must consider the position prediction of the target to achieve better tracking performance.

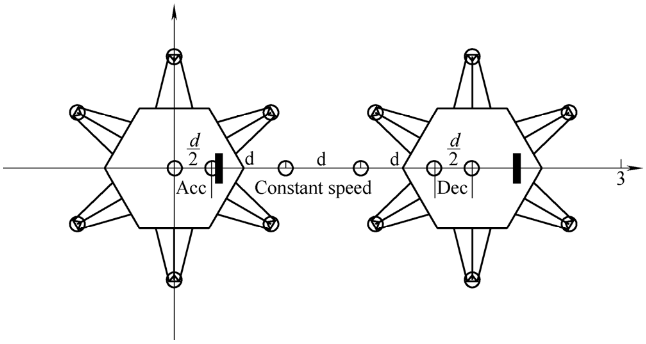


Fig. 3. Walking gait

4 Human Tracking Methodology

The two essential conditions were taken into account while developing our tracking algorithms. The main target was to maintain the target people inside the robot's FOV and keep the distance between the robot and the people with an allowable range. We developed two different tracking strategies: the distance priority strategy and the view priority strategy. The distance priority strategy preferred to satisfy distance requirement rather than view requirement, while the view priority strategy tried to satisfy view requirement first. The following 2 sub sections discuss these 2 strategies in details.

4.1 Distance priority strategy

The distance priority strategy preferentially kept the tracking distance with in a limited range as shown in Fig. 4. The legged robot had a long walking cycle, thus the human position of next step cycle should be predicted based on the human walking velocity and direction. The predicted position of the human is very important for the robot planning process, which would affect the tracking performance a lot. The key point of the distance priority strategy is that turning gait is not needed but the robot need to select walking direction. This is because the robot will always prefer the direction that would make the distance nearest to the center or FOV.

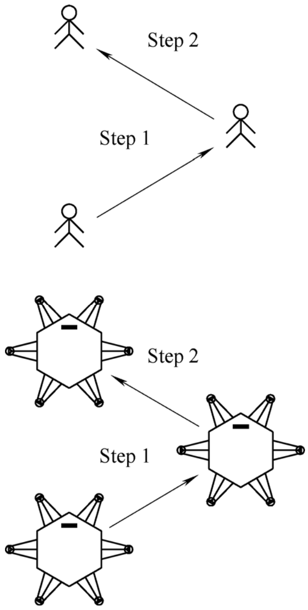


Fig. 4. Distance priority strategy

During the tracking process, the direction of the predicted position of the human was used to compute the robot's walking direction. If the planned walking direction was the same with the previous one, the robot would continue walking in the same direction by adding another constant speed period. If the planned walking direction was different, it would stop firstly and then began to walk along the new planned direction. The above planning procedure was executed in every walking cycle of the robot until the tracking task completed.

4.2 View priority strategy

The vision priority strategy preferentially tried to ensure the target human in the robot's FOV center as shown in Fig. 5. In the vision priority strategy, the robot needed to make sure the human position was located in a small target region. The key point of this strategy was that the tracking gait contained both walking and turning gait, but the robot only needed to walk forward and backward instead of along all 6 directions. Although the turning gait might take some extra time, it can locate the human in the target region to make the human in the FOV as much as possible.

In the tracking process, before planning the next step of the robot, the strategy would first judge the condition that if the human was in the target region or not. If the human was not inside the target region, the robot would then stop first (using decelerating period as mentioned before) and then turn an appropriate angle to make the human inside its target region. If the human was in the target region, the next step(moving forward or backward) will shorten the distance between the human and the center of FOV. In order to analyze the strategy quantitatively, the target region should be defined specifically.

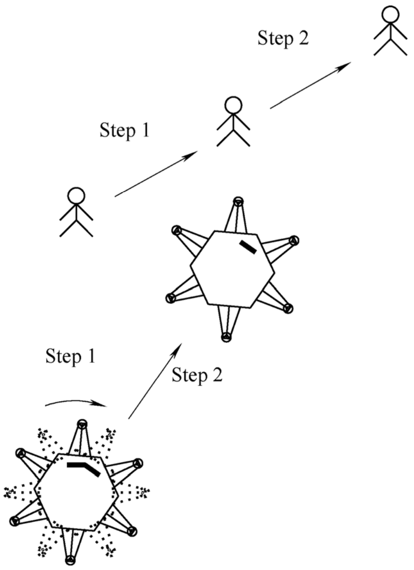


Fig. 5. View priority strategy

5 Implementation

5.1 Human tracking system

The Kinect sensor was used as the human tracking system for our robot, as shown in Fig. 6. In robotic fields, the Kinect sensor had been widely used as a vision sensor to detect both surrounding environment and human skeletons. In this paper, we got the human position by using skeleton stream from Kinect sensor, which is a fundamental function of the Kinect SDK. The skeleton stream offered 3D coordinates of the all human's 20 joints. In our system, the human spine's position was defined as the human position as shown in Fig. 7. The obtained 3D coordinates of the people were with respect to the sensor coordinate system, which can be transformed to the robot coordinate system by using the pose coordinate transformation matrix. In this paper, the tracked human was considered to be walking in a horizontal plane, thus 2D planar coordinates were enough to fully describe the relative position between the human and the robot. Therefore, we let a coordinate pair (x, y) denote the robot human position with respect to the robot.

5.2 Distance priority strategy

Fig. 8 shows two parameters r and D_s, which were defined to divide the whole FOV of the robot into two sub-regions: A and S. Sub-region S was a circular area whose radius was denoted by symbol r, and distance to the vision sensor was denoted by symbol d_s. The center of S is considered to be the ideal target position.

Fig. 9 shows the human initial position D_{H_o} with respect to vision coordinate system, which could be obtained by Kinect sensor, and the human velocity V_H could be calculated by differentiating D_{H_o} in the same coordinate frame. Then Eq. (1) could be used to calculate the vector difference D_{H_p} between the predicted and targeted positions of the human in one robot step cycle. In Eq. (1), t_R denotes the robot step cycle, and D_S denotes the target position.

$$D_{H_p} = D_{H_o} + V_H t_R - D_s . \qquad (1)$$

Fig. 6. Human tracking system

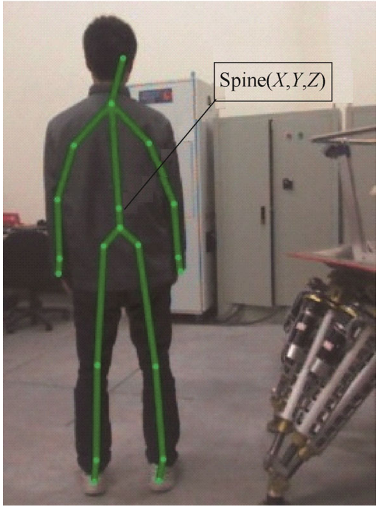


Fig. 7. Human tracking result

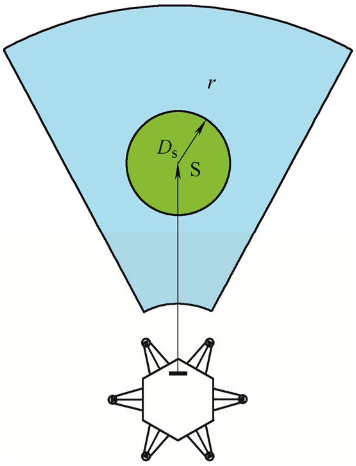


Fig. 8. View regions of distance priority strategy

The magnitude of vector D_{H_p} was denoted by symbol S_{H_p}, Since the robot only walks in a plane, thus D_{H_p} only has 2 components: $[X_{H_p}, Z_{H_p}]$. Thus S_{H_p} could be calculated by following equation:

$$S_{H_p} = \sqrt{X_{H_p}^2 + Z_{H_p}^2} . \qquad (2)$$

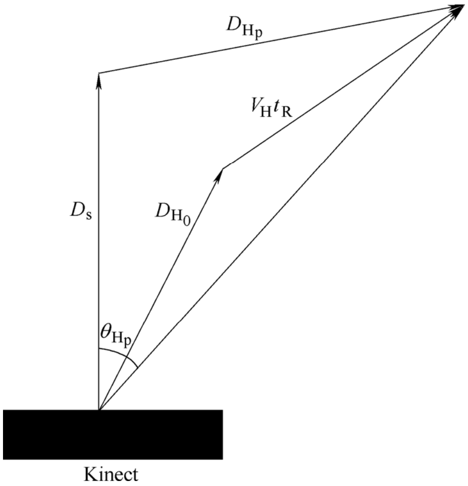


Fig. 9. Predicted position of the human based on the distance priority strategy

The angle θ_{H_p} between the predicted position of the human and the robot could be obtained from Eq. (3):

$$\theta_{H_p} = \arctan \frac{X_{H_p}}{Z_{H_p}} . \qquad (3)$$

Fig. 10 shows the walking direction of the robot which was determined by the variable θ_{H_p}. Since the robot has six walking directions, it will choose the most close direction with respect to θ_{H_p}. The above planning process was executed cycle by cycle until the target human was located in the region S. Obviously in this strategy, the distance S_{H_p} must be less than the radius r.

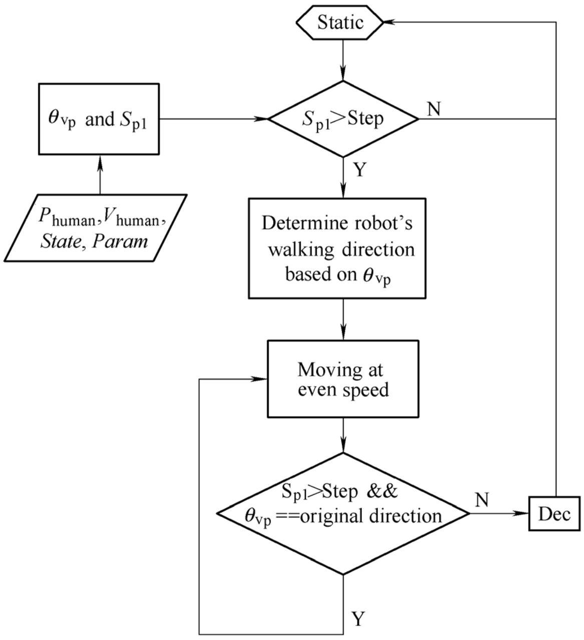


Fig. 10. Flow chart of the distance priority strategy

5.3 View priority strategy

In the view priority strategy, the predicted position $D_{\mathrm{H_p}}$ of the human in one robot step cycle could be calculated from Eq. (4), as shown in Fig. 11:

$$D_{\mathrm{H_p}} = V_{\mathrm{H}} t_{\mathrm{R}} + D_{\mathrm{H_o}}. \tag{4}$$

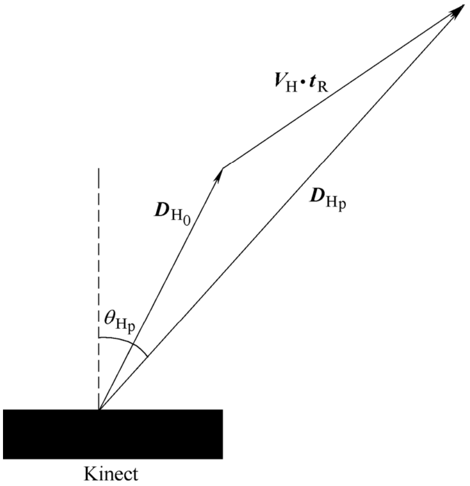


Fig. 11. Predicted position of human based on the view priority strategy

Eq. (5) can be used to compute the distance $S_{\mathrm{H_p}}$ between the human and the robot, and the angle $\theta_{\mathrm{H_p}}$ between the human and the robot can be obtained from Eq. (6):

$$S_{\mathrm{H_p}} = \sqrt{X_{\mathrm{H_p}}^2 + Z_{\mathrm{H_p}}^2}, \tag{5}$$

$$\theta_{\mathrm{H_p}} = \arctan\frac{X_{\mathrm{H_p}}}{Z_{\mathrm{H_p}}}, \tag{6}$$

where $X_{\mathrm{H_p}}$ and $Z_{\mathrm{H_p}}$ are the coordinate components of the predicted position of the human with respect to the ground.

Fig. 12 shows, three parameters r_1, r_2 and θ_0, which were used to divide the detection area into five sub-regions, A, B, C, D, S. Sub-region S is the target region, when the human was in this region, it is considered that ideal tracking result has been achieved and then the robot will stop. If the human was in other sub-regions, the robot will perform corresponding movements to track the human.

Fig. 13 shows, by comparing $\theta_{\mathrm{H_p}}$ and θ_0, we could determine whether the human was in the region ASB (consisting of sub-regions A, S and B). If the human was not in this region, the robot needs to turn $\theta_{\mathrm{H_p}}$ to locate the human inside this region. For the robot has a maximum turning angle $\theta_{\max}$, thus if condition $\theta_{\mathrm{H_p}} > \theta_{\max}$ was satisfied, the robot needs to turn more than one time. If the human was inside the region ASB, $S_{\mathrm{H_p}}$ was used to determine whether the human is in the target region S. If the human was in the region A or B, the robot will move forward or backward to locate the human to the region S. The above procedure was executed in every step cycle of the robot until the human is in the target region S.

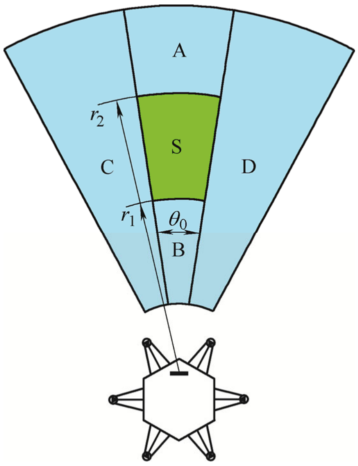


Fig. 12. View regions of the view priority strategy

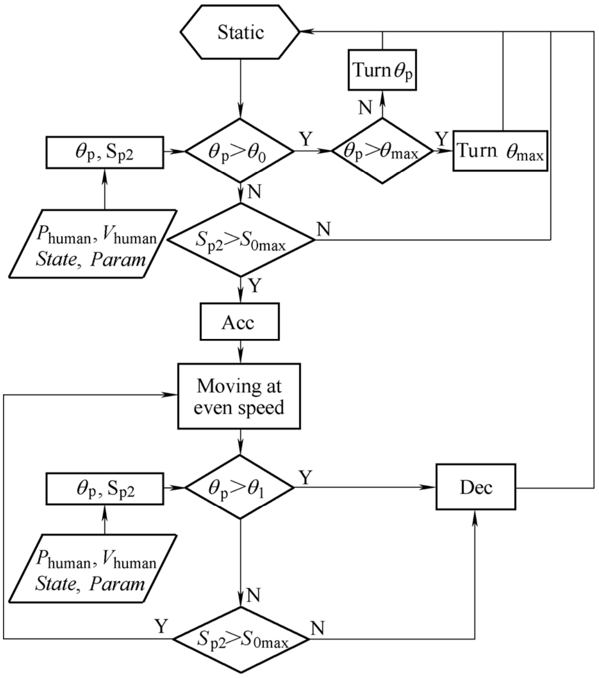


Fig. 13. Flow chart of the view priority strategy

6 Strategy Evaluation and Optimization

6.1 Strategy evaluation

Many important factors can affect the tracking performance and in this section, the tracking capability is evaluated and optimized on these factors. First and foremost, the human velocity should not exceed the robot speed, or the distance between the human and the robot will be forever which leads to failure of tracking process. On the other hand, when the target human walked outside the detection area of the vision sensor, it is considered that the robot has lost its target and cannot track the target anymore. These two factors are caused by the robot and the vision system themselves, and has nothing to do with the tracking algorithms. The tracking algorithms also affect the tracking performance a lot, and this paper mainly focused on effect of different algorithms. The evaluation indexes of the tracking strategy need to be established first, which are used to compare the above two strategies. Also the algorithm parameters can be optimized by these indexes.

Through above analysis, it was stipulated that the robot cannot complete the tracking task when the target human walked outside the detection area. The detection area of the Kinect sensor is a fan-shaped area which is distributed symmetrically along the sensor coordinate system, its central angle is 57°, small radius is 0.8 m and large radius is 4.2 m. The polar diagram was used to specifically describe the tracking capacity of above two strategies, the angle of the polar diagram θ denotes the direction towards which human walks. The radius of the polar diagram denotes the maximum speed of the human $v_{\max}$ which the robot can track. The maximum speed $v_{\max}$ is used to describe the robot tracking capability in the corresponding walking direction. When the human walks from 0° to 360°, the robot tracking capacities of above two strategies are shown in Fig. 14 and Fig. 15.

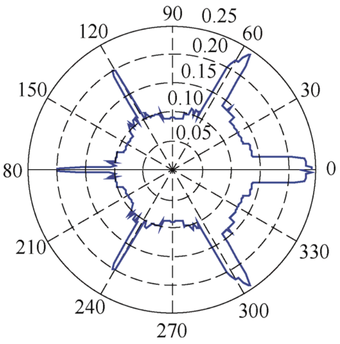


Fig. 14. Tracking capability distribution of the distance priority strategy

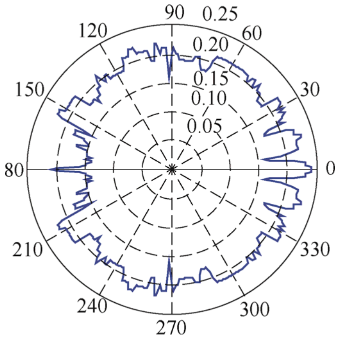


Fig. 15. Tracking capability distribution of the view priority strategy

It is simple to find out that the tracking capability differs in different directions, so relevant indexes need to be defined to evaluate the strategy quantitatively. The average tracking capability(ATC) over all directions should be evaluated, thus following index was defined, which is the integration of $v_{\max}$ as follows:

$$\zeta=\frac{\int_{0}^{2\pi} v_{\max}(\theta)\mathrm{d}\theta}{2\pi}. \tag{7}$$

Apart from the average tracking capability, the minimum tracking capacity(MTC) is also very important. If the speed of the human was slower than the robot minimum tracking capability, the robot could always track the human no matter how the human walks. The minimum tracking capacity could be obtained from Eq. (8):

$$\varsigma=\min\left\{v_{\max}(\theta)\right\}. \tag{8}$$

The tracking capabilities of above two strategies could be obtained from Eqs. (7) and (8). The results can be found in Table 1.

Table 1. Tracking capability index values

Index	ATC $\zeta/(\mathrm{m\cdot s^{-1}})$	MTC $\varsigma/(\mathrm{m\cdot s^{-1}})$
View priority strategy	0.196 6	0.14
Distance priority strategy	0.129 9	0.09

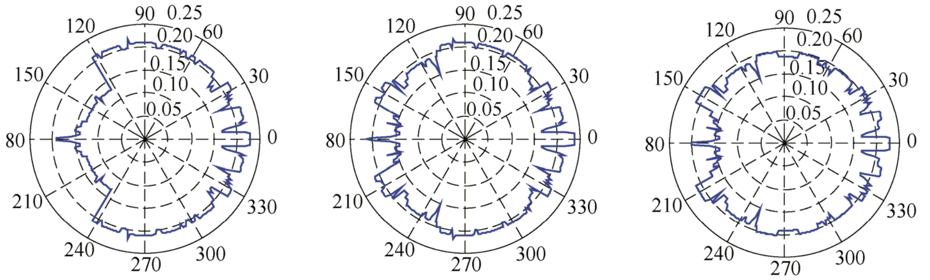
From Table 1, it is obvious that both average and minimum tracking capabilities of the view priority strategy are better than the distance priority strategy. So the view priority strategy was selected as the core algorithm to solve the human tracking problem of the legged robot.

6.2 Strategy optimization

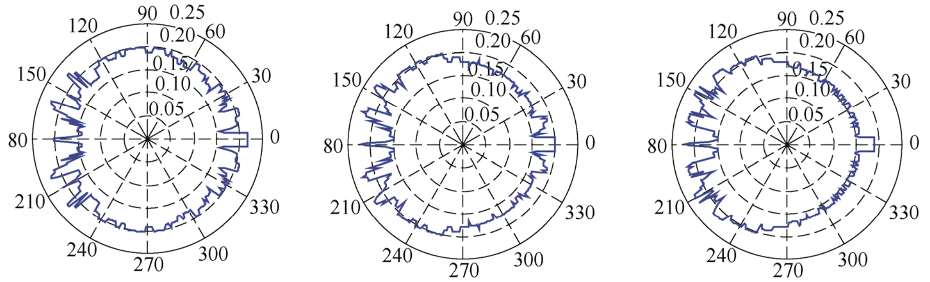
The algorithm parameters of the view priority strategy also would affect the tracking effect, thus in this section, we specifically focused on the optimization based on these parameters in order to achieve better tracking performance. The view priority strategy has three primary parameters: r_1, r_2, and θ_0. With these parameters, the detection area was devided into 5 sub-regions: A, B, C, D and S. S is the target region, when the human was located in it, the robot would not move, and when the human walked outside S, the robot would perform appropriate movements to track the human. Considering the step length of the robot is 0.3 m, we stipulated $r_2-r_1=0.3$, in this way the robot can walk one step to locate the human into S if the human had walked outside the region S just recently. In the following parts, we would optimize r_1 first， with setting θ_0 as a constant value of 13°. In the next paragraph, θ_0 would be optimized with r_1 at its best value. We assumed the initial position of the human was at the center of the target region, and then repeatedly set r_1 value from 0.8 m to 3.9 m to find the maximum ζ and ς. Some polar diagrams results are shown as in Fig. 16. It turned out that the robot has a very poor backward tracking capability when r_1 is very small, but the robot also has a poor forward tracking capability when r_1 is too big.

Fig. 17 shows the tracking capability indexes ζ and ς distribution over r_1. ζ differs greatly, while ς do not differ much except when r_1 was relatively small. The strategy can achieve best tracking performance when r_1=1.45m, $\zeta_{\max}=0.198\,9$ and $\varsigma_{\max}=0.14$.

After determining the optimal value of r_1(1.45 m), the value of θ_0 needed to be optimized by repeatedly setting θ_0 from 1° to 27° to find the optimal ζ and ς. The tracking capability distributions of these indexes are shown as in Fig. 18. The tracking capabilities are both poor when θ_0 is too small or too big.

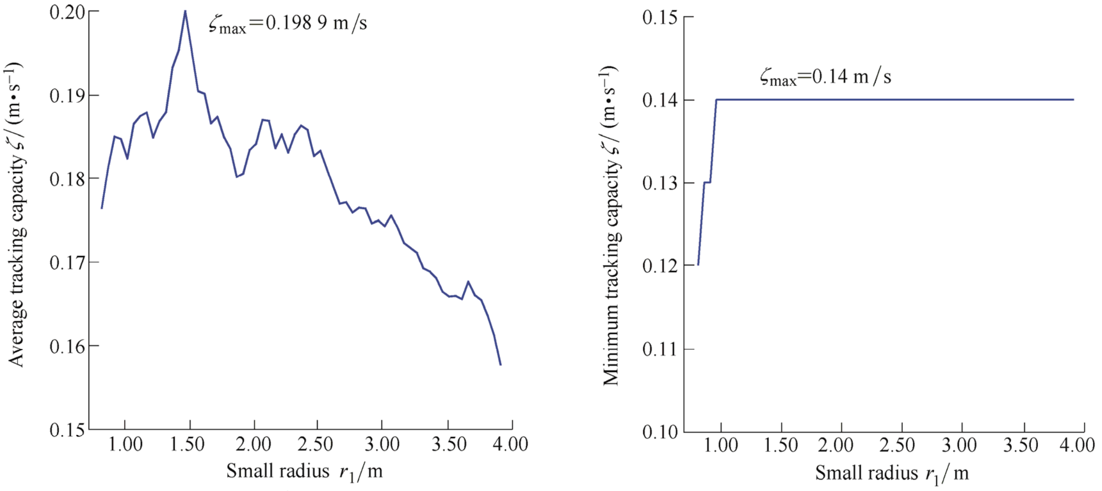


(a) r_1=0.8 m　(b) r_1=1.4 m　(c) r_1=2.0 m



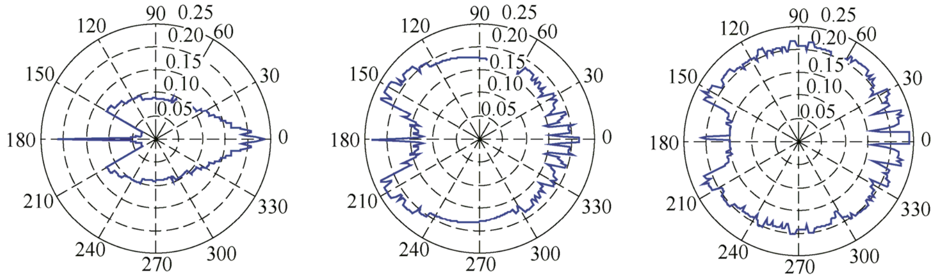
(d) r_1=2.6 m　(e) r_1=3.2 m　(f) r_1=3.8 m

Fig. 16.　Robot tracking capacity over r_1

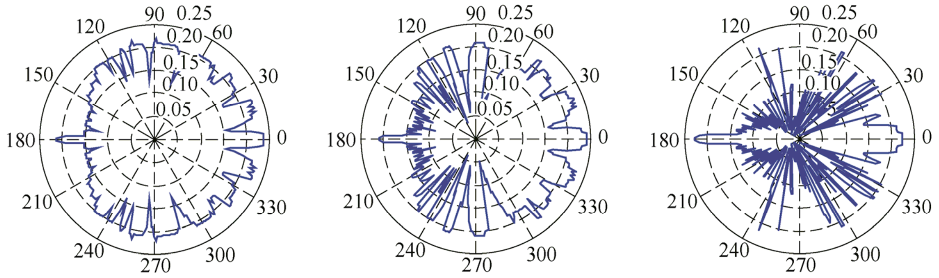


(a) ζ over r_1　(b) ζ over r_1

Fig. 17.　Robot tracking capability indexes over r_1



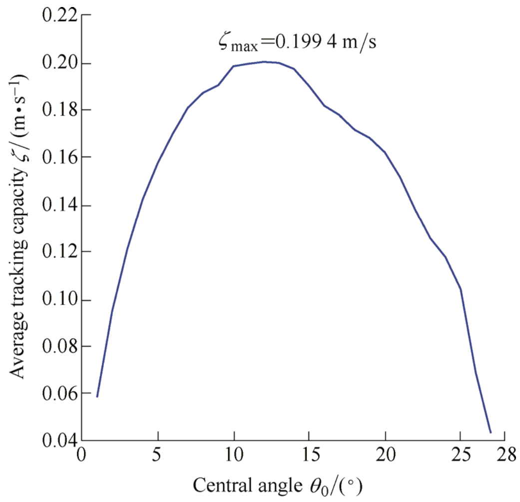
(a) θ_0=1°　(b) θ_0=6°　(c) θ_0=11°



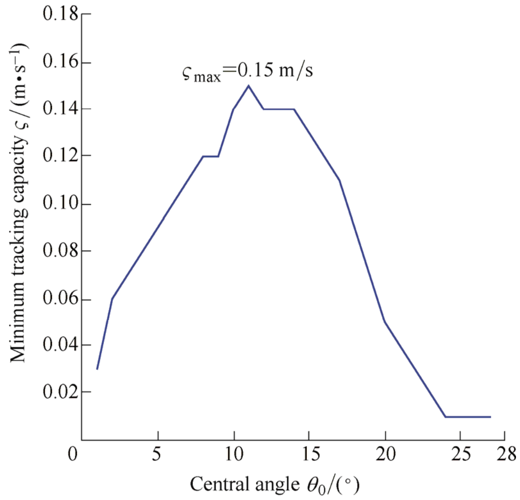
(d) θ_0=16°　(e) θ_0=21°　(f) θ_0=26°

Fig. 18.　Robot tracking capacity over θ_0

The tracking capability indexes ζ and ς over θ_0 are as Fig. 19 shows. ζ and ς both reached their maximum values, which are 0.199 4 and 0.15, and at this time θ_0=11°.



(a) ζ over θ_0



(b) ς over θ_0

Fig. 19. Robot tracking capability indexes over θ_0

Thus it's needed to set r_1=1.45 m and θ_0=11°, and at this time the robot would have best tracking performances, which can be described using evaluation indexes: $\zeta_{\max}$=0.199 4 and $\varsigma_{\max}$ =0.15.

7 Simulations

We obtained the optimum algorithm parameters of the view priority strategy in last section with r_1 =1.45 m and θ_0 =11° through above two optimization processes. Based on the results, we have built the simulation model using MATLAB, which contains the core of the view priority strategy. Several typical paths tracking processes were simulated and the results are shown in Figs. 20–24.

Fig. 20 shows the simulation result of the circle path tracking, the red line denotes the walking path of the target human which is a circle, and the blue line represents the tracking path of the robot. The robot can track after the human, and its tracking path was also a circle whose radius was smaller than the walking path of the human.

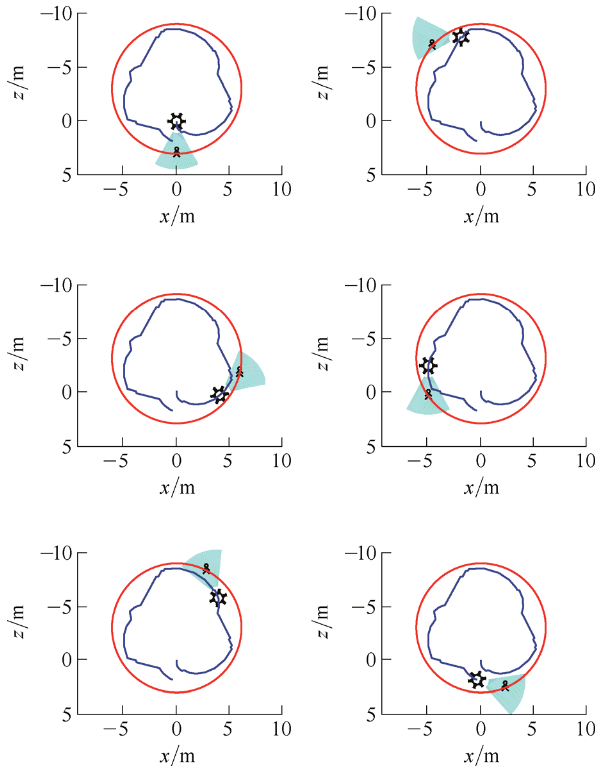


Fig. 20. Circle path tracking simulation

Fig. 21 shows the simulation result of the straight line path tracking. The human walks along a straight line, the robot gradually turned towards the human before it walked forward. The tracking path of the robot showed that the predicted position of the human had functioned to achieve well tracking performance of the strategy.

Fig. 22 shows the simulation result of the screw path tracking. At the start, the robot moves backward, for the predicted position of the human is too close. After that, the robot tracked the human with a similar screw path successfully.

Fig. 23 shows the simulation result of the square path tracking process. Although the robot doesn't walk with a standard square path, it can locate the human in the target region and track the human successfully. Fig. 24 shows the simulation result of the sine path tracking, the robots tracks the human successfully with a similar sine path.

Above simulation results show that our method can solve the human-tracking problem for legged robots.

8 Conclusions

(1) The difference of legged and wheeled robots is brought out and based on the analysis, 2 novel strategies are given: view and distance priority strategies. These 2 stategies use different kinds of robot walking gaits, and focuse on different aspect of targets.

(2) The tracking target position predicting method is proposed. Then the robot view divisions and the basic control schemes are formulated.

(3) The evaluation indexes of these strategies are proposed which are used to describe the robot maximum and average tracking capabilities of a certain target curve. Based on these indexes, the strategies are optimized and the result shows view priority strategy is generally better.

(4) Many simulations of these strategies have been done and it turned out that the robot can successfully track the human with different type of moving curves like strait line, circular, square, sine curves and so on.

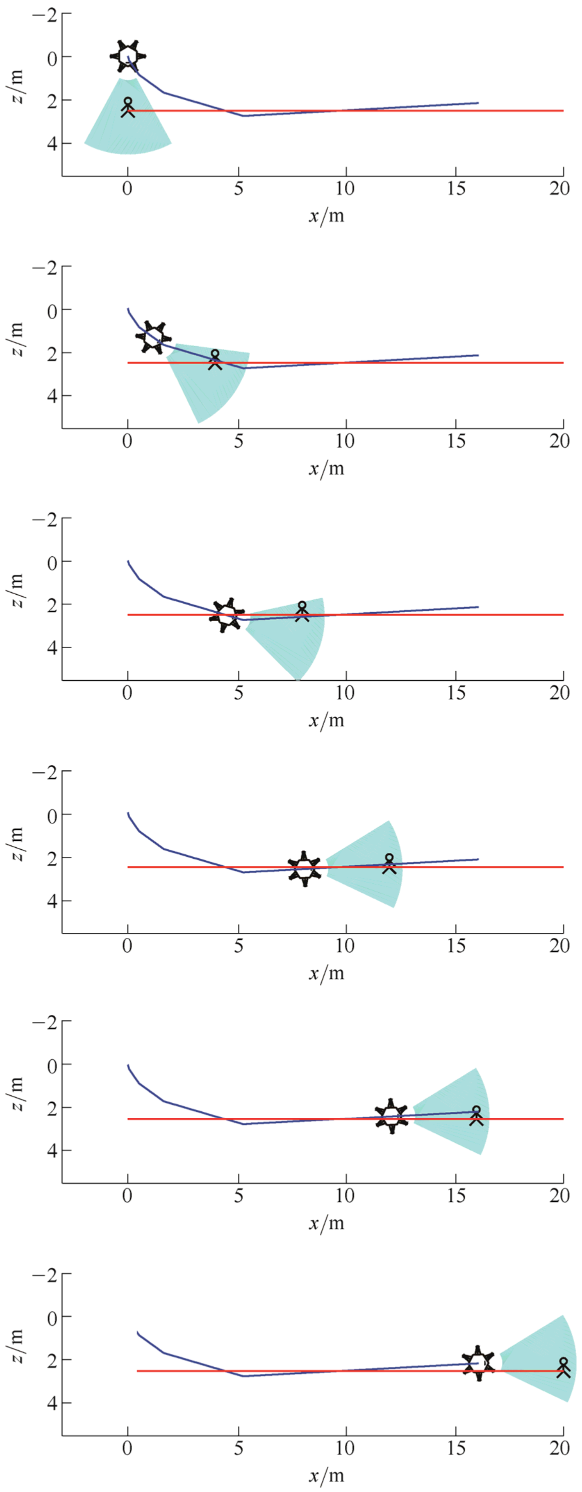


Fig. 21. Straight line path tracking simulation

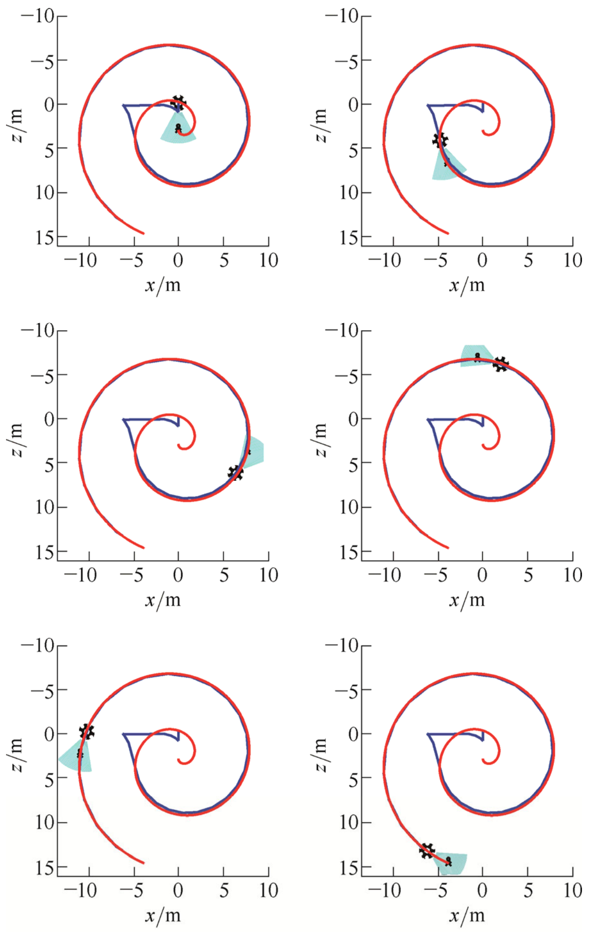


Fig. 22. Screw path tracking simulation

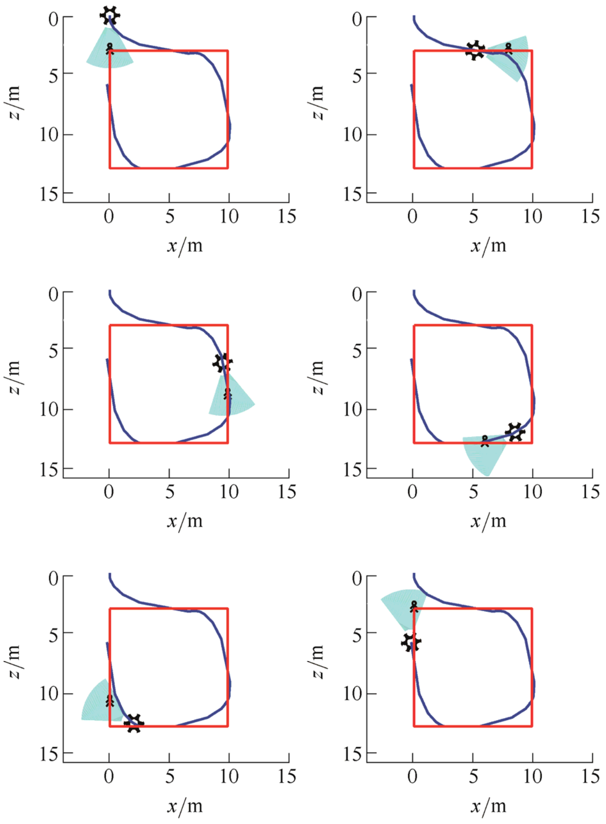


Fig. 23. Square path tracking simulation

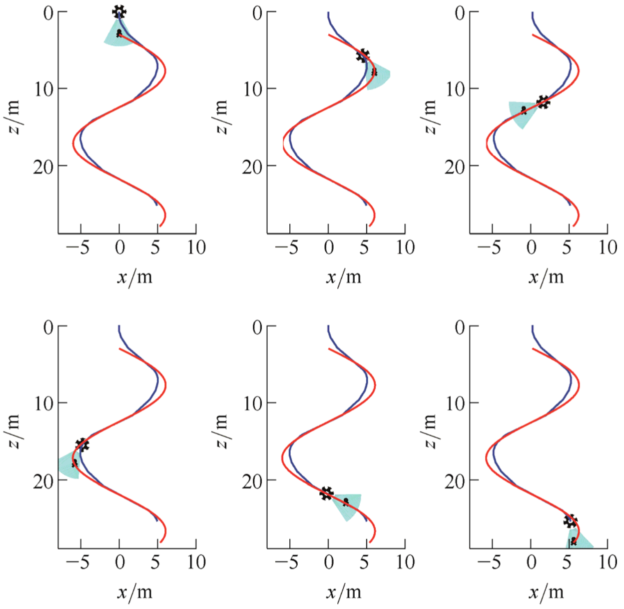


Fig. 24. Sine path tracking simulation

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