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Design A Novel of Path Planning Method for The Vascular Interventional Surgery Robot based on DWA Model

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***Abstract* –In this paper,The surgical navigation system solves the problem of fast and safe delivery of the catheter and guide wire to the target point. A new concept was proposed to help doctors provide better navigation visual feedback, so that doctors can perform surgical operations more effectively and safely. The surgical navigation system proposed in this article is designed based on the DWA(Dynamic window algorithm) model. First of all, we must first take the three-dimensional coordinates and the corresponding image coordinates to obtain the accurate location of the image coordinate collection. We use its own impixelinfo function in matlab to calculate the pixel coordinates of the marker point. We put the glass vessel in the experimental position, use matlab to collect the image of the glass vessel wall coordinates and set up the target point coordinates, then after collecting the coordinates of possible obstacles, the dynamic window algorithm will be implemented for obstacle avoidance planning and Design an evaluation function based on the planned possible path at the next moment, distinguish the pros and cons of the path. Finally, The experimental analysis and verification of surgical operations compared with or without navigation system was demonstrated.**

Index Terms - DWA model, Surgical navigation system, Vascular interventional surgery

I. INTRODUCTION

In cardio-cerebrovascular interventions, there may be different difficulties for cerebrovascular, renal artery and heart, such as vascular bifurcation, which is more difficult and time-consuming; establishment of pathways, thickness of blood vessels, these factors will lead to Some places are more difficult to enter. Therefore, it is especially important for the establishment of the passage. During the operation, there may be situations where some aneurysms cannot be delivered, such as acute-angle aneurysms or curved bends.

Therefore, it is a very important task to study how to assist the doctor to accurately deliver the catheter guidewire to the lesion location. In actual surgery, DSA(Digital subtraction angiography) imaging technology is often used to provide doctors with visual feedback. However, for DSA imaging, there is no way to display the path of the vascular access all the time, and the vascular condition will only be displayed when the contrast agent is injected. The purpose of doctors using DSA equipment is to take a DSA photo when the guide wire or catheter encounters resistance. DSA equipment will be used many times during the subsequent treatment. In addition, in this kind of interventional surgery, the doctor's rich clinical experience is especially important to the safety of the operation. The doctor manipulates the catheter guide wire to reach a certain position, uses the DSA imaging device to image the current unknown environment, and provides the doctor's judgment conditions for the doctor's next action through the imaging. The doctor performs the next operation on the image formed by DSA contrast, and the force feedback is used to judge the operation technique and the moving path during the operation.

For novice doctors, the lack of clinical experience and the lack of judgment on the operation , in terms of visual feedback, because the environment of the blood vessel wall is not dynamically imaged by DSA imaging equipment, when reaching a complex environment, the only way to create a shadow according to the complex blood vessel environment of the current situation, the subsequent operation doctor still judges by force feedback. This is a major challenge for novice doctors, and it cannot guarantee the safety of operations performed by novice doctors. Therefore, this paper proposes a path planning algorithm based on DWA. Provide better visual feedback for the doctor's operation to improve the safety of the operation and reduce the doctor's radiation.

The following figure shows the DSA imaging when the contrast agent is not created. Because the contrast agent is not created, the imaging can only see the catheter and guide wire.

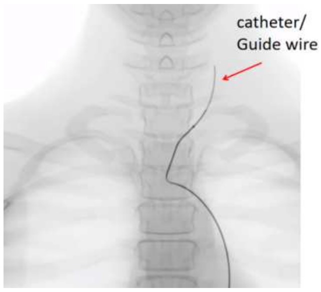


Fig.1 Imaging without contrast agent

The following is the image of the vascular access when the contrast agent is applied.

Fig.2 The image of the vascular access when the contrast agent is applied

Therefore, when there is no angiography, the doctor can only use tactile feedback to perceive the next surgical operation. Frequent radiography can cause great radiation damage to doctors. Therefore, such a surgical navigation system is needed to provide doctors with visual feedback[3].

The proposed method of establishing DWA combines image processing technology to integrate the traditional path planning method into the surgical navigation of the vascular interventional surgery robot.

II. OVERVIEW OF THE PLATFORM

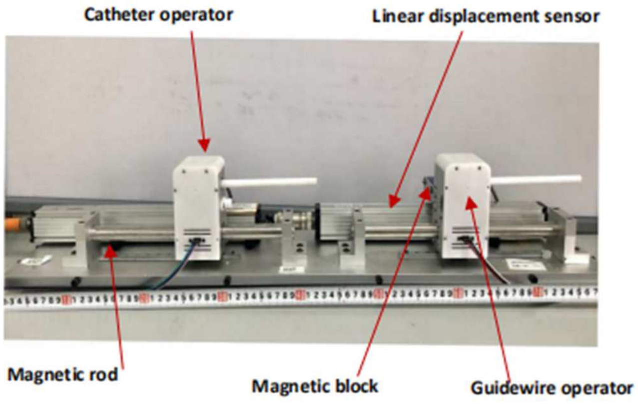
The vascular interventional surgical robot system currently used in the laboratory belongs to the master-slave operating system.The master terminal includes a master operator, a master controller and a display screen; the slave terminal includes a slave operator, a slave controller and an IP camera [4].

The working process is: the operator use manipulator and the main manipulator can collect the operator's motion information. The collected information is processed by the master controller, and then the information is transmitted to the slave controller through CAN communication. The slave controls. In the meanwhile the slave manipulator according to the received information, and then the slave manipulator can control the catheter and the guide wire individually.. [5-7] .

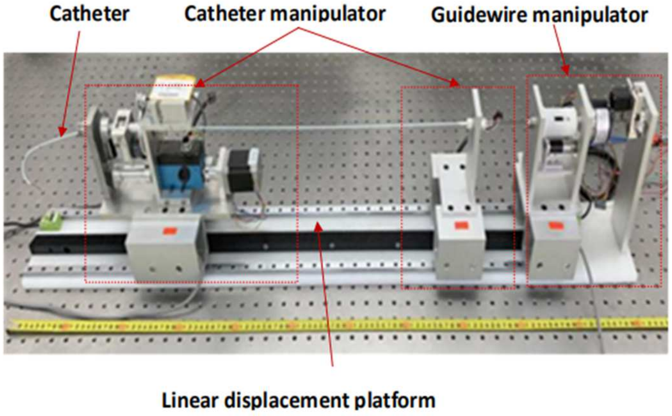
The Fig.3 shows the whole robots system.In Fig.3, (a) is the master manipulator, and (b) is the slave manipulator.

The path planning method adopted in this paper is the dynamic window obstacle avoidance method. The so-called dynamic window method is to sample multiple sets of data and speed data in the current speed space, and simulate the direction and trajectory that the catheter should go next under these speeds. At the current speed, multiple trajectories that should be taken in the next step can be obtained, and these trajectories can be evaluated. And the next trajectory will be reflected in the interface, forming visual feedback[8].

The design block diagram of this algorithm is shown in Fig.4.



(a). The master manipulator



(b). The slave manipulator

Fig.3 Manipulators of vascular intervention surgery robot

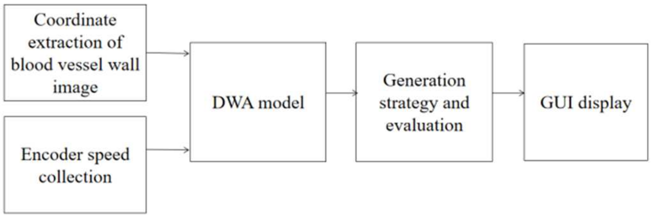


Fig.4 Working flow chart of path planning system

III. PATH PLANNING SYSTEM

The full name of DWA model is dynamic window approach. The process of so-called DWA medel is mainly to obtain the motion trajectory of the robot by simulation, evaluate the trajectory and select the optimal trajectory. Here, We uses a medical catheter as a robot[9].Because in the our robotic system, the movement from the end is to push the catheter to move, and the catheter needs to move in the blood vessel to reach the location of the lesion. The dynamic window expresses the limited number of simulated motion trajectories, mainly because the robot can only reach a certain speed in a short control period[10]. The movement of our catheter is also divided into axial movement and radial movement. Kinematics models of medical catheters have also been established before. The movement speed of the catheter is the movement speed of the slave manipulator, so we obtain the axial linear velocity and radial angular velocity of the catheter movement by obtaining the speed of the axial movement motor driven by the slave manipulator and the angular velocity of the radial movement motor[11].

In the DWA model, to simulate the trajectory of the robot. It assumes that the judgement action of the cahter is a segment of an curve or a line (when the rotation speed is 0), a pair $\left(v_t, w_t\right)$ represents an arc trajectory. The specific derivation is as follows:

First, suppose that the robot is not omni-directional, that is, it cannot move longitudinally, but can only move forward and rotate $\left(v_t, w_t\right)$. The robot here is the catheter guide wire controlled by our slave controller, because the movement of the catheter guide wire is controlled by the slave controller, So the axial movement speed of the catheter guide wire is the axial movement speed of the slave end controller[12]. When calculating the robot trajectory, first consider two adjacent moments. Because the robot has a short movement distance in the adjacent moments (usually measured by the code disc sampling period in ms), the movement trajectory between two adjacent points can be regarded as a straight line, namely Moving $v_t * \Delta t$ along the x-axis of the robot coordinate system, just project the distance Δx and Δy on the x-axis and y-axis of the world coordinate system to get the displacement sum of the robot at time t+1 relative to the coordinate movement of the robot in the world coordinate system at time t[13].

$$\Delta x = v\Delta t\cos\left(\theta_t\right) \tag{1}$$

$$\Delta y = v\Delta t\sin\left(\theta_t\right) \tag{2}$$

By analogy, if you want to calculate the trajectory over a period of time, you only need to add the cumulative sum of the displacement increments during this period of time.

$$x = x + v\Delta t\cos\left(\theta_t\right) \tag{3}$$

$$y = y + v\Delta t\sin\left(\theta_t\right) \tag{4}$$

$$\theta_t = \theta_t + w\Delta t \tag{5}$$

The robot's trajectory motion model is available, and the trajectory can be calculated based on the speed. Therefore, we only need to sample very fast, calculate the trajectory, and then evaluate whether the trajectory is good or not. How speed is sampled is the second core: In the two different dimensional speed, there are many different sets of speeds. However,it has some conditions: the mobile robot is limited by its own maximum speed and minimum speed:

$$V_m = \left\{v \in \left[v_{\min}, v_{\max}\right], w \in \left[w_{\min}, w_{\max}\right]\right\} \tag{6}$$

Mobile robots are affected by motor performance:

Due to the limited motor torque and the maximum acceleration and deceleration limit, there is a dynamic window in the period sim_period of the forward simulation of the trajectory of the mobile robot[14].The speed in this window is the speed that the robot can actually reach:

$$V_d = \left\{(v,\omega) \middle| \begin{array}{l} v \in \left[v_c - \dot{v}_b\Delta t, v_c + \dot{v}_a\Delta t\right] \wedge \\ \omega \in \left[\omega_c - \dot{\omega}_b\Delta t, \omega_c + \dot{\omega}_a\Delta t\right] \end{array}\right\} \tag{7}$$

Among them, v_c and w_c is the current speed of the robot, and the other signs correspond to the maximum acceleration and maximum deceleration.

The following guidelines must be followed:

$$V_a = \left\{(v,\omega) \middle| \, v \le \sqrt{2 \cdot \mathrm{dist}(v,\omega) \cdot \dot{v}_b} \wedge \omega \le \sqrt{2 \cdot \mathrm{dist}(v,\omega) \cdot \dot{\omega}_b}\right\} \tag{8}$$

Where dist(v,w) is the speed (v, w) corresponding to the closest distance to the obstacle on the trajectory.

This condition is not available at the beginning of sampling. We need to simulate the trajectory of the robot, find the position of the obstacle, calculate the distance between the robot and the obstacle, and then see if the pair of speeds currently sampled can stop before it hits the obstacle. If it can stop more, then This pair of speed is acceptable admissible. If you can't stop, the pair of speeds must be discarded[15].

At the same time, note: In order to simplify the calculation of the trajectory corresponding to each group of speed, the algorithm assumes that the robot's speed will not change during the period of time (sim_period) that the robot is on the trajectory, until the next time a new speed command is sampled. In the sampled speed group, several sets of trajectories are feasible, so the evaluation function is used to evaluate each trajectory.[16] The evaluation function used is as follows:

$$G(v,\omega) = \sigma(\alpha \cdot \text{ head } (v,\omega) + \beta \cdot \mathrm{dist}(v,\omega) + \gamma \cdot \mathrm{v}(v,\omega)) \tag{9}$$

The azimuth evaluation function head(v,w) is used to evaluate the angle difference between the heading and the target when the robot reaches the end of the simulated trajectory at the current set sampling speed. The gap $\mathrm{dist}(v, w)$ represents the distance between the robot and the nearest obstacle on the current trajectory. If there are no obstacles on this trajectory, set it to a constant. Velocity v(v,w) is used to evaluate the velocity of the current trajectory.

Finally, normalize each item for the purpose of smoothing. The meaning of the evaluation function is to find an optimal path so that the robot can avoid obstacles and reach the target point at the fastest speed during the local navigation process. Through the above several scoring mechanisms, select the optimal set of speed samples, pass them to move_base, and publish the corresponding local plan. If move_base receives the available speed, it will be released to the chassis, otherwise it will release 0 speed, and if the time to find the optimal speed exceeds the limit, the obstacle cleaning mode will be executed, and state_ will become CLEARING.

In the DWA model, this paper sets a scan radius function, which will set the response radius according to the distance between the tip of the catheter and the vessel wall. As shown in Fig.5, the green area belongs to the safe area, and the red area belongs to the dangerous area. The purpose of this function is to set It is able to make a turning path indication response immediately after the tip of the catheter enters the red zone.

Fig.5 Safe range chart

The DWA model design of vascular access path planning is shown in Fig.6.

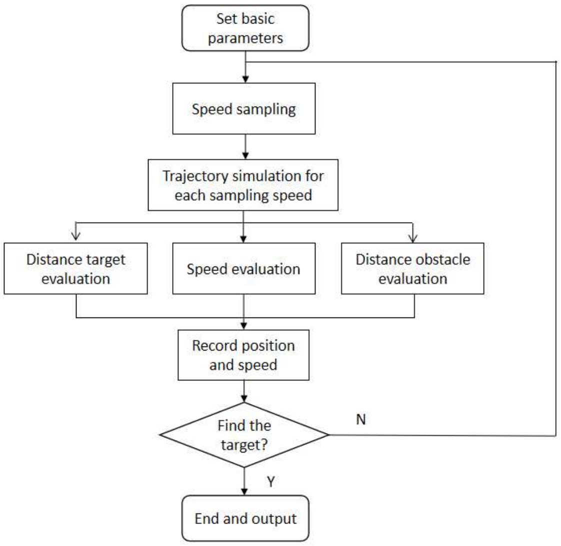


Fig.6 The flow chart of algorithm design flow chart

IV. EXPERIMENTS AND RESULTS

A. *Experimental set up*

Just like the glass vessel shown in Fig.7, the first step in the experiment needs to extract the points that have large curves in the glass vessel and need to be bypassed. The method used in this part is the calibration of camera pixels and pictures to extract the coordinates of obstacle points. In the figure, the starting point and target point of the catheter guide wire are marked to complete the conversion to the world coordinate system established by the DWA model.

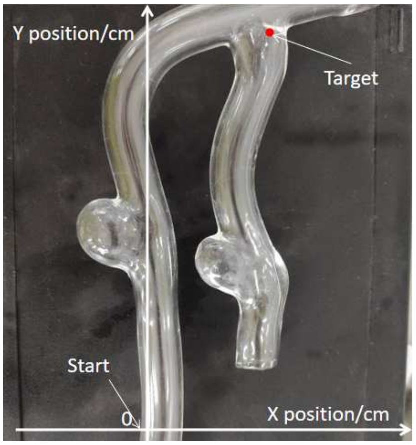


Fig.7 Glass vessel environment map

In the experimental environment, we divide the wall collision problem into two areas, the simple area and the difficult area, as shown in Fig.8 and Fig. 9. The ① in Fig. 8 represents the simple area, which generally only has axial motion. But in the blood vessel may be affected by blood flow resistance and other aspects, it may touch the blood vessel wall, so it may need to do a rotating action. In this experimental study, we specially let the catheter tip touch the blood vessel wall to test result . The response time of the DWA model when it hits a wall, and combined with actual operations, tests the time it takes to leave the dangerous area. Similarly, ② in Fig. 9 represents the difficult area, because the catheter needs to go through a big bend at this time. This is a difficult point for surgical operations. How to reach the target point without damaging the blood vessel wall is a major challenge for novices. We also did the same set of experiments in area ②.

In order to deal with the different degrees of curvature of the blood vessel wall, as well as to ensure the safety of the blood vessel wall, and to demonstrate the feasibility of the algorithm, this paper conducted experiments on path planning and obstacle avoidance prompts under two curvatures.

In addition, a time-dimension control experiment was carried out on blood vessels with two curvatures. The two sets of experiments showed that under the guidance of the navigation system, the operation time was greatly shortened, which ensured that the doctor' s fatigue during the operation was reduced and increased. Improve the safety of surgery.

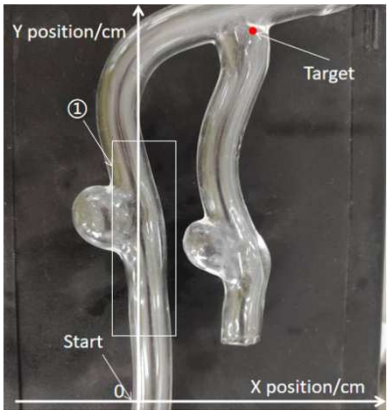


Fig.8 Glass vessel environment map（Simple area）

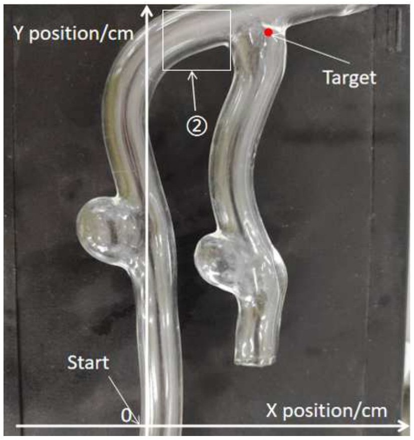


Fig.9 Glass vessel environment map（Difficult area）

B. *Experimental results*

The output results of the path planning evaluation function are shown in Table I. The indicators include heading score, speed score, obstacle distance score, and target distance score. The experiment process simulates the treatment of the catheter guide wire suddenly encountering obstacles during the advancing process, and the treatment of going straight.

TABLE I

EVALUATION OUTPUT TABLE

Goal cost	Destination cost	Speed cost	Final cost
0.4	0.8	0.5	1.864
0.4	0.8	0.5	1.864
0.4	0.8	0.5	1.864
0.4	0.8	0.5	1.864
0.4	0.8	0.5	1.864
0.3	0.8	0.8	1.864
0.3	0.8	0.8	1.864
0.3	0.8	0.8	1.864
0.3	0.8	0.8	1.864
0.3	0.8	0.8	1.864
0.3	0.8	0.8	1.864

In this paper, the path to avoid obstacles is divided into two links, simple path and difficult path, and 10 sets of experiments are done respectively. Fig.11 shows the path planning response time of simple links. The average response time under the guidance of the DWA model is 0.242 seconds, and the response time without the guidance of the DWA model is 0.371 seconds.

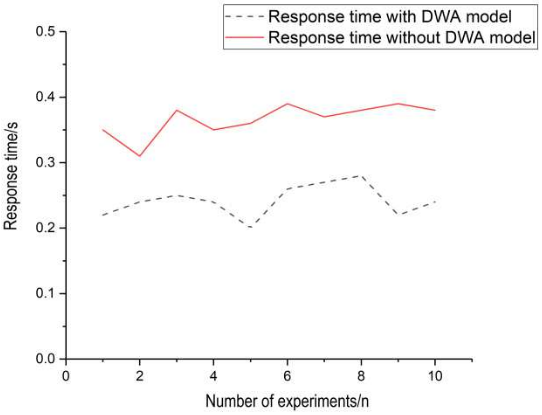


Fig.10 Curve ① response time comparison chart

Fig.10 shows the path planning response time of the difficult link. The average response time under the guidance of the DWA model is 0.556 seconds, and the response time without the guidance of the DWA model is 0.744 seconds.

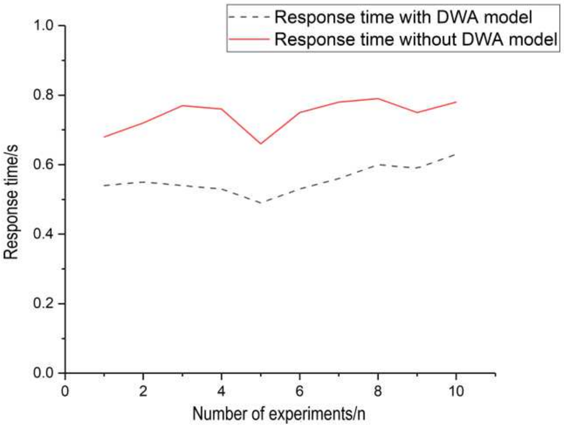


Fig.11 Curve ② response time comparison chart

V. CONCLUSIONS AND FUTURE WORK

This article proposed a method of path planning for the establishment of vascular access in vascular interventional surgery, specifically to deal with the complex vascular environment. Since experienced doctors can establish vascular access through blind puncture during the operation, and novice doctors are not good at this blind puncture technique, it will pose a great risk to the operation and greatly reduce the safety and effectiveness of the operation. Therefore, this paper proposed a local path planning based on the DWA model to provided doctors with better visual feedback, and proved the effectiveness of the algorithm through a wall-hit experiment. In the future work, we will study path planning under the cooperation of multi-catheter guide wires, which is more in line with the needs of surgical operations, and do corresponding in vivo experiments.

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