Planning Path Strategy and Simulation of Infusion Service Robot Based on Ant Colony Algorithm

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Abstract. The infusion service robot was taken as the research object, and the algorithm of path planning for infusion service robot was simulated by the sensor network system in this experiment. The ant colony algorithm was selected based on the sensor network node optimization deployment of the mobile service robot. Based on sensor network for hospital environmental information collection, combined with sensor network node information and RSSI algorithm based on MATLAB to achieve positioning, and then complete the simulation study of infusion service robot navigation. The ant colony algorithm was verified as the basic method and feasibility of applying the path strategy of the robot platform. During the testing process, some conditions and algorithms were simplified to avoid the complexity of the problem.

1. Introduction

The goal of “focusing on the development of the top ten iconic products of surgical robots and intelligent nursing robots in the fields of helping the elderly, helping the disabled, family services, and medical rehabilitation” was proposed by the Robot Industry Development Plan (2016-2020), which made the infusion service robots are valued and quickly promoted[1,2]. At present, the path planning for developing mainstream mobile service robots on the market to achieve positioning and navigation through GPS, ultrasonic or laser positioning. The advantage of GPS is that the robot hardware is simple, but it is limited by the large distance error of the civilian GPS positioning, the GPS technology has not been corrected, resulting in low accuracy, which can't meet the normal work of infusion service robots in hospitals and other places. Therefore, it is necessary to pay a high cost to realize the high-precision positioning and navigation function of the GPS technology[3,4]. Ultrasonic waves or lasers would cause certain interference to the medical electronic equipment detection data of the hospital during the work process.

Aiming at the shortcomings of traditional robot path planning and navigation technology in hospitals or medical institutions, the proposed scheme based on sensor network collects information on hospital environment, combined with information of sensor network nodes and RSSI algorithm to realize the positioning of infusion service robots. The infusion service robot can ensure high precision and reduce the production cost in the path planning strategy through the ant colony algorithm.

In this paper, the simulation research on the path planning strategy of the infusion service robot was carried out. The information acquisition of the sensor network system was used, and the ant colony algorithm was used to plan the path. The feasibility of the application was verified by MATLAB simulation.
2. Test Content and Environment Simulation

During the tests, the infusion service robot's motion environment was a set of mutually separated regular areas with dynamic topological characteristics, simulated in the actual situation of the hospital, such as the obstacles in the designated area (for example, people, beds, Long benches, etc.), as well as hospital inpatient corridors (about 1 meter in width). At the same time, the robot's location of interest to the room would generally have special markings (such as two-dimensional code, etc.) as a road sign during navigation in the above environment[5]. Therefore, some existing road signs were used to realize cooperation with wireless sensor network nodes, and the positioning navigation operation of the infusion service robot was completed together.

The infusion service robot and its surrounding exercise environment of this study have the following characteristics.

i. The wireless sensor network node in the infusion service robot motion environment is pre-deployed and the specific location is clear;
ii. The infusion service robot is also equipped with a wireless sensor network node and moves dynamically with the robot;
iii. Clock synchronization between wireless sensor network nodes;
iv. The infusion service robot does not need a pre-known environmental map, and does not need to be equipped with a positioning device such as GPS, and the surrounding environment of the robot may be dynamically changed.

Sensor network deployment is the precondition of navigation for infusion service robot. The sensor node placement algorithm of the virtual diamond grid (VRGSD, Virtual Rhomb Grid-based Sensor Deployment algorithm) was used as sensor network deployment algorithm[6]. The diamond mesh not only made full use of the sensor's sensing and communication capabilities, but also ensured complete seamless communication and coverage within the sensor area. The minimum number of nodes required in a completely seamless coverage sensor area is calculated by the following formula[7]:

\[ N = \frac{F}{\delta^2} = \frac{F}{2\delta^2} \]

*F*: the area of the sensor area
*\(\delta\)*: the effective coverage area of each node
*R*: the sensing or communication radius of the sensor node.

The data structure of the VRGSD algorithm and the pseudo code of the implementation are simulated by MATLAB, and 20 sensor nodes are randomly generated. The coordinates of the simulation result are: C = [91; 13; 2; 5; 3; 18; 4; 14; 5; 18; 6; 17; 7; 10; 8; 3; 9; 4; 10; 6; 11; 12; 16; 13; 15; 14; 8; 15; 20; 16; 7; 17; 11; 18; 2; 19; 120].

Randomly arranged in the sensor area, each node has a radius of emission of 5 units (r=5) and a sensor area of 30×40 units. Figure 1 shows the simulation results.
Ant colony algorithm is applied to let robots deploy 20 nodes of sensor networks to find the shortest path. The algorithm can be described as follows: \( m \) ants are assumed to be randomly placed on a fully connected graph with \( n \) nodes, \( \tau_{ij}(t) \) indicates the amount of pheromone on the \( i, j \) line at time \( t \), \( \eta_{ij}(t) \) is heuristic information related to the problem, Set here \( \eta_{ij}(t) = 1/d_{ij} \). At the initial moment, the amount of pheromone on each path is equal, assume \( \tau_{ij}(0) = C \) (C is a constant). The ant \( k \) (\( k = 1, 2, ..., m \)) determines the next transfer to which position according to the amount of pheromone on each path during the movement. The equation of \( p^k_{ij}(t) \) is represented the probability that ant \( k \) is transferred from position \( i \) to position \( j \) at time \( t \), as shown by the calculation formula \( 2[8] \).

\[
p^k_{ij}(t) = \frac{\left[\tau_{ij}(t)^\alpha \eta_{ij}(t)^\beta\right]_{j \in \text{tabu}}}{\sum_{\text{tabu}} \left[\tau_{ij}(t)^\alpha \eta_{ij}(t)^\beta\right]_{j \in \text{tabu}}} , j \notin \text{tabu}
\]

In Equation 2, the taboo \( \text{tab}^k_\text{uk} \) records the location where the ant has traversed, \( \alpha \), \( \beta \) is a parameter that adjusts the relative importance of pheromone strength \( \tau \) and heuristic information \( \eta \). After \( n \) moments, the ants complete a tour, and the amount of pheromone on each path is adjusted according to formula \( 3 \).

\[
\tau_{ij}(t+n) = (1-\rho)\tau_{ij}(t) + \sum_{k=1}^{m} \Delta\tau^k_{ij}(t+n)
\]

In the above formula: \( \rho \in [0,1] \) represents the volatilization coefficient of the pheromone, \( \Delta\tau^k_{ij} \) represents the amount of pheromone left by the ant \( k \) on the path \( (i,j) \) in this cycle; \( \Delta\tau_{ij} \) represents the amount of pheromone left by all the ants on the path \( (i,j) \) in this cycle. The flow chart of the ant colony algorithm is shown in Figure 2.

Figure 1. Simulation results of the VRGSD algorithm.
For the 20 nodes of the simulation, the shortest path is sought according to the ant colony algorithm, and the sensor network node is deployed based on the infusion service robot. The run function is as follows [9]:

\[
\text{Function}\[R_{\text{best}},L_{\text{best}},L_{\text{ave}},\text{Shortest\_Route},\text{Shortest\_Length}] = \text{ACATSP}(C, \text{NC}\_\text{max}, m, \text{Alpha}, \text{Beta}, \text{Rho}, Q)
\]

Among them: \(C\): Coordinates of \(n\) locations, \(n \times 2\) matrix; \(\text{NC}\_\text{max}\): maximum number of iterations; \(m\): the number of ants; \(\text{Alpha}\): parameters characterizing the importance of the pheromone; \(\text{Beta}\): parameters characterizing the importance of the heuristic factor; \(\text{Rho}\): Pheromone evaporation coefficient; \(Q\): pheromone increases the intensity coefficient; \(R\_\text{best}\): the best route of each generation; \(L\_\text{best}\): the length of the best route of each generation.

\[
[R\_\text{best},L\_\text{best},L\_\text{ave},\text{Shortest\_Route},\text{Shortest\_Length}] = \text{ACATSP}(C, 55, 20, 4, 0.3, 0.4, 0.7).
\]

The simulation results are derived: Shortest\_Route = 13 14 7 6 4 2 5 8 11 17 19 20 12 15 18 9 10 3 1 16; Shortest\_Length = 116.0402.

The choice of the robot path should take into account the communication radius of the sensor node and the position of the obstacle to ensure communication with all nodes. The RSSI (received signal strength indicator) ranging positioning technology is applied to the infusion service robot navigation to provide accurate location information for the mobile service robot [10]. The infusion service robot may receive signals from \(n\) (\(n \geq 3\)) beacon nodes at the same time, and convert the real-time measurement received signal strength into distance to calculate its own position. The test wireless communication uses the CC2430 chip produced by Chipcon company, and its channel propagation attenuation model as follows [11]:

\[
p = p_0 - 10r\log\left(\frac{d}{d_0}\right) + \xi
\]

(4)

Among them: \(p_0\) is the signal strength from the transmitting node, the value of this \(p_0\) is 41.1 dB; \(d_0\) is the distance between the transmitting node and the receiving node, value \(d_0 = 1\) m; \(r\) is a
parameter related to the signal propagation environment, and the value is r=3; \( \xi \) is a Gaussian distributed random noise with a mean of 0, and the standard deviation ranges from 4 to 10. Test the measured value of the received signal strength of the two nodes and the theoretical value. The measured value and the theoretical deviation are smaller in the range of 0 to 15 m. When the distance between the two nodes is greater than 15 m, the measured value and the theoretical deviation are larger.

A maneuvering statistical model is established for the infusion service robot, and the current statistical model is used to define the state vector as:

\[
X_k = [x_k, y_k, v_{ak}, a_{ak}]^T
\]

The discrete equation of state is:

\[
X_{k+1} = \varphi(k+1, k)X_k + U(k) + W(k)
\]

Among them,

\[
\varphi(k+1, k) = \begin{bmatrix}
I_2 & T I_2 & \frac{1}{\alpha^2}(-1+\alpha T+e^{-\alpha T})I_2 \\
O_2 & I_2 & \frac{1}{\alpha}(1-e^{-\alpha T}I_2) \\
O_2 & T I_2 & e^{\alpha T}I_2
\end{bmatrix}
\]

\( T \) is the sampling period;

\[
U(k) = \begin{bmatrix}
\frac{1}{\alpha}(-T + \frac{\alpha T^2}{2} + \frac{1-e^{-\alpha T}}{\alpha})a_x \\
(T - \frac{1-e^{-\alpha T}}{\alpha})a_x \\
(1-e^{-\alpha T})a_y
\end{bmatrix}
\]

\( W(k) \): a discrete time noise sequence, variance matrix is

\[
Q_k = w[w(k)W^T(k)] = \begin{bmatrix}
2\alpha\sigma^2_{ax}q^3 & O_3 \\
O_3 & 2\alpha\sigma^2_{ay}q^3
\end{bmatrix}
\]

\( \alpha \): the reciprocal of maneuver time

\( \sigma^2_{az} \) and \( \sigma^2_{ay} \) are the mobile service robot acceleration variance, maneuver variance, respectively.

The adaptive adjustment is:

1. The current acceleration is positive

\[
\sigma^2_{ax}(k-l) = \frac{4}{\pi}[a_{ax, max} - a_{ax, k-1}], \quad \sigma^2_{ay}(k-l) = \frac{4}{\pi}[a_{ay, max} - a_{ay, k-1}]
\]
2. The current acceleration is negative

\[ \sigma_{ax}^2(k-1) = \frac{4}{\pi} \left[a_{x,\text{max}} - a_{x,k-1}\right] \]

\[ \sigma_{ay}^2(k-1) = \frac{4}{\pi} \left[a_{y,\text{max}} - a_{y,k-1}\right] \]

\( a_{x,\text{max}}, a_{y,\text{max}}, a_{x,\text{max}}, a_{y,\text{max}} \) represents the maximum and minimum accelerations that the mobile service robot may have in the x and y directions, respectively.

\( a_{x,k-1} \) and \( a_{y,k-1} \) are the filtered output values at time k-1.

The target area is covered with wireless sensor network nodes, but is limited by the node transmit power, which causes the infusion service robot to communicate with only some of the nodes at a certain time. To simplify the problem, suppose that the robot can communicate with the beacon nodes B1 \((x_1, y_1)\), B2 \((x_2, y_2)\) and B3 \((x_3, y_3)\) at the time of k, the system measurement equation is shown below:

\[ Z_k = H(X_k) + V(k) \] (7)

Among them, \( Z_k = \begin{bmatrix} p_{1,k} & p_{2,k} & p_{3,k} \end{bmatrix}^T \), \( H(X_k) = \begin{bmatrix} h_1 \\ h_2 \\ h_3 \end{bmatrix} = \begin{bmatrix} p_0 - 30\log\left(\frac{d_{x,k}}{d_0}\right) \\ p_0 - 30\log\left(\frac{d_{y,k}}{d_0}\right) \\ p_0 - 30\log\left(\frac{d_{z,k}}{d_0}\right) \end{bmatrix} \),

\( d_{i,k} = \sqrt{(x_k-x_i)^2 + (y_k-y_i)^2 + (z_k-z_i)^2} \) (i = 1, 2, 3) is to measure noise, and its variance matrix is \( R[12] \).

3. Simulation and conclusion of the infusion service robot planning path

MATLAB software is used for simulation, the red triangle in Figure 3 is the simulation infusion service robot. The green path in the figure is the path we originally envisioned, and the blue star is the sensor network node distributed in the environment. During the simulation process, the node would turn red after being used. According to the information of the sensor network node, combined with the ant colony algorithm calculation to achieve the role of positioning, and then complete the path planning test.

Figure 3. Effect diagram of robot-assisted positioning and navigation simulation process based on sensor network.

Figure 4. Robot-assisted positioning and navigation simulation results based on sensor network.

Figure 4 shows the black route as the simulation path. The difference between the comparison and
the previously set path is very small. From the result, the simulation effect is better, indicating that the robot has completed the positioning and navigation very excellent. The information of the hospital environment is collected through the sensor network, and the information and RSSI algorithm of the sensor network node are used to realize the positioning and navigation of the infusion service robot. The ant colony algorithm is used to determine the path planning route of the infusion service robot. Combined with the complex and diverse environment of major hospitals and medical institutions, the feasibility and basic methods of applying the simulation results to the practical application of infusion service robots need further research.

Acknowledgement
Fund Project: School-level Scientific Research Project (Project No. KJ1901)

References
[1] Wu Z L 2019 Automatic route generation method based on ant colony algorithm Ship Science and Technology 41 pp 43-5 [CrossRef]
[2] Cai G B 2013 Discussion on the design and safety of hospital medical equipment use environment Medical Equipment 26 pp 48-50 [CrossRef]
[3] Zhang W and Feng L 2018 Simulation research on ground target navigation and positioning of mobile service robot Computer Simulation 35 pp 231-234+292 [CrossRef]
[4] Pan F 2018 Research on characteristics of laser interference infrared/television imaging system Xi’an University of Electronic Science and Technology [CrossRef]
[5] Li Y J 2019 Research on tourism route planning based on ant colony algorithm Computer Knowledge and Technology pp 1-4 [CrossRef]
[6] Li Z and Gu T W 2019 Review on the application of ant colony algorithm in power system New industrialization 9 pp108-13 [CrossRef]
[7] Tu L J, Li L S and Lin G X 2019 Research on path planning of orchard mobile robot in dynamic environment Mechanical Design 36 pp 75-9 [CrossRef]
[8] Zhang W and Feng L 2018 Simulation research on navigation target positioning of mobile robots Computer Simulation 35 pp 231-234+292 [CrossRef]
[9] Ding W, Sun H and Zeng J H 2006 Overview of mobile service robot navigation based on multisensory information fusion Sensors and Microsystems pp 1-3 [CrossRef]
[10] Cao R Y, Li S C, Ji Y H, Xu H B, Zhang M and Li M Z 2019 Multi-machine collaborative work task planning based on ant colony algorithm Journal of Agricultural Machinery 50 pp 34-9 [CrossRef]
[11] Zhao J W, Wang H Y, Tang B and Yang Z Y 2016 Research on GPS trajectory generation and location based on mobile robot Industry and Mine Automation 42 pp 17-9 [CrossRef]
[12] Lu J X, Li J and Zhou Y 2019 Research and application of ant colony algorithm in an IoT medical box system Electronic Products World 26 pp 80-84+88 [CrossRef]