The method of grid map construction of visual characteristics on rocket tank surface and robot automatic cleaning path planning

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Abstract. According to the actual engineering needs, this paper proposed a method of grid map construction of visual characteristics on rocket tank surface and robot automatic cleaning path planning. Through the image processing algorithm, the flange obstacle features and smudge features of the rocket tank surface are extracted, and the cleaning grid map of the rocket tank surface is constructed with these features. Aiming at the circumferential cleaning requirements of rocket tanks, a global path planning method based on artificial potential field loop traversal is proposed to achieve traversal coverage cleaning of stain points. It is verified by simulation experiments that the path planning method proposed in this paper meets the actual needs and is of great significance for realizing the cleaning automation of rocket storage tanks.

1. Introduction

The rocket fuel tank is the core component of the liquid rocket’s internal storage propellant fuel. In the production process, it is necessary to carry out the coating work of the heat insulation layer to maintain the temperature of the tank. Before painting, in order to ensure the coating effect of the insulation layer, the surface of the rocket tank needs to be carefully cleaned. The traditional manual cleaning, low work efficiency, high labor intensity, automatic cleaning by robot can effectively solve the above problems.

Machine vision is the use of a computer to process images or video to identify, detect, perceive, and understand through two- or three-dimensional scenes. At present, machine vision has been widely used in object recognition and surface detection. The target feature detection method based on machine vision has the advantages of high speed, precision and no contact [1]. Artificial potential field method path planning is a kind of virtual force method [2]. The path planned by the potential field method has the advantages of smoothness and security.

In order to realize the robot's automatic cleaning of the surface of the rocket tank, this paper proposed a method for constructing the grid map of the visual characteristics of the rocket tank and the method of robot automatic cleaning path planning. The key to realize the robot automatic cleaning path planning is to identify the characteristics of the rocket tank surface and the smudge features, and construct a grid map with these features, automatically realize the path planning according to the grid map finally.
2. The composition of the cleaning recognition system

As shown as figure 1, the automatic cleaning and recognition system identifies the characteristics of the cleaning area through a CCD camera mounted on the end effector of the robot, and constructs the corresponding grid map with this features, automatically realizes the path planning according to the grid map finally to clean the unwashed area.

![Figure 1. Automatic cleaning recognition system.](image)

The process of identifying and cleaning is as follows:

- Traversing the surface of the rocket tank through the CCD camera, identifying the flange features and constructing a grid map of the rocket tank surface;
- According to the grid map, full coverage cleaning the surface of rocket tank with CCD camera, and marking the cleaned area on the grid map.
- Traversing the surface of the scanned rocket tank through the CCD camera at the end of the robot, identifying the smudge area features of the cleaning residue, and marking the smudged area on the feature grid map.
- Finally, according to the features grid map, traversing cleaning the area of the residual stain with trajectory planning.

3. Construction of feature grid map

3.1 Extraction of visual features

The images of the surface of the rocket tank is obtained by a CCD. In order to achieve the matching between the pixel distance and the actual distance, it is necessary to perform distortion correction on the camera, obtain the internal parameter of the camera, and construct a transformation matrix from the pixel coordinate system to the actual coordinate system. Through the Zhang Zhengyou calibration method, the camera internal parameters $dx, dy, u_0, v_0, f$ can be obtained[3-4]. The transformation matrix of the pixel coordinate system to the actual coordinate system can be obtained by equation (1).

$$
\begin{bmatrix}
x_c \\
y_c \\
z_c / f
\end{bmatrix} =
\begin{bmatrix}
1/dx & 0 & u_0 \\
0 & 1/dy & v_0 \\
0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
u \\
v \\
1
\end{bmatrix}
$$

In the equation (1), $(x_c, y_c, z_c)$ represents the coordinates of the world coordinate system (camera coordinate system), and $(u, v)$represents the coordinates of the pixel coordinate system. Since the distance of the cleaning end from the surface of the rocket tank during the cleaning process does not change, $z_c$ does not change. And because of the fixed camera, the camera internal parameters will not change. Therefore, the matrix (1) is simplified to:

$$
\begin{bmatrix}
x_c \\
y_c \\
m
\end{bmatrix} =
\begin{bmatrix}
u \\
v \\
1
\end{bmatrix}
$$

In the equation (2), $m=z_c/f$, and $k$ is a matrix of $3 \times 3$.

Since there are protruding flanges on the surface of the rocket tank, it is necessary to visually recognize the position and size of the flange. At present, the flanges on the surface of the rocket tank
are mainly divided into two types, a square flange and a circular flange. The type of the two flanges is discriminated by image processing, and the position of the center point of the flange is obtained. Firstly, the acquired image is denoised and filtered, then the image is grayed out, the Canny operator is used to extract the contour of the flange [5], and the contour boundary is filled by morphological processing to extract the minimum circumscribed rectangle and the minimum circumscribed circle of the contour. The area contrast is used to judge the shape of the flange.

As shown in figure 2-3, the square flange and the circular flange can be distinguished by Peripheral contour features. Further, the obtained flange center coordinates \((u,v)\) and the flange area coordinates are converted to world coordinates \((x_c,y_c,z_c)\) according to the equation (2). In the cleaning process of the surface of the rocket tank, due to the phenomenon of stain residue in the cleaning process, it is necessary to identify the features of the cleaned area, mark the grid map, and plan the path of the cleaning end.

Aiming at the scattered smudge features on the surface of the rocket tank, the smudge area and the template area are compared by image difference. Firstly, the collected image is filtered and denoised, grayed out, then the image is blurred by Gaussian operator to obtain the background template, then the foreground is distinguished from the background template, and the small area is filtered out by gray threshold segmentation. Figure 4 is the smudge area to be identified, figure 5 is the smudge area extraction. Further, the region center \((u,v)\) is converted into world coordinates \((x_c,y_c,z_c)\) according to the transformation matrix of equation (2).

3.2 Grid map construction of visual features
The grid map divides the environment into a series of grids, each of which is given a possible value, indicating the occupied state of the grid [6]. In order to reduce the computational workload, the grid map is used as the basis for the construction of the rocket tank surface map. The surface of the rocket tank is cylindrical, and its surface is unfolded to obtain a rectangular surface. Construct a Cartesian coordinate system, determine the scale, and calibrate the raster map.

\[
x_{\text{Grid}} = \text{INT}\left(\frac{x}{G_{\text{Size}}}\right)
\]

\[
y_{\text{Grid}} = \text{INT}\left(\frac{y}{G_{\text{Size}}}\right)
\]
In equations (3)(4), \((x,y)\) represents the actual coordinates of the rocket tank, \((x_{Grid}, y_{Grid})\) represents the grid map coordinates, \(G_{Size}\) represents the length of grid unit, \(INT\) is taken Entire function.

Before cleaning, firstly scan the surface of the rocket tank in the direction shown in figure 6. Then identify the flanges’ features, and construct the grid map, as shown in figure 7. The black area is the area occupied by the square and circular flanges.

The direction of the arrow in figure 7 is the cleaning direction of the cleaning end (column scanning cleaning). The cleaned area is gray and the unwashed area is white.

After the cleaning is completed, the cleaning degree of the rocket tank surface is scanning detected by the CCD camera. The scanning direction is same as figure 6. The stained area is marked as white, cleaned area is marked as gray in figure 8.

4. Cleaning path planning

4.1 Basic principle

The artificial potential field includes the gravitational field \(U_{att}\) and the repulsive field \(U_{rep}\). The object is driven by the combined force of the two, wherein the target point generates gravity to the object and guides the object toward its movement [7]. An obstacle creates a repulsive force on an object, and the resultant force of the object at each point on the path is equal to the sum of all repulsive forces and gravitational forces at that point. The gravitational field function is:

\[
    U_{att}(p_{current}) = \frac{1}{2} k_t \rho^2(p_{current}, p_{aim})
\]

Where \(k_t\) is the gravitational coefficient, \(p_{current}\) is the current end effector coordinate, and \(p_{aim}\) is the coordinate of the target point. Indicates the distance between the current point and the target point. The repulsion field function is:

\[
    U_{rep}(p_{current}) = \begin{cases} 
    \frac{1}{2} k_t \left( \frac{1}{\rho(p_{current}, p_{obstacle})} - \frac{1}{\rho_0} \right)^2, & \rho < \rho_0 \\
    0, & \rho > \rho_0 
\end{cases}
\]
In equations (6), \(p_{\text{obstacle}}\) is the obstacle coordinate, and \(\rho_0\) is the obstacle potential energy field range, indicating the distance between the current end effector and the obstacle. \(U_{\text{rep}}\) has no effect when the distance between the end of the robot and the obstacle is greater than \(\rho_0\).

4.2 Cleaning path planning based on artificial potential field method

After constructing the grid map of features as shown in figure 8, the smudged area of the white mark needs to be traversed and cleaned. Since the rocket tank will maintain directional rotation during the cleaning process, the cleaning end and the surface of the rocket tank will have a relative speed in the direction of column (Y). If the next target point is farther in the -Y direction of the current point, the direct planning will be The speed of the robot movement is relatively high, so it is necessary to advance to the next column of cycles and then plan the target point. The column cycle artificial potential field global planning algorithm is used to traverse the cleaning path planning of the cleaning area, as shown in figure 10, and the result is as shown in figure 9.

![Diagram](image)

Figure 10. Column cycle artificial potential field global path planning algorithm flow.

As shown in figure 10, \((X_i, Y_i)\) is the current point coordinate, \((X_{i+1}, Y_{i+1})\), \((X_{i+1}', Y_{i+1}')\) is the next target point coordinate, and \(Y_{\text{len}}\) is the length of the map at the Y direction.

5. Path planning simulation experiment

Using software to simulate the global path planning algorithm of the column cyclic artificial potential field. The simulation results are shown in the figure 11-12:
It can be seen from the simulation results that the global path planning algorithm of the method used in this paper satisfies the requirements of the surface cleaning conditions of the rocket tank. In the environment with many stains and few stains, the path planning meets the requirements.

6. Conclusion
This paper presents a method for grid map construction and robot cleaning path planning of rocket tank surface visual features. The flange and smear features of the rocket tank surface were identified. The corresponding grid map was constructed with this features, and the cleaning path was planned based on the grid map. Through simulation analysis, the automatic cleaning trajectory planning meets the actual needs. Using the method proposed in this paper is of great significance for the automatic cleaning of the robot to improve the surface of the rocket tank.

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