SIMULATION OF TASK-ORIENTED MULTISENSOR INTELLIGENT CONTROL OF MICROASSEMBLY ROBOT

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ABSTRACT: The traditional single sensor control has a fuzzy point, which causes that the microassembly robot is unable to avoid the obstacle effectively. To address this problem, a task-oriented multisensor intelligent control of microassembly robot is proposed in this paper. The task model for microassembly robot is built. Sonar sensor and odometer are selected as the sensors. The he sensing data is fused to avoid blurring. PID control method is used to control the motion of microassembly robot. The change of attitude angle of the robot with visual processing and recognition and the deviation of the given attitude angle are the input of PID controller. According to the output control of the controller, the pose of the robot is adjusted to realize the control of the robot. Whether there is obstacle in front of the robot is determined with the distance of the robot and the wall collected by sonar sensor and odometer to achieve the control decision of robot at the corner. Experimental results show that the proposed method can effectively avoid obstacle.

KEYWORDS: Task-oriented; microassembly; robot; multisensor; intelligent control

1 INTRODUCTION

As a new type of production tool for human, robot has shown great superiority in reducing labor intensity, increasing productivity, changing production mode and freeing people from dangerous, harsh and heavy working environment. Since 1960s, various types of robots such as machining, arc welding, spot welding, spraying, assembling, and testing have appeared and quickly applied in industrial production, which greatly improved the consistency and quality of various products. As people explore more and more activities in the microcosm, such as microsurgery, biological chromosome gene modification and injection, precise micro-part assembly and processing, all objects are required to operate in micro size, millimeter, sub millimeter, micron or even nanometer level. Therefore, the micro operating robot used for operation and assembly has become a hot spot in the research of robot in recent years. Microassembly robot is the core equipment of flexible automatic assembly system, which consists of robot operating machine, controller, terminal actuator, and sensing system. The structure types of the operating machine include the horizontal joint, the Cartesian coordinate, the multi-joint, and the cylindrical coordinate. Compared with the general industrial robot, the microassembly robot has the characteristics of high precision, good flexibility, small working range, and can be used with other systems. As the core of microassembly robot, robot intelligent control is a comprehensive science and technology across many disciplines, which involves automatic control, computer, sensing technology, artificial intelligence, electronic technology, and mechanical engineering. The advanced degree and function of the microassembly robot are usually directly related to the control system. In recent years, with the development of technology in these fields, the control technology of microassembly robot has also made great progress.

The fuzzy point in the traditional single sensor control causes the microassembly robot cannot avoid the obstacle effectively. A multisensor intelligent control method with the orientation of assembly task is proposed in this paper. A system with the function of task level is achieved. Multisensor information fusion refers to the fusion of data collected from different knowledge sources and sensors to achieve better understanding of observation phenomena, which can effectively solve the fuzzy point of single sensor, and observe and interpret the environment more accurately.

2 TASK-ORIENTED MULTISENSOR INTELLIGENT CONTROL OF MICROASSEMBLY ROBOT

2.1 Task model of microassembly robot

Task-oriented multisensor intelligent control of microassembly robot is usually achieved through dynamic monitoring and sensing information of...
assembly object, operation process, and system environment provided by multisensor integration module, so as to assist the control decision-making of main control system of microassembly robot. Information interaction can be divided into three cases. (1) When there is no occurrence of uncertain event, the optimized detection information is provided to ensure the normal operation of the assembly operation. (2) When uncertain event is detected, the master control system is assisted for online task replanning and error recovery. (3) When there is a serious recoverable event, the emergency handling is performed, that is, the shutdown for user's offline processing. The above relationship can be defined by the task model of the microassembly robot.

Table 1. The relationship of the assembly operation process and the monitoring task

<table>
<thead>
<tr>
<th>Task detection</th>
<th>Target perception</th>
<th>Free movement</th>
<th>Complia nt movement</th>
<th>Coordinat ion test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target presenta tion</td>
<td>Target recognition</td>
<td>Target location</td>
<td>Environment monitoring</td>
<td>Environment monitoring</td>
</tr>
<tr>
<td>Move ment parame ter</td>
<td>Contact monitori ng</td>
<td>Anti-collision monitoring</td>
<td>Environment monitoring</td>
<td>Environment monitoring</td>
</tr>
<tr>
<td>Contact monitori ng</td>
<td>Force detection</td>
<td>Physical co ordinati on</td>
<td>Reli able coordinati on</td>
<td></td>
</tr>
<tr>
<td>Force application detection</td>
<td>Functiona l coordinati on</td>
<td></td>
<td></td>
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</tr>
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</table>

The assembly task of microassembly robot consists of meta-task sequence, that is, the assembly schedule (Khan, 2016). The assembly meta-task model $T_i$ can be described and defined by assembly target state $B(t)$, structured environment state $E(t)$, manipulator state $H(t)$, multi physical sensor state $Q(t)$, and standardized operation sequence $G(t)$, that is,

$$I_i = I(B(t), E(t), H(t), Q(t), G(t))$$

(1)

where $i = 1, 2, L - n$. The assembly meta-task is composed of the standardized operation process, that is, objective perception→operator free movement→flexible movement of operator and target→test of coordination state. The control task is shown in Table 1. The control task model $T_i$ can be decomposed into 3 sub control task modules, which are parameter detection module $T_i^1$, state monitoring module $T_i^2$, and sensor combination coordination module $T_i^3$, that is:

$$T_i = \{T_i^1, T_i^2, T_i^3\}, \quad i = 1, 2, 3$$

(2)

Parameter detection module defines the type of parameters and the sequential relationship for the required detection, which is expressed as

$$T_i^1 = \{a_i, f_i, (A, F) \rightarrow I_i\}$$

(3)

where $A(t)$ and $F(t)$ are the target pose and applied force of the microassembly robot, $a_i$ and $f_i$ are the mapping from parameter space to task space.

The state monitoring module defines the state event and sequential relationship for the required monitoring, which is expressed as

$$T_i^2 = \{a_2, f_2, (A, F) \rightarrow \xi, \xi \in I_i\}$$

(4)

where $\xi$ is the state event monitoring threshold space defined in the task space, $a_2$ and $f_2$ is the mapping relationship between parameter space and threshold space.

The sensor combination coordination module defines the combination of the physical sensor subset and the timing coordination during the corresponding parameter detection and state monitoring, which is expressed as

$$T_i^3 = \{q_1, q_2, q_3, q_4, q_i \in Q, q_i \in Q\}$$

(5)

where $Q$ is physical sensor set, $r_i$ defines the mapping relationship from sensor subset to
parameter space or state space, \( r_1(q,t) \rightarrow a_1(A) \), \( r_2(q,t) \rightarrow f_1(F) \), \( r_3(q,t) \rightarrow a_2(A) \), and \( r_4(q,t) \rightarrow f_2(F) \).

The target pose parameter \( A(t) \) of the microassembly robot can be estimated by the vision, distance sense and the surface array tactile. The transform \( a_1 \) is the motion control parameter of the microassembly robot with free movement in Cartesian space or joint space. The transform \( a_2 \) can provide the safety state information of the microassembly robot with free movement and the geometric quantity test information of the assembly results. Force parameter \( F(t) \) can be detected by brawn sense and grip sense. Its relationship with \( A(t) \) can be defined by the constraint coordinate system of the task space. The transformation \( f_1 \) provides compliant movement control and active force trajectory control for an operator. The transformation \( f_2 \) provides physical quantity inspection information for the main control system for finding and processing events such as rigid collision, target shedding, and assembly products or semi-finished products.

2.2 Multisensor information fusion

In the intelligent control of multisensor of microassembly robot, multi-sensing information should be fused to avoid fuzzy points. Compared with all single sensor signal processing or low-level multisensor data fusion and multisensor data fusion, single sensor signal processing or low-level multisensor data fusion is a low-level imitation of human brain information processing, which cannot used multisensor resources effectively. The multisensor system can obtain more information about the target and environment to be detected. There is also an essential difference between multisensor data fusion and classical signal processing. The key is that the multisensor information processed by data fusion has a more complex form. The fusion of information can be carried out at different levels of information processing, namely, data layer fusion, feature layer fusion, and decision layer fusion, which can be selected according to the type of sensor data or type of sensor preprocessing in practical application.

Sonar can be traced back to 1490 at the earliest. In 1916, Langevin invented the first sonar in the world and was able to locate the target with the echo. At present, sonar can analyze and process complex signals, and the accuracy and reliability of the measurement are very high.

Sonar is used to measure the distance between a microassembly robot and an obstacle. The basic operation principle is as follows. Sonar transmits a sound wave and the target reflects the transmitted wave to the sonar. If the time when the amplitude of the received reflection wave exceed preset threshold \( \varepsilon \) is, the distance between the obstacle and sonar is \( d = v_r \times t/2 \), where \( t \) is the time interval of transmission and reception, \( v_r \) is the velocity of sound in the air.

In this paper, there are only 3 sonar sensors on the experimental platform, which cannot meet the measurement range of 180 degrees. So through the user input and output channel, 2 sonar sensors are added to the front of the mobile robot, and the interval between each sonar sensor is about 45 degrees. In this way, the blind area is eliminated and the mutual influence between the sensors is ensured.

The sonar sensor used in this paper is DUR5200. The working frequency is 40 kHz. When the ambient temperature is 20 °C, the velocity of the sound wave is 344 m/s. When the ambient temperature changes, the velocity of the sound wave can be corrected by the temperature sensor in the microassembly robot. The velocity of the sound in the air \( v_r \) is given by

\[
v_r = 332 + 0.6T_r \tag{6}
\]

where \( T_r \) is the current ambient temperature.

The basic operation of the DUR5200 sonar sensor measurement is shown in Fig. 1. Distance measurement starts from the rising edge of TE. TE becomes low level after \( t_1 \) time, \( t_1 \) is the time from the start of measurement to the return and reception of the sound wave (RS in the rising edge), which is the one-way propagation time between sensor and target. The time interval \( t_2 \) between the two measurements should not be less than 20ms, in order to prevent the interference of the received acoustic signal. The measurement range of the DUR5200 sonar sensor is 5cm~250cm.

2.3 Sensor selection

2.3.1 Sonar sensor
2.3.2 Odometer

The odometer can provide the required pose information for the positioning and navigation of a microassembly robot within a short range. But the external sensor is required to provide correction information for the case of a long distance movement. The working principle is based on the photoelectric encoder encode installed on the two driving wheel motors to detect the radian of wheels passing in a certain time, and then calculate the relative pose change of the microassembly robot.

Assume the wheel diameter is \( d \), the output pulse number of the photoelectric encoder per rotation is \( p \) line, the output pulse number of the photoelectric encoder in \( \Delta t \) time is \( M \). Then the moving distance \( \Delta d \) of the wheel in \( \Delta t \) time is given by

\[
\Delta d = (M/p) \times \pi \times d \tag{7}
\]

Assume the moving distances of the left and right wheel detected by the photoelectric encoder are \( \Delta d_l \) and \( \Delta d_r \), and the interspacing of two wheels is \( c \). Microassembly robot moving from the state point \( o_n(x_n, y_n, \theta_n) \) to the state point \( o_{n+1}(x_{n+1}, y_{n+1}, \theta_{n+1}) \), then the moving distance \( \Delta L \) is given by

\[
\Delta L = \frac{(\Delta d_l + \Delta d_r)}{2} \tag{8}
\]

The moving angle \( \Delta \phi \) is given by

\[
\Delta \phi = \frac{(\Delta d_r - \Delta d_l)}{2} \tag{9}
\]

In the condition of the known initial state point \( o_n(x_n, y_n, \theta_n) \), through the effective odometer model the target position of the robot is calculated as \( o_{n+1}(x_{n+1}, y_{n+1}, \theta_{n+1}) \). The odometer model of the microassembly robot is expressed as

\[
o_{n+1} = f(o_n, \delta_n) + s_n \tag{10}
\]

where \( \delta_n = (\Delta L_n, \Delta \phi_n) \) is the measured value of the odometer, \( \Delta L_n \) is the arc length of the microassembly robot moving in \( \Delta t \) time, \( \Delta \phi_n \) is the difference of the direction angle between the end pose and the starting pose, \( s_n \) is the noise and assumed as Gaussian white noise.

The odometer model can be divided into arc model and linear model. Arc model is a general model. Not only the displacement changes in the motion of the micro assembly robot are considered, but also the change of the navigation angle in the movement is also considered. The linear model is actually a simplified form of the arc model. It approximates that the change of the direction angle of the microassembly robot in a very short time is very small, approximately zero, that is, \( \Delta \phi_n = 0 \). Therefore, a simple linear model can be used to simulate the movement of the microassembly robot. The linear model can be expressed as

\[
f(o_n, \delta_n) = \begin{bmatrix} x_n + \Delta L_n \cos \phi_n \\ y_n + \Delta L_n \sin \phi_n \\ \phi_n \end{bmatrix}
\]

(11)

In this paper, the linear model is taken as the odometer model. WiRobotX80 robot experimental platform is used in this paper. Two high performance rotary encoders are installed on the platform. The number of pulses in the encoder output is 1200 lines / rotation, and the reading is 0–32500. If the reading exceeds the loop range, the counter starts from 0. The diameter of the wheel is 16.8cm. According to these data, it is easy to calculate the distance of the wheel walking.

The visual sensor module MCI3908 uses the CMOS image sensor CAM3908. Although it is worse than the CCD sensor in sensitivity, resolution, and noise control, it has the advantages of low cost, low power consumption, and high integration degree. The maximum collected image by camera can reach 352\times 288 pixels. The maximum transmission frequency is 15 frames per second. It not only ensures the real-time performance of the system, but also meets the requirements of the experiment.
2.4 Task-oriented multisensor intelligent control of microassembly robot

PID control method is used to control the movement of microassembly robot. The deviation of the change of attitude angle of robot detected by vision system and the given attitude angle is the input of the PID controller. According to the output control of the controller, the pose of the robot is adjusted to enable the microassembly robot to track the given target trajectory accurately.

Meanwhile, whether there is an obstacle in front of a robot is determined by the distance between a robot and a wall collected by the sonar sensor and the odometer to achieve the control the robot at the corner.

The control block diagram is shown as Fig. 2.

Assume the given target value is the angle between the path and the X axis when the microassembly robot is accurately controlled, denoted as \( \beta_r \). In the image coordinate system, the angle \( \beta \) corresponds to the attitude angle of the robot in the global coordinate system, as shown in Fig. 2.

\[
\Delta \beta = \beta_r - \beta
\]

\[
y(k) = K_p e(k) + K_i \sum_{i=1}^{k} e(i) + K_o \Delta e(k)
\]

Where

\[
e(k) = \beta_r - \beta(k)
\]

\[
\Delta e(k) = \beta(k-1) - \beta(k)
\]
From the discrete system

\[ \omega(k) = \frac{\beta(k) - \beta(k-1)}{t_r} \]

t, it can be seen that the direction of the rotational velocity of the microassembly robot is related to the attitude angle deviation of the two adjacent sampling times, where 

\( t_r \) is sampling time. When the microassembly robot tracks the desired path, the change of the rotation direction is as follows.

1. When \( e(k) > 0 \), \( \omega(k) > 0 \), the microassembly robot rotates reverse clockwise.
2. When \( e(k) < 0 \), \( \omega(k) < 0 \), the microassembly robot rotates clockwise.

Let \( v = v_f = v \) is a fixed constant at the initial time. According to \( \omega(k) \), the controls of driving motor of micro assembly robot are given by

\[ v_j(k) = v - (k) \times D \] \hspace{1cm} (13)

\[ v_j(k) = v + (k) \times D \] \hspace{1cm} (14)

where \( D \) is the distance between the sonar sensor and the middle point of the odometer to the signal electrode.

A group of satisfactory parameters \( K_r, K_i, K_o \) are determined by the method of adjusting the PID parameters with multiple tests to achieve multisensor intelligent control.

In the process of control, the work of sonar sensor and the odometer is carried out all the time. The collection of sonar sensor and odometer and the calculation of the velocity control when the microassembly robot tracks the straight line are implemented in two threads.

Assume the sensor 2 and the sensor 3 are installed in the front of the microassembly robot, the distance detected by the two sensors are \( l_2 \) and \( l_3 \). The standard value is \( \gamma \).

In the process of control, determine whether \( l_2 \leq \gamma \) or \( l_3 \leq \gamma \) for each collected distance. At the first corner of the path, if \( l_2 \leq \gamma \) or \( l_3 \leq \gamma \), the microassembly robot will stop straight tracking and be controlled to rotate reverse clockwise until no obstacle ahead. Then control algorithm for tracking straight line of microassembly robot is continued. When the robot moves to another corner, it will make the same judgment and process to ensure the second rotation and continue to track the straight line path.

3 EXPERIMENTAL RESULTS AND ANALYSIS

Under the given task orientation, the microassembly robot is trained for multiple simulation obstacle avoidance training by using the proposed method. The purpose is to make the robot accomplish the task well in the unknown environment, avoid multiple obstacles and reach the preset target location. The starting coordinates of the microassembly robot are (-10, 55) and the end point is (-39, 5).

To verify the effectiveness of the proposed method, the proposed method is compared with the neural network method and the PLC method. The results are shown in Fig. 4.
From Fig. 4, it can be obtained that, in the proposed method multiple sensors are to obtain the surrounding environment information, carry out the control decision of robot, and achieve the obstacle avoidance in completely unknown environment. Compared with other methods, the proposed method is improved in real-time and robustness.

4 CONCLUSION

In this paper, a multisensor intelligent control method for micro assembly robot is proposed. A monitoring task planning model is established under the orientation of the assembly task. The sensor information fusion method, multi-objective three-level perception information decision model, and the corresponding sensor are discussed. Dynamic closed loop intelligent control of microassembly robot is achieved.

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