Research on simulating the movement track of consumers holding cigarettes by using manipulator

Hao WANG, Ying ZHANG, Xu WANG, Zhenhua YU, ZHAN Jianbo, Tao WANG, Han ZHENG*, Baoshan YUE, Tingting YU, Jiao XIE, Jiang YU
R&D Center, China Tobacco Yunnan Industrial Co., Ltd, Kunming, 650231, China
*Corresponding author’s e-mail: 93320213@qq.com

Abstract. Consumers' different smoking habits and movement trajectories in the process of smoking have an important impact on cigarette combustion quality and consumption feeling. By analysing the typical action of holding a cigarette, the position, posture and spatial trajectory of the cigarette were described, and the position and posture of the end effector at the beginning and end of the smoking process were considered. The curve function connecting two endpoints can be selected according to the actual constraints. There are 6 degrees of freedom in space of cigarettes, therefore, in order to simulate the motion trajectory of consumers holding cigarettes, 6R industrial robot can realize the motion trajectory of cigarettes in space. The cigarette is clamped by the cigarette holder installed on the flange at the end of the robot, and the robot drives the cigarette holder to complete the movement track of the cigarette.

1. Introduction
The research results of cigarette ash worldwide mainly focus on the factors affecting the performance of cigarette ash, but the research on the relevant detection parameters and methods of cigarette ash is only limited to the indicators such as crack rate. The indicators of cigarette ash performance are not perfect and specific, and the detection methods are not standardized and systematic[1,2]. For the development of cigarette ash detection equipment, there is no unified standard for test conditions, the test equipment is simple and the degree of automation is low, and the test is lack of accuracy and objectivity[3,4]. In particular, there is little research on consumers' cigarette holding and movement trajectory.

In order to accurately study the ash wrapping performance of cigarettes, the development trend of cigarette ash wrapping detection technology is as follows: firstly, image capture and simulation of cigarette combustion process are more close to the real consumer smoking action. Static photography can not truly simulate the real suction environment and suction process. Simulating the process of real consumers and popping the ash can better reflect the advantages and disadvantages of cigarette ash wrapping performance[5-7]. Therefore, the detection of cigarette ash must have a more real simulation of consumers' smoking behaviour. In this way, all kinds of test data can have guiding significance for carrying out relevant experiments and research. Secondly, more realistic simulation on puff is necessary. In order to more truly simulate the smoking process of consumers, a puff device is used to simulate. The puff mode, puff capacity, puff duration and puff interval can be adjusted according to needs within a certain range. Thirdly, more simple and efficient automatic test are significant to simulate smoking behaviour. The characteristics of a single cigarette have a certain randomness, which often needs to reach a certain number of test data to have guiding significance. A large number
of tests require that the test method of cigarette ash wrapping performance is simpler, and the test efficiency and automation degree are higher.

2. Analysis of typical movement trajectory of consumers holding cigarettes
Firstly, the typical actions of consumers holding cigarettes are analysed as follows, after one puff process, consumers hold cigarettes, swing their arms with elbows as the axis. Taking the mouth as the starting point and ashtray as the end point, they will turn their wrists with wrist joints as the axis after reaching the ashtray, or turn their wrists at the same time in the process of swing, as shown in Figure 1. Typical actions of consumers holding cigarettes were carefully analysed, and the circular motion around elbow joint and circular motion around wrist joint in space could be realized. The difference is the radius and angle of circular trajectory.

3. Description of the trajectory of consumers holding cigarettes
In order to determine the geometric shape of cigarette in space, 3 displacement coordinates (position degrees of freedom) and 3 rotation coordinates (attitude degrees of freedom) need to be determined. In robotics, the above 6 degrees of freedom states of a space object are called the pose of the object.

3.1 Description of cigarette position
In the 3-dimensional rectangular coordinate system \{A\}, you can use a 3 \times 1 column vector to represent the cigarette filter end position \( P \), which is the coordinate vector of point \( P \) in the rectangular coordinate system \{A\}, i.e. \( P^x \), \( P^y \) and \( P^z \),

\[
P^A = \begin{bmatrix} p^x \\ p^y \\ p^z \end{bmatrix}
\] (1)

In Eq.1, \( P^x \), \( P^y \) and \( P^z \) represent the coordinate component values on the X, Y and Z axes respectively, as shown in Figure 2.

3.2 Cigarette posture description
To determine the attitude of cigarettes is to determine the direction of each coordinate axis. The rectangular coordinate system \{B\} is defined, in which the cigarette is consolidated, and the origin of
the coordinate system \{B\} is selected at the center of the end position of the cigarette filter. The orientation of the cigarette relative to the coordinate system \{A\} can use a $3 \times 3$ is represented by the rotation matrix $^{A}R_{B}$.

\[
^{A}R_{B} = \begin{bmatrix}
^{A}X_{B} & ^{A}Y_{B} & ^{A}Z_{B}
\end{bmatrix} = \begin{bmatrix}
r_{11} & r_{12} & r_{13} \\
r_{21} & r_{22} & r_{23} \\
r_{31} & r_{32} & r_{33}
\end{bmatrix}
\]

Coordinate system \{A\} is the reference coordinate system, and coordinate system \{B\} is the current coordinate system. Column vectors are unit vectors $^{A}X_{B}$, $^{A}Y_{B}$, $^{A}Z_{B}$, which are perpendicular to each other and satisfy the orthogonality condition.

![Figure 3 Cigarette posture](image)

The position and posture of cigarettes can be uniquely determined in the form of matrix. If the matrix of position and posture above is used, the position and posture of cigarettes in Eqs.3-4 can be $4 \times 4$ homogeneous matrix $T$,

\[
T = \begin{bmatrix}
r_{11} & r_{12} & r_{13} & P^{x} \\
r_{21} & r_{22} & r_{23} & P^{y} \\
r_{31} & r_{32} & r_{33} & P^{z} \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

Generally, $n$, $o$ and $a$ are used to represent the direction vectors of X, Y and Z coordinate axes in the current coordinate system \{B\}, then the pose of cigarettes can be expressed as follows,

\[
T = [n \ o \ a \ p] = \begin{bmatrix}
n_{x} & o_{x} & a_{x} & P^{x} \\
n_{y} & o_{y} & a_{y} & P^{y} \\
n_{z} & o_{z} & a_{z} & P^{z} \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

3.3 Spatial trajectory description of cigarettes

At present, the trajectory of cigarette in space can not be measured directly by sensors. However, from the description of the typical motion trajectory analysis of the cigarette held by the consumers, we can see that the starting point (mouth) and ending point (ashtray) of the cigarette motion trajectory are determined, and the center and radius of the circular motion around the elbow joint are also determined. Therefore, it is relatively easy to determine the trajectory of cigarettes in space.

Only the pose of the end effector at the start and end points is considered. The curve function connecting the two endpoints can be freely selected according to the actual constraints. Among them, polynomial function and parabolic transition linear function are commonly used to realize motion trajectory planning.
4. Realization of movement track of consumers holding cigarettes

There are 6 degrees of freedom of cigarettes in space. In order to simulate the motion trajectory of consumers holding cigarettes, 6R industrial robot was applied, and the robot has 6 degrees of freedom, which can realize the motion trajectory of cigarettes in space.

The cigarette is clamped by the cigarette holder installed on the flange at the end of the robot, and the robot drives the cigarette holder to complete the movement track of the cigarette, as shown in Figure 4.

4.1 Pose description of 6R robot

The pose description of robot includes the description of position and pose. Articulated robot is actually an open chain linkage system connected by rotating and moving joints. Each independently driven joint determines a degree of freedom of the robot. The naming of robot coordinate system is in accordance with the standard GB/T 16977-2005, which specifies a special standard coordinate system.
Base coordinate system \{B\}: it is located on the base of the robot and is fixedly connected to the static part of the robot. It is used as the reference coordinate system of connecting rod 0 in robot linkage mechanism.

Workbench coordinate system \{S\}: located at a corner of the robot workbench. Users generally take this coordinate system as the reference coordinate system for trajectory planning pose, sometimes also known as world coordinate system and general coordinate system. The workbench coordinate system can be described by the robot base coordinate system, which represents the workbench coordinate system. In Figure 6, we take the upper left corner of the workbench (table) where the ashtray is placed as the workbench coordinate system \{S\}.

Wrist coordinate system \{W\}: the wrist coordinate system is located on the end link of the robot operating arm. The tool clamped at the end of the robot can be described conveniently in this coordinate system. The wrist coordinate system can be defined by the base coordinate system and expressed in. In Figure 6, we take the center of the flange for installing the cigarette holder as the wrist coordinate system \{W\}.

Tool coordinate system \{T\}: for the tool installed on the end of the robot operating arm, its posture can be described in the wrist coordinate system, expressed in \(^{w}T\); It can also be described as \(^{s}T\) by the workbench coordinate system. In Eq.5, the end of the cigarette filter is taken as the tool coordinate system \{T\}.

\[
^{w}T \cdot ^{w}T = \quad ^{s}T \cdot ^{s}T
\]  
(5)

From the above formula,

\[
^{w}T = \quad ^{s}T \cdot ^{s}T \cdot ^{s}T^{-1}
\]  
(6)

It can be seen from the above definition that once set, \(^{s}T\) and \(^{s}T\) will be fixed and will not change with the change of robot end trajectory, but they will change with the trajectory of the end of the robot.

4.2 Spatial trajectory simulation of cigarette

In trajectory planning, the workbench coordinate system is usually selected as the reference coordinate system to teach or specify some key points (such as the spatial position of the consumer's mouth, the spatial position of the ashtray, etc.), which is the input sequence \(^{s}T\). Such a parameter will generally be transformed into the planning under the base coordinate system \{B\} in the calculation of the planner, which is obtained according to Eq.6 as the input of the inverse solver, and the angle of each rotating joint will be obtained.

The specific simulation results are shown in Figure 7.

It can be seen that through the above methods and simulation process, the robot arm can better realize the spatial motion trajectory simulation of cigarettes, and provide experimental equipment and basic methods for the analysis of future consumption behaviour and the improvement of cigarette ash setting performance.
5. Conclusion

By analysing the typical action of holding a cigarette, the position, posture and spatial trajectory of the cigarette were described in this paper, and considers the position and attitude of the end effector at the beginning and end. In order to simulate the movement trajectory of consumers holding cigarettes, 6R industrial robot was applied to realize the movement trajectory of cigarettes in space. The cigarette is clamped by the cigarette holder installed on the flange at the end of the robot, and the robot drives the cigarette holder to complete the movement track of the cigarette. The simulation of cigarette spatial motion trajectory is well realized, which provides experimental equipment and basic methods for the analysis of future consumption behaviour and the improvement of cigarette ash setting performance.

Acknowledgments

The financial support of Science and Technology Project of China Tobacco Yunnan Industrial Co., Ltd. (Grant No. 2021CP02) is greatly acknowledged.

References

[1] Altendorf Maria B., Smit Eline S., Azrout Rachid, Hoving Ciska, Weert Julia C.M van. A smoker’s choice? Identifying the most autonomy-supportive message frame in an online computer-tailored smoking cessation intervention [J]. Psychology & Health, 2021, 36(5): 1-26.

[2] Kang Z, Wang X, Cha S, et al. A Multirelational Social Network Analysis of an Online Health Community for Smoking Cessation [J]. Journal of Medical Internet Research, 2016, 18(8):e233.

[3] Agac Sumeyye, Shoaib Muhammad, Incel Ozlem Durmaz. Context-aware and dynamically adaptable activity recognition with smart watches: A case study on smoking [J]. Computers and Electrical Engineering, 2020, 90(3): 106949. DOI: 10.1016/j.compeleceng.2020.106949

[4] Zheng H, Wang H, Zhan J, et al. Effect of Different Puff Modes on Ash Condensation Performance of Cigarettes [J]. Journal of Physics Conference Series, 2020, 1676:012026.

[5] ZHENG H, ZHANG Y, Wang H, et al. Research Progress and Application of Low Ignition Propensity Cigarette Paper [J]. China Pulp & Paper 2017, 36(9): 78-81.

[6] ZHENG H, ZHAN J B, WANG H, et al. Analysis on Research Progress of Cigarette Ash Condensation Properties [J]. The Journal of New Industrialization, 2018, 8(11): 93-97.

[7] ZHANG Y, ZHAN J B, MIAO M M, et al. Evaluation and Analysis of Ash Condensation Performance of Cigarette Paper [J]. China Pulp & Paper 2017, 36(7): 44-47.