A Product Automatically Queuing and Positioning Technology Based on Conveyor Belt

Ma Ziling* and Hao Yongxing

North China University of Water Resources and Electric Power, Zhengzhou, Henan, 450045, P.R. China

Abstract: In order to reduce complexity of a manipulator system grabbing and locating product with uncertain position and posture on conveyor belt, in mobile phone production line as the research background, a product automatically queuing and positioning technology is proposed, which can implement the functions of product storage, queuing and positioning. By analyzing the application environment, mobile phone automatically queuing solutions are proposed, theoretical models about mobile phone automatically queuing are designed. Using non-fixed point collision theory based on rigid body dynamics, collision models between the phone and the phone automatically queuing mechanical device model and between the phone and the phone are analyzed, and collision equations are deduced. The simulation analysis for all kinds of the mobile phone automatically queuing solutions are implemented based on ABAQUS, the results show that multi-adaptive V-groove can queue and position mobile phone with uncertain position and posture efficiently and automatically.

Keywords: ABAQUS simulation, auto queuing and positioning, manipulator, rigid body collision.

1. INTRODUCTION

A manipulator is good at moving objects from a fixed position to another a fixed position, but has larger difficulty to directly moving the objects with uncertain position and posture. Aimed at the problem, the common practice is to first use some kind of method to fix the objects on a fixed position and then move them. In mobile phone production line as the research background, a technology of automatically queuing and positioning products shaped like a mobile phone with uncertain position and posture is researched.

Currently, the production line of testing of the overall unit about mobile phone mainly relies on manpower that pick up the phone to place on testing equipment for testing. After the process, manpower pick up the phone back onto the conveyor belt to flow to the next detection process. Due to rising labor costs, some factories begin to use Multi-DOF (Degree of Freedom) manipulator and testing equipment to replace manpower. But because of high cost and technical complexity the Multi-DOF manipulator do not have the ability of grabbing the moving mobile phone with uncertain position and posture directly from the conveyor belt, it still needs manpower to complete that grab mobile phone and place onto a specialized mobile phone tray according to the demand of fixed position and posture for the multi-DOF manipulator grabbing. In order to replace the work of this staff, according to the ideas of the function of modularization, decentralization and equalization, an intelligently positioning mobile phone manipulator system with low DOF, low cost and good maintainability will be developed to provide mobile phone positioning services for the multi-DOF manipulator. The intelligent positioning mobile phone manipulator system consists of mobile phone automatically queuing module, visual servo module and manipulator module of completing the action of grabbing and placing. This paper focuses on the mobile phone automatically queuing module which can implement the functions of mobile phones storage, queuing and positioning before mobile phones are captured by the manipulator module. The works of the mobile phone automatically queuing module is conducive for the manipulator module to capture mobile phones.

2. MOBILE PHONE AUTOMATICALLY QUEUING SCHEME

Mobile phones are moving forward on the conveyor belt, the position of mobile phones is randomly placed by the production worker. The transported products shape: Length $a = 110$ mm, Width $b = 60$ mm, Thickness $c = 10$ mm, Mass $m = 120$ g. The material of shell is PC (Poly Carbonate), Modulus of elasticity $E = 2300$ Mpa. The speed of conveyor belt $V = 6$ m/min, Width of conveyor belt $B = 500$ mm. The coefficient of friction between the phones is 0.05. The coefficient of friction between the belt and the phone is 0.3. Because the mobile phone locations are not in order and not fixed, it has greatly increased the difficulty of capturing phones for manipulator. Therefore, we consider to design a V-groove (whose function is shown in Fig. 1) to rank these irregular located phones (as in Fig. (1a) to rank these irregular located phones (as in Fig. 1a) and make them have a uniform direction (as in Fig. (1b) after passing through the V-groove. The V-groove can reduce the number of DOF of manipulator to capture the phones when needed.
Solution (1): The ordering of phones by fixed v-groove device. As in Fig. (2), a fixed V-groove and a guide groove are placed on a conveyor belt. We can find a few mobile phones with a specific position can get through by ABAQUS software simulation, but a large number of specially located phones will extrude the V-groove and pile up there without passing through. So this scheme is unfeasible.

Fig. (3). Anti-extrusion V-groove device

Solution (2): The ordering of phones by anti-extrusion v-groove device. We find that an anti-extrusion device should be used if we want to make the irregularly located mobile phones to pass through the v-groove smoothly from the solution (1). As in Fig. (3), the device consists of a pair of symmetrical placement rollers and a guide groove. The cambered surface of the counter rotating device, which is toward the incoming materials, forms an anti-extrusion V-groove together with the conveyor belt [1]. Direction of rotating rollers and the movement direction of the conveyor belt is shown in Fig. (3). Through the ABAQUS simulation, it is found that the large number of specially located phones can pass through the V-groove smoothly by continuously adjusting the speed of two rollers.

Fig. (4). Phones ordered by anti-extrusion V-groove device.

Solution (3): The ordering of phones by the multi-adaptability V-groove device. It is known that the large quantity of and specially located phones can smoothly get through the V-groove by adjusting the speed of the rollers. However, varied rotating speeds are required for different situation. For example, in Fig. (4a), only when the gap between the rotating speeds of two rollers is large and has reached more than 3.5 times can these phones pass through rapidly; in Fig. (4b), only when the differences of the rotating speed between two rollers is relatively small can these phones pass through smoothly. For the situation shown in Fig. (4a), it is required to constantly observe the situation of phones in the v-groove and continuously adjusting the speed ration of two rollers to make phones get through successfully, which greatly increased the difficulty level for monitoring and controlling. Nevertheless, in the process of making simulation analysis with ABAQUS software, it is observed that phones can pass most easily when they are away from the centerline of the conveyor belt. Based on this, we can fix a guide post on the center line of the conveyor belt to separate the mobile phone flow with purpose to make phones close to edge of the roller as much as possible, as in Fig. (5).

Fig. (5). Multi-adaptive V-groove device.

3. MOBILE PHONE COLLISION THEORY MODEL

For the simulation of movement of mobile phone through various V-grooves, theoretical analysis need to be carried out for mobile phone collision process. As to simplify the problem, and in consideration of the actual situation, we assume that the actual contact area in the process of mobile phone collision do not have normal and tangential distortion [2], which belong to rigid contact. So, the mobile phone collision can be simplified as rigid body non-fixed point external impact [3]. For the convenience of analysis, the shape of the mobile phone is simplified into a cuboid, and the rollers is simplified into a cylinder, so the collision model between the mobile phone and the rollers is shown in Fig. (6a), and the collision model between mobile phone and mobile phone is shown in Fig. (6b). The collision between the phone and the guide post and the collision between the phone and the V-groove are similar to the collision between the mobile phone and the rollers.

Fig. (6). The collision model in V-groove.

To study mobile phone collision motion law [2] using the momentum balance method (discretization method), for the collision phenomenon and system we assume that [4]: 1) Collision process is completed instantaneously, the collision process has greatly impact force, the ordinary force of elastic
force and gravity can not compare with it, so the momentum of these common force is negligible; 2) Collision contact surface is very small, which can be regarded as a line segment, collision deformation is within a very small range based on the line segment; 3) The displacement of the object is negligible in the collision process; 4) Do not consider the impact of friction during the collision; 5) Before and after the collision, all objects’ geometry and inertia parameters are unchanged; 6) Recovery coefficient only depends on the material, which is regardless of local and overall geometry of the object, the size of the speed and the tangential velocity. Here, the recovery coefficient is 1 [5].

3.1. Mathematical Model of Collision Between Mobile Phone and Roller

The collision model between the mobile phone and the rollers is shown in Fig. (7), rectangular plane coordinate system is established in the center (Point P) of the collision zone, and the model is simplified as the collision between rectangle ABCD and arc surface. Before the collision, the speed of barycenter of rigid body M (which is the mobile phone, whose barycenter is M) is \( \mathbf{V}_M \), and the angular velocity is \( \mathbf{W}_{m0} \). After collision speed, the speed of barycenter of rigid body M is \( \mathbf{V}_M' \), the angular velocity is \( \mathbf{W}_{m1} \). The quality of the rigid body is \( m \), the length is \( a \), the width is \( b \), and the moment of inertia is \( J = \frac{1}{12}m(a^2+b^2) \).

Here are the collision equations in rigid body plane motion.

\[
\begin{align*}
\text{m}\mathbf{V}_{Mx} - \text{m}\mathbf{V}_{Mx}' &= \sum I_x \\
\text{m}\mathbf{V}_{My} - \text{m}\mathbf{V}_{My}' &= \sum I_y \\
\text{JW}_{m1} J\mathbf{W}_{m0} &= \sum M \mathbf{I}^{(e)}
\end{align*}
\]

(1) (2) (3)

Because the contact collision is frictionless, only the Y-direction collision momentum \( I_y \) is considered, \( I_y = 0 \). As the rigid body is doing plane motion, we can get

\[
\mathbf{V}_c = \mathbf{V}_M + \mathbf{V}_{CM}, \quad \mathbf{V}_c' = \mathbf{V}_M' + \mathbf{V}_{CM} \quad \text{(4)}
\]

And because

\[
\mathbf{V}_{Mx}' = \mathbf{V}_M, \quad K_x \left| \frac{\mathbf{V}_c'}{\mathbf{V}_c} \right| = 1 \quad \text{(5)}
\]

According to Equation (1)-(5), we can deduce

\[
\begin{align*}
\mathbf{W}_{m1} &= \frac{12\mathbf{V}_{Mx}\cos\beta + (3\cos^2\beta - 1)\mathbf{W}_{m0}\sqrt{a^2+b^2}}{(3\cos^2\beta + 1)\sqrt{a^2+b^2}} \\
\mathbf{W}_{m1} &= \mathbf{V}_{Mx}' + \mathbf{W}_{m0}\sqrt{a^2+b^2}\cos\beta - 3\mathbf{V}_{Mx}\cos^2\beta \\
&= 3\cos^2\beta + 1
\end{align*}
\]

(6) (7)

3.2. Mathematical Model of Collision Between Mobile Phone and Mobile Phone

The collision model between mobile phone and mobile phone is shown in Fig. (8), rectangular plane coordinate system is established in the center (Point P) of the collision zone, and the model is simplified as the collision between rectangle ABCD and rectangle EFGH, whose barycenter are M and N. Before the collision, the speed of barycenter of rigid body M (which is one mobile phone) is \( \mathbf{V}_M \), the angular velocity is \( \mathbf{W}_{m0} \), the distance between collision point and barycenter is \( L_1 \); the speed of barycenter of rigid body N (which is one mobile phone) is \( \mathbf{V}_N \), the angular velocity is \( \mathbf{W}_{n0} \), the distance between collision point and barycenter is \( L_2 \). After collision speed, the speed of barycenter of rigid body M is \( \mathbf{V}_M' \), the angular velocity is \( \mathbf{W}_{m1} \), the speed of barycenter of rigid body N is \( \mathbf{V}_N' \), the angular velocity is \( \mathbf{W}_{n1} \). The quality of the two rigid body
are \( m \), the length is \( a \), the width is \( b \), and the moment of inertia is \( J = \frac{1}{12} m(a^2 + b^2) \). Collision process is as follows:

According to the law of conservation of momentum

\[
m\vec{V}_M + m\vec{V}_N = m\vec{V}'_M + m\vec{V}'_N \tag{8}
\]

According to the theorem of impulse moment

\[
JW_{11} - JW_{20} = \sum M_M (I_M^0) \tag{9}
\]

\[
JW_{11} - JW_{20} = \sum M_N (I_N^0) \tag{10}
\]

According to the theorem of impulse

\[
m\vec{V}_M - m\vec{V}_N = \sum I_M^0 \tag{11}
\]

\[
m\vec{V}_N - m\vec{V}_M = \sum I_N^0 \tag{12}
\]

According to Newton's recovery coefficient [6]

\[
K = \left| \frac{\vec{V}_c - \vec{V}_p}{\vec{V}_c - \vec{V}_p} \right| = 1 \tag{13}
\]

According to theorem of kinetic energy

\[
\frac{1}{2} JW_{11} + \frac{1}{2} mV_{11}^2 + \frac{1}{2} mV_{20}^2 = \frac{1}{2} JW_{00} + \frac{1}{2} mV_{00}^2 + \frac{1}{2} JW_{00} + \frac{1}{2} mV_{00}^2 \tag{14}
\]

Because it is smooth contact collision, only the Y-direction collision momentum \( I_y \) is considered, \( I_x, I_z = 0 \). The rate in the X direction remains unchanged before and after the collision.

And because

\[
I_M^0 = I_N^0 \tag{15}
\]

\[
\vec{V}_c = \vec{V}_M + \vec{V}_C \tag{16}
\]

\[
\vec{V}_c = \vec{V}_N + \vec{V}_C \tag{17}
\]

\[
\vec{V}_p = \vec{V}_N + \vec{V}_PN \tag{18}
\]

\[
\vec{V}_p = \vec{V}_N + \vec{V}_PN \tag{19}
\]

Thus, according to Equation (8)-(19), we can calculate

\[
W_{11} = \frac{(mL_1^2 \cos \alpha + 2J mL_1^2 \cos \beta) W_{11}}{(mL_1^2 \cos \alpha + 2J mL_1^2 \cos \beta)} \tag{20}
\]

\[
W_{11} = \frac{(mL_1^2 \cos \beta + 2J mL_1^2 \cos \alpha) W_{11}}{(mL_1^2 \cos \beta + 2J mL_1^2 \cos \alpha)} \tag{21}
\]

\[
V_M = \frac{JW_{11} + JW_{20}}{mL_1 \cos \beta} + V_M \tag{22}
\]

\[
V_N = \frac{JW_{11} - JW_{20}}{mL_1 \cos \beta} + V_M \tag{23}
\]

The barycenter speed and the angular velocity after the two mobile phones collision can be obtained according to the above conditions, and so the movement path can be determined.

### 3.3. Law of Motion After the Collision

Mobile phone status after the collision: Translation and rotation (As in Fig. 9), the barycenter speed \( V_c \) and the angular velocity \( \omega \) are known. The coefficient of friction between mobile phone and the plane is \( \mu \).

**Fig. (9).** Motion model after mobile phone collision.

1. For translational motion: On the plane to make uniform deceleration, the change relationship of the speed can be obtained

\[
V_t = V_{0t} - gt \tag{24}
\]

2. For rotational movement around the z axis

As shown in Fig. (9), a rectangular figure unit with length \( dy \) and width \( dx \) is taken out.

The friction the figure unit suffered is

\[
df = \mu dN = \mu gd m \frac{dy}{ab} \tag{25}
\]

The torque the figure unit suffered relative rotation is

\[
dM = \sqrt{x^2 + y^2} df \tag{26}
\]

The total torque physical block suffered is

\[
M = \int dM = \frac{\mu gm}{2b} \int_{-a}^{a} \int_{-b}^{b} \sqrt{x^2 + y^2} \, dx \, dy \tag{27}
\]

Assuming that rotation time of mobile phone is \( t \). According to angular momentum theorem, there is

\[
\int_0^t M \, dt = JW_0 \tag{28}
\]
4. THE SIMULATION AND VERIFICATION OF THE MULTI-ADAPTIVE V-GROOVE TO QUEUE AND POSITION MOBILE PHONE

In the above, the simulated effect about Solution (1) and Solution (2) are explained. Here, the effectiveness of the Solution (3) with good expected effect will be verified.

Fig. (10). Simulation verification by ABAQUS.

On the premise of setting roller speed is a fixed value, the result of using ABAQUS software modeling and simulation is shown in Fig. (10), the model parameters are shown in Table 1, the friction coefficients between each components are shown in Table 2. Fig. (10) (a) and (b) show that: When high flow, special position mobile phone through the multi-adaptive v-groove, Solution (3) not only can achieve the purpose of queuing and positioning mobile phone, but also eliminates the issue that the anti-extrusion v-groove need to constantly adjust rollers speed because the rotational speed of each of the two rollers is fixed. Therefore, this scheme is feasible. In addition, ABAQUS software simulation show that the program are highly adaptable for a variety of conditions, Fig. (4) condition, Fig. (1a) and other special locations can be solved.

But a large amount of simulations show that: Time of mobile phone through V-groove changes with two roller speed adjustment. When one roller velocity is fixed, the relationship between the time of mobile phone through V-groove and the roller velocity ratio is shown in Fig. (11); when the roller speed ratio is fixed, the relationship between the time of mobile phone through V-groove and the roller velocity with larger velocity is shown in Fig. (12). In addition, ABAQUS software simulation show that: The distance between guide post and roller edge should not be too far, which is about a little more phone diagonal. Otherwise it unable to play a good guide. Finally, the optimized model operating speeds are shown in Table 3.

To further facilitate the work of manipulator grabbing, we can add a baffle at the end of the guide groove, as in Fig. (13). After adding the baffle, the queued phone will be stored in the guide groove. Whenever grabbing, the manipulator just goes grabbing the phone close to baffle. After the phone closed to baffle were taken, the phone stored in the guide groove will move forward into a mobile phone's location, so there is another phone to stay close to baffle in the guide groove to wait for next grabbing. This allows the manipulator to grab the phone each time at a fixed position, which reduces the complexity of the manipulator greatly and helps to reduce system cost and improve system maintainability.

Fig. (11). The relationship between transit time and the roller velocity ratio.

Fig. (12). The relationship between transit time and roller speed in a certain speed ratio.

According to the relevant parameters mentioned above, three-dimensional entity model of a multi-adaptive V-groove device is designed, as shown in Fig. (14). Among them, additive special product tray, manipulator, camera and its holder is for hinting the function relationship between them and the multi-adaptive V-groove device.

<table>
<thead>
<tr>
<th>Table 1. Model parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
</tr>
<tr>
<td>Roller</td>
</tr>
<tr>
<td>Conveyor belt</td>
</tr>
<tr>
<td>Mobile phone</td>
</tr>
<tr>
<td>Guide roove</td>
</tr>
<tr>
<td>Guide post</td>
</tr>
</tbody>
</table>
Table 2. The coefficient of models.

<table>
<thead>
<tr>
<th></th>
<th>Mobile Phone</th>
<th>Roller1</th>
<th>Roller2</th>
<th>Guide Post</th>
<th>Guide Groove</th>
<th>Conveyor Belt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile phone</td>
<td>0.05</td>
<td>0.4</td>
<td>0.4</td>
<td>0.05</td>
<td>0.05</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table 3. The operating speed of models.

<table>
<thead>
<tr>
<th></th>
<th>Roller1</th>
<th>Roller2</th>
<th>Conveyor Belt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating speed</td>
<td>0.08 rad/s</td>
<td>0.3 rad/s</td>
<td>0.1 m/s</td>
</tr>
</tbody>
</table>

Fig. (13). Multi-adaptive v-groove with a baffle.

Fig. (14). Three-dimensional entity model of a multi-adaptive V-groove device.

CONCLUSION

In this paper, it mainly studies on how to queue and position the products shaped like a mobile phone with uncertain position and posture automatically when they move on the conveyor belt. In mobile phone production line as the research background, using kinetic knowledge, the kinetic equations of mobile phone non-fixed point external impact and after the collision the kinetic equations of mobile phone are deduced. And using ABAQUS software to model, simulate and analyze, the feasibility of the multi-adaptive V-groove to queue and position mobile phone is determined. The program can make the original chaotic phone have unified direction and fixed position. The study not only provides a method for automatically queuing and positioning products shaped like a mobile phone with uncertain position and posture on conveyor belt, but also can reduce the cost of products and the operation difficulty of the manipulator greatly.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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