Collision algorithm design based on dynamic rotation model

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Abstract. This article aims to study the inelastic collision between system, based on the daily life of drum ball collision problems, by combining the collision body as well as the impact of instantaneous rotation process of damping kinetic energy consumption situation, designs a Rotating collision model algorithm model of concentric drums collision problem, and then apply those algorithms to stimulate the size of the drum’s offset that produced by the effect of different tension.

1. Introduction

1.1 Research Introduction

"Working together" (also known as "Tong Xin drum") is a team cooperation ability development project. The prop of the project is a cow leather double-sided drum, with multiple ropes fixed in the middle of the drum body. The fixed points of the ropes on the drum body are evenly distributed along the circumference, and each rope has the same length. Each team member pulls a rope to keep the drum level. At the beginning of the project, the ball falls vertically from the center of the drum surface, and the players work together to shake the ball up and make it beat on the drum surface rhythmically. In the process of hitting the ball, the players can only grasp the end of the rope and cannot touch the drum or other positions of the rope.

In this activity, the collision process between the drum and the ball involves a series of processes such as the material type, deformation, rotation of the object and so on, among which the stress situation is extremely complex. People often change their own tension strategy according to their own experience in the process of this activity, and the different tension produced by different people also has a variety of hard to estimate effects on the whole system.

The purpose of this paper is to study the process of this kind of collision, to study the optimal force of individuals by establishing a dynamic rotation collision damping model, and to use this model to simulate the impact of the timing and size of human forces on the collision of the whole system in various situations.

1.2 Background assumptions

According to the actual data of "working together" drum beating activities, this paper sets up the ball drum collision model, in which the rope length is 1.7m, the sphere diameter is 21cm, the drum surface diameter is 40cm, and the drum surface height is 20cm. There are eight people evenly around, pulling the rope at the same level. Initially, the end height of the rope is 11cm higher than the drum surface. At the same time, after each collision, the distance between the ball and the drum should be at
least 40 cm. An example of the model background is shown below.

**Figure 1.** Ball and drum collision model

2. Introduction to the model

In the actual situation, it is impossible to control the timing and intensity of each person’s force accurately, so some people may exert too much force or pull at different times. Therefore, this paper takes 8 ropes connected to the concentric drum as the research object, establishes the dynamic rotation mode, and simulates the offset of system entanglement under different external forces.

Because the drum is in the state of suspension and its force is uneven, so it's going to rotate. Assuming the tension lasts for 0.1s, during this period, the drum's rotation axis is a diameter passing through the drum center and the axis will not change. When the rotation axis is taken as the reference system, the cosine of the drum's surface inclination angle is the target function

$$\cos \theta = \frac{(H_{\text{high}} - H_{\text{low}})}{0.4}$$

(1)

Where $H_{\text{high}}$ is the rising distance on the higher side of the edge, $H_{\text{low}}$ is the rising distance on the lower side.

2.1 Dynamic rotation model

2.1.1 Determination of rope tension

In the problem hypothesis, we think that the tension of people is horizontal, so the tension of each person to the rope along the rope direction is:

$$F_{\text{rope}} = F \cos \theta_{\text{rope}}$$

(2)

$\cos \theta_{\text{rope}}$ is the angle between the rope and the horizontal plane, whether the drum surface is higher or lower than the position of the hand, the angle between the rope and the horizontal plane is $\cos \theta_{\text{rope}}$, and it has the following equation relationship:

$$\cos \theta_{\text{rope}} = \left| \frac{H_k - 0.11}{1.7} \right|$$

(3)

$H_k$ is the relative displacement of the Kth rope node

Because the drum is in an inclined state, the height change of the rope at different positions is different from the initial position. By similarity, we get the relative displacement of each rope as follows:

$$H_{ik} = H_{\text{low}} + \frac{(H_{\text{high}} - H_{\text{low}}) \times (0.2 + (-1)^i \sin(\theta_{ik}) \times 0.2)}{0.4}$$

(4)

The higher side is called the high-level surface, and the lower side is called the low-level surface, $i$ represents the level surface of the rope, $i \in (0, 1)$. 0 is the high-level surface, and 1 represents is the
low-level surface.

2.1.2 Determination of moment

Because the resultant force of the drum is not zero, it will rotate along a fixed axis under the action of external force, and it will produce torque and angular momentum in the process of rotation.

A. Decompose the force

The force on the rope is divided into two forces $F_{ikc}$ and $F_{ikp}$, which are perpendicular to the axis, $K$ is the $K$th stress point.

From the above figure, it can be seen that $\theta$ is the inclination of drum surface, $\theta_{ikr}$ is the inclination of rope, $F_{ikc}$ is the force perpendicular to the center of mass at the k-th point of force, $F_{ikp}$ is the force parallel to the center of mass, and $Z$ is the rotation axis perpendicular to the in-plane of drum. We take the axis of rotation as the dividing line, and the tension on the rope in the high and low plane is decomposed into:

$$
\begin{align*}
F_{ikc} &= F_{ik} \cdot \sin(\theta_{ikm}) \\
F_{ikp} &= F_{ik} \cdot \sqrt{1 - (\sin(\theta_{ikm}))^2}
\end{align*}
$$

Expansion by cosine theorem

$$
\begin{align*}
F_{ikc} &= F_{ik} \cdot (\sin(\theta_{ikr}) \cdot \cos(\theta_{ikr}) - \cos(\theta_{ikr}) \cdot \sin(\theta_{ikr})) \\
F_{ikp} &= F_{ik} \cdot \sqrt{1 - (\sin(\theta_{ikr}) \cdot \cos(\theta_{ikr}) - \cos(\theta_{ikr}) \cdot \sin(\theta_{ikr}))^2}
\end{align*}
$$

At the same time, we can see from the figure that the included angle of the drum surface angle $\theta$ is only at the angle perpendicular to the axis plane, but for other rope nodes, the included angle of the mass center plane and the horizontal plane will vary with the rope position.

From the cross-section diagram, we can see that the horizontal section is an ellipse, its top is a circular surface, radius is 0.2m. We assume that the inclination angle of the drum in the process of
inclination will not exceed \( \arctan \frac{0.22}{0.4} \), that is, make a vertical line from the inside of the circle surface of the elliptical surface, and the distance between the point where the vertical line is and the center of the circle is always 0.2. Therefore, for each rope node, we can get the long and short axis lengths \( a \) and \( B \) of the ellipse, according to the ellipse formula, the angle \( \theta_i \) is

\[
\begin{align*}
\frac{x^2}{A^2} + \frac{y^2}{B^2} &= 1 \\
A &= 0.2 / \cos(\theta) \\
B &= 0.2
\end{align*}
\]  

(7)

\[
\cos(\theta_i) = \frac{0.2*(B^2 + \tan^2(q) * A^2)}{\sqrt{A^2 * B^2 * \cos(q)}}
\]

(8)

In which \( q_{ik} \) is the angle between the Kth rope node and the shaft.

Due to the inertia of the drum, there may be a situation where the rising height exceeds the rope height, as shown in the figure below.

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**Figure 5.** Stress analysis figure two

So, the force of the drum on the rope is decomposed into

\[
\begin{align*}
F_{ikc} &= F_i * (\sin(\theta_{ikr}) \cos \theta_{ikr} + \cos(\theta_{ikr}) \sin \theta_{ikr}) \\
F_{ikp} &= F_i * \sqrt{1-(\sin(\theta_{ikr}) \cos \theta_{ikr} + \cos(\theta_{ikr}) \sin \theta_{ikr})^2} \\
L_{ik} &= \sum_{i=0}^{1} ((\sum_{k=0}^{n} F_{ikc} * Len_{ik}) - \frac{W \times g \times R \times \cos}{\pi}) \\
V_{ik} &= \sum_{i=0}^{1} \frac{L_{ik}}{I} \times R \times \cos \theta
\end{align*}
\]

It can be concluded that in the process of motion, the change of angle between \( \theta_{ikr} \) and \( \theta_{ik} \) will lead to a certain change in the calculation method at the same time.

Then, the force arm size of all ropes is

\[
Len_{ik} = 0.2 * \sin(q_{ik})
\]

(9)

Therefore, in the higher half area, the torque applied by the rope to the drum body is

\[
M_0 = \sum_{k=1}^{n} F_{ikc} * Len_{ik}
\]

(10)

In the lower half area, the torque applied by the rope to the drum is
\[ M_k = \sum_{k=1}^{n} F_{dc} \cdot \text{Len}_{sk} \]  

(11)

Since the rotation of the drum is divided into upper and lower half, the gravity of the drum is also divided into two plates in the upper and lower half. According to the query data, the center of mass of the hollow semicircle ring is based on the center of the circle, so the moment provided by the gravity in the upper and lower half is

\[ M_w = \frac{M \cdot g \cdot R \cdot \cos \theta}{\pi} \]  

(12)

Where \( G \) is the acceleration of gravity, taking 9.8 m/s\(^2\) here, To sum up, the moments in the upper and lower half are \( M_0 - M_w \) and \( M_1 - M_w \) respectively.

### B. Detection of rotation state

It is known that under the action of external force, we can calculate the torque and rotation direction of "concentric drum", so the angular velocity of drum can be obtained. Because there are different angular velocities at the high and low ends of drum, we need to use the rotation axis as the reference system, and then calculate the drum surface angle based on the relative displacement of the high and low sides of drum.

If we regard a drum as a rigid body with a fixed axis, its angular momentum is

\[ L = I \omega \]  

(13)

The inside of the drum is hollow, and most of its mass is concentrated on the outside. We can regard the drum as a hollow ring, and its moment of inertia \( I \) is \( \frac{I = M \cdot R^2}{2} \) so the angular velocity generated by the half sector is \( \omega = \frac{M_0 - M_w}{I} \), and the angular velocity of the lower half sector is \( \omega = \frac{M_1 - M_w}{I} \). In order to simplify the model, we use the displacement difference between the ends of the two sectors to calculate the drum inclination.

That is, the end velocity of the upper half of the sector is \( V_0 = \omega \cdot R \cdot \cos \theta \). Similarly, we can get \( V_1 = \omega_1 \cdot R \cdot \cos \theta \).

### 2.2 Establish dynamic rotation model

The dynamic rotation model established is as follows

\[ \theta = \arccos\left( \frac{H_{\text{high}} - H_{\text{low}}}{2 \cdot R} \right) \]  

(14)
\[
\cos \theta_{ik} = \frac{|h_k - 0.11|}{1.7}
\]
\[
\cos \theta_i = 0.2 / (\sqrt{A^2 \times B^2} / (B^2 + \tan^2(q_k) \times A^2)) / \cos(q_k)
\]
\[
F_{ik} = F_k \times (\sin(\theta_{ik}) \times \cos(\theta_{ik}) \pm \cos(\theta_{ik}) \times \sin(\theta_{ik}))
\]
\[
Len_{ik} = 0.2 \times \sin(q_k)
\]
\[
L_{ik} = \int_{t=0}^{0.1} \left( \sum_{k=0}^{n} \frac{F_{ik} \times Len_{ik}}{W \times g \times R \times \cos(\theta)} \right) dt
\]
\[
V_{ik} = \int_{t=0}^{0.1} L_{ik} \times R \times \cos(\theta) dt
\]
\[
H_{high} = \int_{t=0}^{0.1} V_{ik} \times dt
\]
\[
H_{low} = \int_{t=0}^{0.1} V_{ik} \times dt
\]

Where \( k \) represents the rope number, \( \theta_{ik} \) represents the angle between the \( K \)th rope and the horizontal direction, \( R \) is the abbreviation of rope, \( \theta_i \) represents the angle between the elliptical surface and the centroid surface, \( I \) represents the high and low level surface, \( 0 \) represents the high level surface, \( 0 \) represents the high level surface, \( t \) represents the time change, where \( q_{ik} \) is the angle between the rope node and the shaft.

In the establishment of the problem model, triple or even quadruple integration is used to solve the problem. The direct solution is very difficult and the operation speed is very slow. Therefore, we divide the time in \( 0 \sim 0.1s \), the time step is \( 0.0001 \), and transform the integration into difference. The equation is solved by the initial condition \( \theta = 0 \). By using MATLAB, the solution results are as follows:

| serial | strategy | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Raised Angle |
|--------|----------|---|---|---|---|---|---|---|---|--------------|
| 1      |          | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2021       |
|        |          | 90| 80| 80| 80| 80| 80| 80| 80|               |
| 2      |          | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.3153       |
|        |          | 90| 90| 80| 80| 80| 80| 80| 80|               |
| 3      |          | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1335       |
|        |          | 90| 80| 80| 90| 80| 80| 80| 80|               |
| 4      |          | -0.1| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2309       |
|        |          | 80| 80| 80| 80| 80| 80| 80| 80|               |
| 5      |          | -0.1| -0.1| 0 | 0 | 0 | 0 | 0 | 0 | 0.0217       |
|        |          | 80| 80| 80| 80| 80| 80| 80| 80|               |
| 6      |          | -0.1| 0 | 0 | -0.1| 0 | 0 | 0 | 0 | 0.0131       |
|        |          | 80| 80| 80| 80| 80| 80| 80| 80|               |
| 7      |          | -0.1| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5736       |
|        |          | 90| 80| 80| 80| 80| 80| 80| 80|               |
| 8      |          | 0 | 0 | 0 | 0 | -0.1| 0 | 0 | 0 | 0.1466       |
|        |          | 90| 80| 80| 90| 80| 80| 80| 80|               |
| 9      |          | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.1233      |
|        |          | 90| 80| 80| 90| 80| 80| 80| 80|               |

During the calculation of the drum tilt angle, it is found that the drum tilt angle is very small, and
there is no case that the tilt angle is greater than \( \frac{0.22}{0.4} \arctan \) (as shown in Figure 3-4), so the model fits the reality.

3. Summary

In the force analysis of the "concentric drum" movement, this paper use the geometric relationship and force analysis to simulate the whole drum movement process, and convert the multiple integral into difference skillfully to improve the feasibility and efficiency of the operation.

At the same time, the established equivalent spring damping model has a wide range of applicability, which can be applied to other kinds of ball collision scenes. The collision between volleyball and drum can be replaced by the collision between table tennis and racket. By quantifying the separation speed and angle and applying it to the sports competition of artificial intelligence, the current artificial intelligence is extremely hot in sports competition, but most of the current research focuses on the determination of the contact impact point, the equivalent spring damping model can be used to quantify the subsequent motion process and further expand its application direction.

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