Design and motion analysis of a novel track platform

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Abstract. Combining with the advantages of traditional track and omnidirectional wheels, omnidirectional track was proposed. A variety of track platforms were designed based on the structure of omnidirectional track, which have omnidirectional motion ability, and compared their advantages and disadvantages. The kinematics model, Lagrange dynamic model were established. Selecting a typical platform as the analysis object, virtual prototype was developed using ADAMS, and the typical omnidirectional motions were simulated, longitudinal motion, lateral motion and centre steering motion. Simulation results show that the platform has omnidirectional motion performance.

1. Introduction
The traditional track platforms have strong ability to adapt to the various complex terrain, but lack of mobility comparing to the wheeled platform. However, omnidirectional platforms have perfect mobility with three degrees of freedom, but often on the flat ground, not in the complex terrain [1-2]. In some special circumstances, omnidirectional platforms have great advantages in their applications [3-4]. Therefore, we should combine the advantages of them. In the paper [5], the omnidirectional track, which has multiple degrees of freedom, was designed, based on the walking structure of common wheeled omnidirectional platform and the structure of the traditional track, and a track omnidirectional platform was developed. Based on omnidirectional track, in this paper the platform structure was optimized, and some new structures with overlapping and symmetrical layout were proposed, and the kinematics model, dynamic model analysis were carried out. Finally, through simulation of the virtual prototype in ADAMS, the platform's motion performance is verified.

2. Design of platform structure
In order to ensure that the platform has strong off-road capability, its four tracks were in accordance with the symmetrical form of layout, just like traditional track platform. The structure of longitudinal symmetrical non-overlapping shown in figure 1(a) was studied in paper [5], and experiment results show that it has strong off-road capability. However, the volume of the platform is limited to its layout shown in figure 1(a). On the basis of the platform, some longitudinal overlapping layout structures are proposed, partially overlapping as shown in figure 1(b), and completely overlapping as shown in figure 1(c). The new layouts not only guarantee the omnidirectional motion ability and strong off-road capability of the platform, but also can further reduce the platform volume size. However, the difficulty in the installation of track and the design of drive system is increasing, making the whole structure of walking system becomes more complicated.
(a) Longitudinal symmetrical non-overlapping

(b) Longitudinal symmetrical partially overlapping

(c) Longitudinal symmetrical completely overlapping

Figure 1. Structure of platforms.

The parameters of the platform are as follows. The length of the main body is $L$ and the width of the main body is $b$. The ground length of track is $L_1$ and the width of track is $h_1$. The radius of the driving wheel is $R$. The longitudinal overlapping degree of the track in same side is $\eta$ (0 ≤ $\eta$ ≤ 1). The longitudinal outside distance between driving wheel in same side is $\alpha$. As shown in figure 1(a), $\eta = 0$, the total ground length of the platform is $2L + 2R + \alpha$, and the width of the platform is $b + 2h_1$. As shown in figure 1(b), $0 < \eta < 1$, the total ground length of the platform is $(2 - \eta)L_1$, and the width of the platform is $b + 4h_1$. As shown in figure 1(c), $\eta = 1$, the total ground length of the platform is $L_1$, and the width of the platform is $b + 4h_1$. According to requirements in design of the traditional track platforms, generally the ratio between the ground length of the track and the center distance is less than 1.6-1.8 [6]. Therefore, the design process of omnidirectional platform proposed in this paper needs to pay attention to the ratio value to ensure the platform’s performance. Overall, the two types of platforms in figure 1(a) and 1(c) are easier to implement in engineering design and easy to use, and the platform shown in figure 1(c) is smaller in volume size. However, the platform shown in figure 1(b) is more difficult in engineering design, but the two tracks on the front can be designed as active tracks.
When encountering obstacles two front tracks can automatically lift as joint tracks to furtherly improve the abilities of climbing obstacles of the platform, which could expand more applications for the platform.

3. Motion analysis of platform

Generally, there are two main methods for the motion analysis, Newton Euler method and Lagrange method [7]. In this paper, the dynamic analysis is performed by Lagrange method for the platform shown in figure 1(c).

The Lagrange dynamics equation with dissipative function is [7]

$$\frac{d}{dt}(\frac{\partial L}{\partial \dot{q}}) - \frac{\partial L}{\partial q} + \frac{\partial \Phi}{\partial q} = Q$$

(1)

Where $L$ is Lagrange function of the system, equaling to the difference between kinetic energy and potential energy of the system. $q$ is the system generalized coordinate. $Q$ is the generalized force or torque to the generalized coordinate. $\Phi$ is the dissipation function. In general, if $q$ is the line coordinate, $Q$ is the generalized force. if $q$ is the angular coordinate, $Q$ is the generalized torque [8].

Assuming that the platform moves on flat road, the potential energy of the platform is $U = 0$. The kinetic energy in track vehicle includes two parts, implicated kinetic energy and relative kinetic energy [9]. In order to calculate the kinetic energy of the relative motion of the track, the equivalent rotary inertia of the whole track is obtained by converting the rotating components, such as track shoes, loading wheels, carrier wheels, inducer and other parts, rollers out the track, to the driving wheels [10], which is

$$I_w = \frac{1}{2} \sum_{i=1}^{n} a_i \left( m_i + \frac{m_i}{n} \right) r_i^2$$

(2)

Where $I_w$ is the equivalent rotary inertia of the entire track. $m_i$ is the mass of the $i$-th wheel in the track. $m$ is the overall mass of track and rollers (don’t including any wheels). $n$ is the whole number of all wheels in the entire track (including driving wheels, loading wheels, carrier wheels, inducer wheels). $r_i$ is the radius of the $i$-th wheel. $r_i$ is the radius of the driving wheel. $a_i = \frac{r_i}{r_j}$ is the conversion ratio.

Ignoring rotation of rollers out of omnidirectional track, the kinetic energy of the platform is

$$V = \frac{1}{2} m \left( v_x^2 + v_y^2 \right) + \frac{1}{2} I_z \omega_z^2 + \frac{1}{2} I_w \sum_{j=1}^{4} \omega_j^2$$

(3)

Where $m$ is the total mass of the platform (including all of tracks, wheels). $I_z$ is the overall rotary inertia of the platform. $v_x, v_y, w_z$ are the x-axis, y-axis velocity components and z-axis angular velocity components of the platform. $w_j$ is the angular velocity of the $j$-th ($j=1,2,3,4$) driving wheel.

The dissipation function in the track vehicle consists of two parts, dissipation energy of track system and dissipation energy of friction between track shoes and ground. Generally, the first part is coming from track itself, containing of friction between track shoes and driving wheels, loading wheels, carrier wheels, inducer and other parts, and friction of driving system with motors, and dissipation energy of vibration in the shock absorption system [11]. The second part is mainly friction between track shoes and ground, containing sliding friction and steering friction. Taking the dissipation factor as $D$, then

$$\Phi = \frac{1}{2} D \sum_{j=1}^{4} \omega_j^2$$

(4)

The platform shown in figure 1(c) is simplified to getting top view, and platform structure parameters are obtained, as shown in figure 2.
Getting the kinematics equation of platform is [5]

\[
\begin{pmatrix}
v_y \\
v_x \\
\omega_z
\end{pmatrix} = r
\begin{pmatrix}
\frac{1}{4} & -1 & -1 & 1 \\
-\tan \alpha & -\tan \alpha & \tan \alpha & \tan \alpha \\
\frac{1}{4} & \frac{1}{4} & \frac{1}{4} & \frac{1}{4} \\
B_1 & B_2 & B_3 & B_4
\end{pmatrix}
\begin{pmatrix}
\omega_1 \\
\omega_2 \\
\omega_3 \\
\omega_4
\end{pmatrix}
\]  

To simplify the calculation, assuming \(B'_1 = \frac{B_1}{2B_1^2 + 2B_2^2}\), \(B'_2 = \frac{B_2}{2B_1^2 + 2B_2^2}\), then get the kinematics equation of platform

\[
\begin{pmatrix}
\alpha_y \\
\alpha_x \\
\omega_z
\end{pmatrix} = \frac{r}{4}
\begin{pmatrix}
1 & -1 & -1 & 1 \\
-\tan \alpha & -\tan \alpha & \tan \alpha & \tan \alpha \\
4B'_1 & 4B'_2 & 4B'_3 & 4B'_4
\end{pmatrix}
\begin{pmatrix}
\omega_1 \\
\omega_2 \\
\omega_3 \\
\omega_4
\end{pmatrix}
\]  

The generalized coordinate of the platform is \(\theta_i\), which is the angular displacement of the driving wheels. The generalized force is \(T_i\), which is the torque of driving wheels out from motors. Based on the kinematic equation of the platform, the Lagrange dynamic equation of the track omnidirectional platform can be obtained

\[
\begin{pmatrix}
M_1 + I_{z1} + I_w \\
-M_z + I_{z12} \\
-M_1 + I_{z12}
\end{pmatrix}
+ \begin{pmatrix}
\theta_1 \\
\theta_2 \\
\theta_3
\end{pmatrix}
\begin{pmatrix}
0 & 0 & 0 & 0 \\
0 & D & 0 & 0 \\
0 & 0 & D & 0
\end{pmatrix}
\begin{pmatrix}
\theta_1 \\
\theta_2 \\
\theta_3
\end{pmatrix}
= \begin{pmatrix}
T_1 \\
T_2 \\
T_3
\end{pmatrix}
\]

Where \(M_i = \frac{mr^2}{16}(1 + \tan^2 \alpha)\), \(M_z = \frac{mr^2}{16}(1 - \tan^2 \alpha)\), \(I_{z1} = I_1 r^2 B_1^2\), \(I_{z2} = I_2 r^2 B_2^2\), \(I_{z12} = I_1 r^2 B_1 B_2^2\).

Based on the dynamic equation, the further motion analysis and intelligent motion control algorithm of the platform can be carried out.

4. Dynamics simulation of platform

Above all, for the three types of platforms shown in figure 1, the platform shown in figure 1(b) has all the characteristics of the other two platforms, so it is chosen as the analysis object to carry out simulation for verification. For the platform shown in figure 1(b), virtual prototype of the platform is established in ADAMS. The typical omnidirectional motions are simulated, longitudinal motion, lateral motion and center steering motion. Simulation time is 5s, and platform motion trajectory are
shown in figure 3. It can be seen that the platform has the omnidirectional motion capability, but the motion trajectory have little skewness. So the precise tracking and planning of trajectory needs to be realized through some intelligent algorithms.

(a) Longitudinal motion

(b) Lateral motion

(c) Centre steering motion

Figure 3. Motion trajectory of platform.

5. Conclusions
Based on the omnidirectional track, a variety of novel track omnidirectional platforms were designed and kinematics model, Lagrange dynamic model were established. Finally, the virtual prototype of platform was established in ADAMS to verify the omnidirectional motion capability. In the future research, precise control and engineering design of the platform should be done.

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