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Research on the steering gait and error of a novel type of heavy load Automated Guided Vehicle

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Abstract. Automated Guided Vehicle is a kind of mobile robot Guided by vision, magnet, laser or tracking marks and cables on the ground .In the process of changing the driving direction, if the AGV is directly forced to flatten, the wheels will be "locked" in the force and unable to move, which will also cause damage to the driving system. Therefore, we adopt the way of steering in two or three sections to stabilize and overbalance, ensuring flexibility and safety.

1. Introduction

AGV "Automated Guided Vehicle" (as defined by AMHA, America Material Handling Association) is a kind of mobile robot Guided by vision, magnet, laser , tracking marks or cables on the ground.
In this paper, a large AGV is modeled and its turning gait is analyzed to find the main factor affecting the accuracy, and a feasible solution is given.

2. Kinematic Of Automated Guided Vehicle

2.1. Position Description of AGV

Firstly, based on the world coordinate system, a reference coordinate system is fixed for each joint, and then the transformation operator between any two adjacent coordinate systems is determined, and finally the total transformation operator is obtained.
Since the wheel mechanism is parallel, we take a branch road as an example for transformation.
{G}, known to the world coordinate system in the centroid to build A solid AGV coordinate system {A} the x axis parallel AGV length direction parallel to the y axis AGV width direction, {G} in the coordinate system, set up to determine the origin of the {A} vector for ${}^{A}P_{BORG} = \begin{bmatrix} x & y & z \end{bmatrix}^{T}$ connect the coordinate system relative to the rotation of the {G} with ${}^{G}_{A}R$ said, and will coordinate transformation to {A} {G}, first of all, will coordinate {A}.into an origin with {A}, and {G} in the middle of the same coordinate system, By means of the left multiplication attitude transform matrix

$$R = \begin{bmatrix} \overrightarrow{e_{xA}} \cdot \overrightarrow{e_{xG}} & \overrightarrow{e_{yA}} \cdot \overrightarrow{e_{xG}} & \overrightarrow{e_{zA}} \cdot \overrightarrow{e_{xG}} \\ \overrightarrow{e_{xA}} \cdot \overrightarrow{e_{yG}} & \overrightarrow{e_{yA}} \cdot \overrightarrow{e_{yG}} & \overrightarrow{e_{zA}} \cdot \overrightarrow{e_{yG}} \\ \overrightarrow{e_{xA}} \cdot \overrightarrow{e_{zG}} & \overrightarrow{e_{yA}} \cdot \overrightarrow{e_{zG}} & \overrightarrow{e_{zA}} \cdot \overrightarrow{e_{zG}} \end{bmatrix} \quad (1)$$

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The vector symbol of A is eliminated, and the attitude of the vector coordinate system is unified. At this point, all vectors can be added. For simplicity' ,we combine ${}^{G}_{A}R$ with ${}^{A}P_{BORG} = \begin{bmatrix} x & y & z \end{bmatrix}^{T}$ Using a matrix operator ${}^{G}_{A}T$

Represents the transformation of two coordinate systems

$$\begin{bmatrix} {}^{G}P \\ 1 \end{bmatrix} = {}^{G}_{A}T \begin{bmatrix} {}^{A}P \\ 1 \end{bmatrix} = \begin{bmatrix} {}^{G}_{A}R & {}^{G}P_{AORG} \\ 000 & 1 \end{bmatrix} \begin{bmatrix} {}^{A}P \\ 1 \end{bmatrix} \tag{2}$$

Namely,

$${}^{G}P = {}^{G}_{A}T \, {}^{A}P \tag{3}$$

In general, the motion of the AGV in the vertical direction is very small. Therefore, when researching the overall movement of the AGV, we can reduce the AGV and the world coordinate system to two dimensions.

On the frame, there are four off-centered oriental wheels, and the wheel carrier can rotate freely relative to the car frame. Taking a certain wheel carrierB_i as an example, we can obtain from the above method

$$\begin{bmatrix} {}^{A}P \\ 1 \end{bmatrix} = {}^{A}_{B_i}T \begin{bmatrix} {}^{B_i}P \\ 1 \end{bmatrix} = \begin{bmatrix} {}^{A}_{B_i}R & {}^{A}P_{B_iORG} \\ 000 & 1 \end{bmatrix} \begin{bmatrix} {}^{B_i}P \\ 1 \end{bmatrix} \tag{4}$$

Namely,

$${}^{A}P = {}^{A}_{B_i}T \, {}^{B_i}P \tag{5}$$

$${}^{G}P = {}^{G}_{A}T \, {}^{B_i}P = {}^{A}_{B_i}T \, {}^{A}_{B_i}T \, {}^{B_i}P \tag{6}$$

The wheel The wheel B_i on the rack C_i

$$\begin{bmatrix} {}^{B_i}P \\ 1 \end{bmatrix} = {}^{A}_{C_i}T \begin{bmatrix} {}^{B_i}P \\ 1 \end{bmatrix} = \begin{bmatrix} {}^{B_i}_{C_i}R & {}^{B_i}P_{C_iORG} \\ 000 & 1 \end{bmatrix} \begin{bmatrix} {}^{C_i}P \\ 1 \end{bmatrix} \tag{7}$$

$${}^{B_i}P = {}^{A}_{C_i}T \, {}^{B_i}P \tag{8}$$

$${}^{A}P = {}^{A}_{B_i}T \, {}^{B_i}P = {}^{A}_{B_i}T \, {}^{A}_{C_i}T \, {}^{B_i}P \tag{9}$$

$${}^{G}P = {}^{G}_{A}T \, {}^{B_i}P = {}^{A}_{B_i}T \, {}^{A}_{B_i}T \, {}^{B_i}P = {}^{G}_{A}T \, {}^{A}_{B_i}T \, {}^{A}_{C_i}T \, {}^{B_i}P \tag{10}$$

In order to verify the accuracy of the above operator, the data at the initial position of the AGV were taken and the correct conclusion was drawn. It is proved that the homogeneous transformation operator is correct.

2.2. Kinematics Analysis of AGV

In this research, we regard AGV as a rigid body, whose input is tangential acceleration and angular acceleration.

$$\mathrm{p} = \left(p_x, p_y, p_z \right) \tag{11}$$

Is the coordinates of AGV center in geodetic coordinate system {A}.

Three Euler angles （ψ， θ， φ） In the fixed connected coordinate system, the first state equation is:

$$\dot{p} = R(\psi,\ \theta,\ \varphi) \cdot v_r \tag{12}$$

For

$$R(\psi,\ \theta,\ \varphi) = R_{\psi} R_{\theta} R_{\varphi} = \begin{bmatrix} \cos\psi & -\sin\psi & 0 \\ \sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\varphi & -\sin\varphi \\ 0 & \sin\varphi & \cos\varphi \end{bmatrix}$$

$$= \begin{bmatrix} i \mid A & j \mid A & k \mid A \end{bmatrix} = \begin{bmatrix} \cos\theta\cos\psi & -\cos\varphi\sin\psi + \sin\theta\cos\psi\sin\varphi & \sin\psi\sin\varphi + \sin\theta\cos\psi\cos\varphi \\ \cos\theta\sin\psi & \cos\varphi\cos\psi + \sin\theta\sin\psi\sin\varphi & -\cos\psi\sin\varphi + \sin\theta\cos\varphi\sin\psi \\ -\sin\theta & \cos\theta\sin\varphi & \cos\theta\cos\varphi \end{bmatrix} \tag{13}$$

Take the derivative of the above expression, then:

$$\ddot{p} = \dot{R} \cdot v_r + R \cdot \dot{v}_r \tag{14}$$

In another way:

$$\dot{v}_r = R^T \cdot \ddot{p} - R^T \dot{R} \cdot v_r \tag{15}$$

$$R^T \dot{R} = Ad\left(R^T \omega\right) \tag{16}$$

$$R^T \cdot \ddot{p} = \mathrm{a}_r \tag{17}$$

Then

$$\dot{v}_r = \mathrm{a}_r - Ad\left(\omega_{R_1/R_0|R_1}\right) \cdot v_r \tag{18}$$

The above equation is the second equation of state
Finally, we get

$$\omega_{|R_0} = R(\psi,\ \theta,\ \varphi) \cdot \omega_{|R_1} \tag{19}$$

then

$$\begin{bmatrix} 0 & \dfrac{sin\varphi}{cos\theta} & \dfrac{cos\varphi}{cos\theta} \\ 0 & cos\varphi & -sin\varphi \\ 1 & tan\theta sin\varphi & tan\theta cos\varphi \end{bmatrix} \begin{bmatrix} \dot{\psi} \\ \dot{\theta} \\ \dot{\varphi} \end{bmatrix} = R(\psi,\ \theta,\ \varphi) \cdot \omega_r \tag{20}$$

If you extract the vector, you get the third equation of state. There are three simultaneous state equations

$$\dot{p} = R(\psi,\ \theta,\ \varphi) \cdot v_r$$

$$\dot{v}_r = \mathrm{a}_r - \omega_r \wedge v_r$$

$$\begin{bmatrix} \dot{\psi} \\ \dot{\theta} \\ \dot{\varphi} \end{bmatrix} = \begin{bmatrix} 0 & \dfrac{sin\varphi}{cos\theta} & \dfrac{cos\varphi}{cos\theta} \\ 0 & cos\varphi & -sin\varphi \\ 1 & tan\theta sin\varphi & tan\theta cos\varphi \end{bmatrix} \cdot \omega_r \tag{21}$$

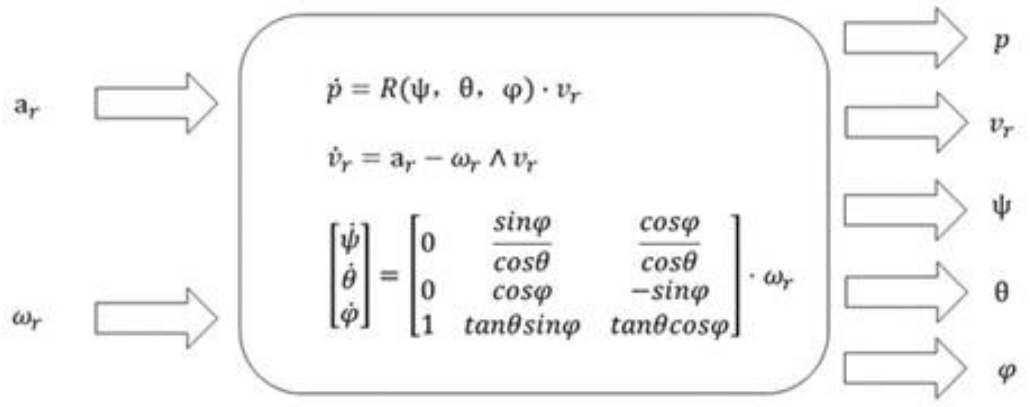
Since the objects in this research only move on the horizontal surface, there are $\psi = \theta = 0$

From the model

$$\dot{\psi} = \omega_{r3} \tag{22}$$

$$\dot{\theta} = \omega_{r2} \tag{23}$$

$$\dot{\varphi} = \omega_{r1} \tag{24}$$



2.3. Dynamic modeling

In this research, we derive the dynamic equation based on the kinematics model, taking into account the angular acceleration and tangential acceleration generated by the force and dynamic characteristics. The relation between acceleration and force is derived from Newton's second law or the basic principle of dynamics.

The mass of AGV is denoted by f and denotes the resultant force in the inertial coordinate system.

$$\mathrm{m}\ddot{p} = f \tag{28}$$

$$\mathrm{m}\left(\dot{R}\cdot v_r + R\cdot \dot{v}_r\right) = f \tag{26}$$

$$R^T\cdot \ddot{p} = R^T\left(\dot{R}\cdot v_r + R\cdot \dot{v}_r\right) = \mathrm{a}_r \tag{27}$$

$$mR^T\cdot \ddot{p} = mR^T\left(\dot{R}\cdot v_r + R\cdot \dot{v}_r\right) = m\mathrm{a}_r \tag{28}$$

$$m\mathrm{a}_r = R^T f \tag{29}$$

From this, the tangential acceleration (which is used as an input to the kinetic model) is an algebraic equation for the forces applied to the robot.

3. Error Analysis And Accuracy Research Of Steering Gait

In the translation process, since the off-centered oriental wheel rotation is a process of constant change in the direction of speed, and the transverse deviation is what we care about, and most affects the parameters of the docking accuracy, we take the first-order integral process as an example to calculate the maximum error.

The formula is as follows:

Taking a single off-centered oriental wheel as the research object, the displacement generated when it rotates around the rotation center is studied:

When the off-centered oriental wheel rotates to an arbitrary Angle

$$S_o = \int_0^{\psi}\cos\theta V_o\cdot\frac{\psi e}{V_o}d\theta = \int_0^{\psi}\psi\mathrm{e}\cdot\cos\theta d\theta = \varphi e\sin\theta\,|_0^{\varphi} = \varphi esin\varphi \tag{30}$$

In the range of 0-90 degrees, the migration distance of off-centered oriental wheels keeps increasing. In the range of 90-180 degrees, the displacement direction of off-centered oriental wheels is opposite to that of the previous stage. Finally, it is offset in the position of rotation 180 degrees

$$\mathrm{t} = \frac{\pi e}{2V_o} \tag{31}$$

$$S_o = \int_0^{\frac{\pi}{2}}\cos\theta V_o\cdot\frac{\pi e}{2V_o}d\theta = \int_0^{\frac{\pi}{2}}\frac{\pi e}{2}\cos\theta d\theta = \int_0^{\frac{\pi}{2}}\frac{\pi e}{2}\cos\theta d\theta = \frac{\pi e}{2}\sin\theta\,|_0^{\frac{\pi}{2}} = \frac{\pi e}{2} \tag{32}$$

From the integral process, it can be seen that the displacement of the off-centered oriental wheel when it rotates around the center of rotation is independent of its speed, which is only related to the magnitude of the eccentricity e of the off-centered oriental wheel and is independent of its speed.

In terms of the four off-centered oriental wheels of AGV as a whole, the rotation directions of the four off-centered oriental wheels respectively will bring different deviations.

Now, we're going to be rotating 90 degrees with a single wheel

1. The four wheels have the same migration direction and migration path

$$S_F = S_{o1} = S_{o2} = \frac{\pi e}{2} \tag{33}$$

$$S_B = S_{o3} = S_{o4} = \frac{\pi e}{2} \tag{34}$$

So, Angle of deflection is equal to 0

The offset distance is evaluate e/2

2. One turn is opposite to the other three

$$S_F = S_{o1} = S_{o2} = \frac{\pi e}{2} \tag{35}$$

$$S_B = S_{o3} - S_{o4} = 0 \tag{36}$$

$$\varphi = \arctan\frac{\pi e}{2l} \tag{37}$$

or

$$S_F = S_{o1} - S_{o2} = 0 \tag{38}$$

$$S_B = S_{o3} = S_{o4} = \frac{\pi e}{2} \tag{39}$$

$$\varphi = \arctan\frac{\pi e}{2l} \tag{40}$$

3. The two front wheels have the same direction of deflection, and the two rear wheels have the same direction of deflection, but the front and rear wheels have the opposite direction of deflection

$$S_F = S_{o1} = S_{o2} = \frac{\pi e}{2} \tag{41}$$

$$S_B = S_{o3} = S_{o4} = \frac{\pi e}{2} \tag{42}$$

$$\varphi = \arctan\frac{\pi e}{l} \tag{43}$$

4. The deflection direction of the two front wheels is opposite, and the deflection direction of the two rear wheels is opposite

$$S_F = S_{o1} - S_{o2} = 0 \tag{44}$$

$$S_B = S_{o3} - S_{o4} = 0 \tag{45}$$

But the two deflection distances are in opposite directions
The offset distance is 0
From the above process, we can see that in the case of unknown disturbance, there are various possibilities for the lateral error of the docking AGV, but all of them are independent of the speed, and only related to the eccentricity of the off-centered oriental wheel e and the distance L between the two sets of off-centered oriental wheels. Among them, the eccentricity of the off-centered oriental wheel e has the greatest influence on the car frame. However, the greater the eccentricity distance of off-centered oriental wheel, the better its orientation.

4. Mechanics Analysis

The designed product tends to run on flat road, so the performance of the suspension system is not required. We use the simplest method, namely, the wheel itself is designed to be flexible, and the rubber deformable tire is used on the small casters to make an active suspension [autonomous mobile robot introduction p29]. In general, in rolling friction, we assume that the wheels and the ground are point contact, that is, the wheels and the ground have no deformation, but in fact, the wheels and the ground have a small deformation. At the same time, the wheels actually produce a contact surface between the wheels and the ground, and the wheels are subject to distributed forces, which we can simplify to a force and a torque. The introduction of this theory has answered some of our questions, such as:
In general modeling simulation, some simulation results are different from the actual situation. For one thing, the external environment such as the ground is not ideal; for another, there is deformation between the wheel and the ground.
So here we introduce the rolling friction coefficient
The force analysis of ten thousand star wheels in AGV motion (static analysis) is as follows

$$\sum M_A(F) = 0 \tag{46}$$

Namely,

$$-\mathrm{f} \cdot R + M_{max} = 0 \tag{47}$$

For

$$M_{max} = \delta F_N \tag{48}$$

Combine the two

$$\mathrm{f} \cdot R = \delta F_N \tag{49}$$

Consequently ,we've got

$$\mathrm{f} = \frac{\delta}{R} F_N \tag{50}$$

Let $\mu_r = \frac{\delta}{R}$

The coefficient of static friction is greater than the coefficient of rolling friction
By type, we noticed a problem: when the direction of the driving wheel and castor wheels into 90 degrees, underpowered would happen to drive the AGV investigate its reason, driving wheel power provided by the ground reaction force in the face of the wheel, and at this point, the point of view of universal wheel makes the does not exist between the scroll with the ground, the stress for the static friction force, its theoretical calculation is as follows:
When the drive wheel does not roll

$$F_M = \mu_s F_N \times \frac{2S_M}{2S_M + 4S_o} \tag{51}$$

$$F_f = \mu_s F_N \times \frac{4S_o}{2S_M + 4S_o} \tag{52}$$

Because drive wheel and off-centered oriental wheel size difference is not big, contact surface area is similar, then have apparently

$$\frac{2S_M}{2S_M + 4S_o} < \frac{4S_o}{2S_M + 4S_o} \tag{53}$$

So, obviously, when the drive wheel is rolling (idling)

$$F_M < F_f \tag{54}$$

$$F_M = \mu_r F_N \times \frac{2S_M}{2S_M + 4S_o} \tag{55}$$

$$F_f = \mu_s F_N \times \frac{4S_o}{2S_M + 4S_o} \tag{56}$$

It is worth mentioning that in the engineering practice to process, it is a large demand for power directly to turn around in 90 degrees, easy to cause the drive wheels of the motor overload and instability caused by instantaneous electric current too large, big horsepower driving wheels would increase the cost, the oscillation of the driven wheel will be too large, affect the accuracy, therefore, we turn to its gait is optimized, the first rotating driving wheel, turn 45 degrees in the direction of translation, travel distance and then rotate 90 degrees to the direction, can from straight moving to traverse, the gait optimization, save power and reduce the cost. At this time, the friction is calculated as

$$F_M = \mu_s F_N \times \frac{2S_M}{2S_M + 4S_o} \tag{57}$$

$$F_f = \mu_s F_N \times \frac{4S_o}{2S_M + 4S_o} \times \frac{\sqrt{2}}{2} \tag{58}$$

At this point, the calculation could not be carried out by approximate method. We adopted Adams simulation to verify the simulation results, and after gait improvement, AGV could successfully achieve the purpose of lateral movement.
However, although its demand for power has declined, it is still considerable. In particular, the power of this AGV is provided by batteries, and frequent charging is not conducive to the improvement of production efficiency. Therefore, in the following research, we plan to further optimize the turning gait, and install the steering motor at the turning shaft above the off-centered oriental wheel. Before

the steering, the off-centered oriental wheel is rotated to the direction of motion, that is, each off-centered oriental wheel Oi is rotated under the action of torque output by the motor. However, when the power is saved, the torque caused by the motor also causes the rotation of the AGV, and its calculation formula is T=I spark.

5. Conclusion

From this research , we can draw the following conclusions:

1. The offset Angle of the car frame is inversely proportional to the distance L between the front and rear off-centered oriental wheels, and is directly proportional to the eccentricity distance e of off-centered oriental wheels .

2. The best way to reduce the deviation error is to make the deviation errors generated by each wheel offset each other, which is also the aspect that we need to plan after installing the steering motor .

(train of thought motor is used to add disturbance, only to guide the steering, while driving.)

In the process of changing the driving direction, if the AGV is directly forced to flatten, the wheels will be "locked" in the force and unable to move, which will also cause damage to the driving system. Therefore, we adopt the way of steering in two or three sections to stabilize and overbalance, ensuring flexibility and safety.

In terms of turning accuracy, we have another solution: namely, starting from the control system, to establish a feedback control rate of constant correction.

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