Load Prediction for AGV Quasi-Stop Control

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Abstract. In the AGV variable load quasi-stop problem, in order to establish the quasi-stop mathematical model, it is necessary to judge the magnitude of the load. According to the current load characteristic of the motor, the motor output current is positively correlated with the load. For this reason, a motor current start Characteristic load prediction method is proposed. Firstly, the ARM-based AGV DC servo motor current measurement experimental platform is built according to the needs. Secondly, in order to extract the effective data, we collected the current data under different loads and analyzed the overall law of the data and, and the linear regression analysis and least squares fitting of the effective data are performed. Finally, the mathematical model between load and current is established, and the model is brought back to the AGV experimental platform to verify the model. The experimental results show that the mathematical model can predict the load and the prediction accuracy is around 5%, which proves the effectiveness of the proposed method.

1. Introduction
Automatic guided vehicle (AGV) is a relatively common equipment in modern factories, and its application scenarios are diverse. Among them, it is widely used in logistics, automobile, dock, tobacco, food and chemical industries [1]. Among the many usage scenarios, the most common application method is docking with the pipeline, transporting related equipment and products to complete the operation. In some cases, it is necessary to ensure good docking accuracy and work tempo to achieve normal production and transportation of the product. Therefore, it requires good stability during AGV operation and high parking accuracy when parking [2].

The stability of AGV operation and the guarantee of parking accuracy depend on two aspects, one is the hardware system of AGV, and the other is the control model. The hardware system can be guaranteed by reasonable selection. So, the design of the control model is especially necessary in the operational stability and parking accuracy of the AGV. In the literature [3], the author controls the model to use the constant deceleration curve plus the mechanical auxiliary parking device, and cooperate with the limit switch at the parking point to ensure the parking accuracy of the AGV.

In the literature [4], the author uses multi-stage deceleration and additional mechanical auxiliary devices to greatly improve the sense of frustration during the parking process, making the parking process more gradual, but there is still impact inertia, resulting in parking error.

Analysis of the above two methods found that there is a large impact inertia, because when the load contained in the AGV changes, the deceleration curve in the control model fails to adjust in time according to the change of the load, so that the impact inertia occurs. Therefore, before building the deceleration model, we need to know the size of the load carried by the AGV. If we adopt direct weighing method, it will inevitably increase the workload of weighing and reduce the working efficiency. In this paper, a load prediction method based on motor current starting characteristics is
proposed, and the mathematical model between current and load is established, according to the magnitude of the current, the prediction of the load is realized.

2. Construction of the experimental platform
Construction of the experimental platform is shown in Figure 1. Including control system, drive system, navigation system, obstacle avoidance system, operating system, power supply module and data acquisition module.

![AGV experimental platform](image)

**Figure 1. AGV experimental platform**

The control system adopts ARM as the main control chip, executes the control algorithm, and completes the control and information interaction of each system and module. The drive system adopts DC servo brushless motor, which is completed by voltage, the signal is continuous, and the response speed is fast. The navigation system uses an 8-point magnetic strip sensor to make the AGV follow the preset trajectory by recognizing the magnetic strip on the ground. The obstacle avoidance system uses photoelectric sensors to scan the fan-shaped area within a certain range in front, when an obstacle is found, stopping in time. The data acquisition module comprises two parts, namely a current collecting module and a voltage collecting module. The current collecting module collects the phase current of the servo motor and converts the current signal into a voltage signal, and the voltage collecting module displays the converted voltage signal on the upper computer and Generate reports for later data analysis and processing.

3. Data collection and verification

3.1 Data collection and verification
In order to establish a mathematical model between the load and the current and complete the current-to-load estimation, it is first necessary to sample the current of the motor. According to the analysis, the motor load increases, the output current of the motor increases, and the corresponding electromagnetic torque also increases. Therefore, to accurately estimate the current to the load, it is necessary to find out the current parameter that best reflects the load change. We can know that from the relationship between load, current and electromagnetic torque, Which current parameter is most closely related to the electromagnetic torque, and it can be used as the current value to estimate the load. In this paper, the motor we use is a three-phase star-connected brushless DC motor with a phase difference of 120°. The phase current of the motor is equal to the line current. The torque equation of the motor is:

\[
T_e = \frac{p_e}{\omega} = \frac{E_a i_a + E_b i_b + E_c i_c}{\omega}
\]  
(1)
Where $E_a$, $E_b$, $E_c$ are the opposite electromotive forces of A, B, and C respectively, $i_a$, $i_b$ and $i_c$ respectively represent the current of each winding. $T_e$ is the electromagnetic torque. When non-commutation, take the A and B phases as an example. When A and B phases are turned on, there is $E_{a}=E$, $E_{b}=-E$, current has $i_a = i$, $i_b = -i$, $i_c = 0$, which is brought into the torque equation (1). The magnitude of the phase current best reflects the change in electromagnetic torque, which is most relevant to the magnitude of the load.

The relationship between the back electromotive force of the brushless DC motor and the mechanical angular velocity is:

$$E = k_e \frac{60}{2\pi} \omega = K \omega$$  (2)

Where $k_e$ is the reverse electromotive force coefficient and we can know that when (2) is brought into the torque equation.

$$T_e = Ki$$  (3)

It can be seen from equation (3) that the phase current during non-commutation is proportional to the torque. Therefore, the current sampled this time is the phase current of the brushless DC motor.

3.2 Phase current sampling method analysis

As can be seen from Section 3.1, the output torque of the brushless DC motor is proportional to the phase current. Therefore, we use phase current to realize the pre-judgment of the load. The most effective way to sample the phase current is measuring the three-phase output of inverter with three current sensors directly, and then integrating and analyzing of the three-phase output values to obtain all the information of the phase current. But, this method is costly and the data processing is troublesome.

We use a single current sensor to measure the DC bus current to approximate the phase current. The sensor installation position is shown in Figure 2. The current sensor is placed between the DC power supply negative and the capacitor, where U is the DC power supply, L is the inductor, C is the filter capacitor, Q0-Q5 is the power switch, D0-D5 is the freewheel switch, and A, B, C are the three-phase load.

![Figure 2. Installation position of current sensor](image)

Taking the two phases A and B as an example, when Q1 and Q4 are turned on, the two phases A and B are turned on. At this time, the phase current $i$ is the bus current which are the sum of the sensor current $i_d$ and the capacitor current $i_c$. When Q4 is turned off, the sensor current $i_d$ is equal to the capacitor current $i_c$. Regardless of the commutation or non-commutation period, the bus current is one direction and not 0, and the change trend is also consistent with the phase current. Therefore, it is proposed to replace the phase current with the bus current.
3.3 Sample waveform verification and analysis

In order to verify whether the bus current can be used as the current value for predicting the magnitude of the load, we first analyze the torque equation of the AGV from the unacted to the accelerated start to the steady state. Formula 4 is the moment equation of the AGV in the moving and unmoved phase.

\[ T = T_L + f_s \times R \]  \hspace{1cm} (4)

Where \( T \) is the torque output of the motor and \( T_L \) is the load torque, \( f_s \times R \) is the static friction torque.

Formula 5 is the torque equation for the AGV in the process of accelerating start to steady state.

\[ T = T_L + f_m \times R + \frac{1}{2} mRa \]  \hspace{1cm} (5)

It can be known from the torque equation (4) that when the AGV has not started, the output torque is getting larger and larger, the static friction force reaches the maximum at the critical state of starting, and the output torque also reaches the maximum value. When the AGV starts and is in the acceleration phase, the static friction force becomes the dynamic friction force, and the friction torque decreases. It is known from the torque equation (5) that the output torque drops to a certain value. After the end speed of the acceleration section reaches the steady state, the output torque slightly decreases and continues to maintain a certain value until the AGV parking. The approximate torque versus time curve is shown in Figure 3.

In the figure, the abscissa is time, the ordinate is the torque output by the motor, and a and b represent different loads, respectively, where the load a is greater than the load b. \( t_1 \) is the start-up to the critical state phase, \( t_2 \) is the acceleration phase, and \( t_3 \) is the steady-state operation phase. Waveforms under three different loads were collected in the experiment, and the trend is shown in Figure 4. The trend of the motor current with time is almost the same as the trend of the analyzed torque. Therefore, the bus current can be used as the current for predicting the magnitude of the load.
4. Data analysis and processing

In order to find out the relationship between load and current during AGV startup, Figure 5 is the variation of current with time in three groups of different loads (load 1 is 221 kg, load 2 is 151 kg, load 3 is 85Kg). Comparing and analyzing the current change value and the load of the AGV from the start-up to the acceleration-to-speed, and then to the steady-state, a mathematical model of the current and the load is established by linear regression fitting the current value with the largest correlation degree with the corresponding load value. The accuracy of the mathematical model is verified by the AGV.

![Figure 5: Current variation curve at start-up of different loads](image)

In order to find out the current value with the largest load correlation degree, we take the peak value in critical state and the average value of steady-state current in steady-state operation of AGV. Comparing the peak current steady-state current with the corresponding load value as shown in Table 1.

| Load(kg) | 85  | 151 | 221 |
|----------|-----|-----|-----|
| Peak current (A) | 4.052 | 4.205 | 4.415 |
| steady-state current (A) | 2.72 | 2.76 | 2.86 |

The least squares fit of the peak current and the corresponding load value to obtain the formula 6.

\[ i = 0.0027m + 3.8169 \]  \hspace{1cm} (6)

The formula 7 is obtained by the least square fitting of the steady-state value current and the corresponding load value.

\[ i = 0.001m + 2.6226 \]  \hspace{1cm} (7)

The measured values of the currents under the two sets of loads are compared with the theoretical values calculated by the formula. The comparison results are shown in Table 2.

| Load(kg) | 165 | 291 |
|----------|-----|-----|
| Actual peak current | 4.26 | 4.598 |
| Theoretical Peak current | 4.26 | 4.602 |
| Actual steady-state current | 2.78 | 2.90 |
| Theoretical steady-state current | 2.76 | 2.93 |

It can be seen from Table 2 that the steady-state current is used to predict the load with an accuracy of about 15%. The peak current is used to predict the load with an accuracy of about 5%. Therefore,
The peak current has the greatest correlation with the load. The peak current can be used to predict the load size of AGV.

5. Conclusion
Aiming at the load pre-judgment problem in the quasi-stop model, a method based on the load characteristics of the motor starting is proposed. The validity of load prediction by peak current during startup is proved by experiments. The experimental results show that the error of predicted load value is within 5%. So, the method is feasible.

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