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Application of the Improved S-Curve Algorithm in the Speed Control of Shuttle Vehicle

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Abstract

The Smooth of the shuttle vehicle speed control system is the guarantee of the safe operation of the car body, the current shuttle vehicle parking in the start acceleration and deceleration will happen when the shaking phenomenon, It reduces the shuttle car shelf system security and stability. The S-curve to add and subtract in the simplified method is applied to speed regulation system of shuttle car, can reduce the occurrence of this phenomenon. But the S-curve algorithm without considering the bodies weight and load change on the result of speed regulation. In this paper, we improve the S-curve and speed reduction algorithm. Considering the factor of the weight of the vehicle and the load factor, realize the smooth control of shuttle car. This paper introduces the method and principle of the speed control of shuttle car. An improved method for calculating the S curve acceleration and deceleration is presented. And Matlab simulation is carried out. Results of simulation and actual equipment show that the improved algorithm can control the smooth running of the shuttle vehicle.

Keywords*: Shuttle vehicle; S-curve; acceleration and deceleration algorithm; control system of the speed*

1. Introduction

The application of the shuttle vehicle rack system is becoming more and more extensive in the intensive storage and logistics system, shuttle bus rack system is the track of shuttle car on a specific shelf. It is a system of up and down or homing of bus body or table [1]. Shuttle car has the advantages of simple operation, small area, safe and accurate access to the goods, such as short, *etc.*, it can not only improve the work efficiency, but also connected with other logistics system. The system is widely used in fast consumption industry, cold chain storage industry, food and beverage industry, pharmaceutical and tobacco and other industries. Shuttle bus is the core equipment of the whole shelf system. The speed adjusting system of the shuttle vehicle is the guarantee of the safe operation of the vehicle when shuttle bus works. The current shuttle car often produces a certain jitter when starting acceleration and deceleration stop, especially in the deceleration parking process. For the certain inertia in the running process, the motor step is easy to lose or exceed, and the body is easy to be unstable, if the goods are piled high, it will cause the collapse, damage to the shelves, cargo or shuttle, and even dangerous to people. Therefore, acceleration and deceleration algorithm can be used in the shuttle vehicle speed control system. In this paper, based on the conventional S-curve algorithm, influence of weight of body and goods on speed system is considered to get the new optimal control speed.

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2. The Speed Control System of the Shuttle Vehicle

Shuttle vehicle speed control system is constituted by PLC and dc motor drives, dc gear motor, photoelectric encoder, photoelectric sensor. In this paper, the shuttle car speed system is controlled by differential signal model. Input voltage of DC motor is controlled by PLC analog output with DC drive to achieve the speed control [2], the motor speed is converted to pulse by rotary encoder and give back to PLC to achieve closed loop control, distance is texted by photoelectric sensor. In the shuttle vehicle speed control system, the feedback speed which referenced to speed curve change the voltage singal continuously for smoothly running of the shuttle car. When a shuttle bus is required to arrive at a destination address, driven analog voltage values are adjusted by presetted control strategy the shuttle bus runs at a high speed to the location of the destination address, and then smoothly slows down to a lower speed, and stops at a time when the destination is reached [9].

3. The Algorithm of S-Curve Acceleration and Deceleration

In the speed governing，the control of S-curve acceleration and deceleration can ease the speed of the mutation greatly, the process of the speed change is very smooth, Because of its acceleration is constant, so the control of derivative of acceleration

Can decrease the instability of the bodywork running, so that the operation is safe, the position is accurate [6].

The S-curve acceleration and deceleration turn the process of traditional 3-step acceleration deceleration

Into process of 7 sections acceleration deceleration, and forming a S-shape. The section of acceleration is made of the section of the increased acceleration(T1), the section of the unchanged acceleration(T2), the reduced acceleration(T3); The section of deceleration is made of the section of the increased acceleration(T5), the section of the unchanged acceleration(T6), the reduced acceleration(T7) [5].

In the section of Tl, the acceleration change from 0 to the maximum $A_{\max}$. The speed was promoted from Vs to V_L.Now we seu up: The rate of change of acceleration is J, So we can get the result is $J = a_{\max}/T_1$.If the $A_{\max}$ is constant, the bigger the J, the smaller the T_1,it will cause the speed to increase faster, and the impact on the system becomes large; on the contrary, the smaller the J, the bigger the T_1,it will cause the speed to increase slower, and the impact on the system becomes small [3].

The shuttle vehicle was accelerated to Vm/s with the acceleration of Amax in T2;

The shuttle bus was accelerated towards Vc with reduction of acceleration in T3, and the speed of the motor will not be lost;

The shuttle vehicle is in uniform motion at Vc in T4;

The shuttle vehicle run at the speed which dropped from Vc to Vm , and the acceleration dropped from J to Amax in T5 at the same time;

The shuttle vehicle run at the speed which dropped from Vm to VI with uniformly acceleration in T6;

The shuttle vehicle run at the speed which dropped from VI to Ve with reduction of acceleration in T7;

For the convenience of analysis, Figure 1 is given to show the ideal speed curve of the shuttle vehicle running. Diagram including the shuttle vehicle speed, V, acceleration, A, and the derivative of the acceleration, J. The maximum speed of the system reflects the maximum operational capability of the system, Maximum acceleration reflects the maximum acceleration and deceleration capability of the system, the derivative of the acceleration reflects the flexibility of the system, This parameter is inversely proportional to t, and if it is large, the impact is large, It is infinite in limit, The curve of acceleration and deceleration is reduced to the linear of acceleration and deceleration. The system of the slow process of the slow process, when it is small, you can make your chose, according to the needs and performance of the system [4].

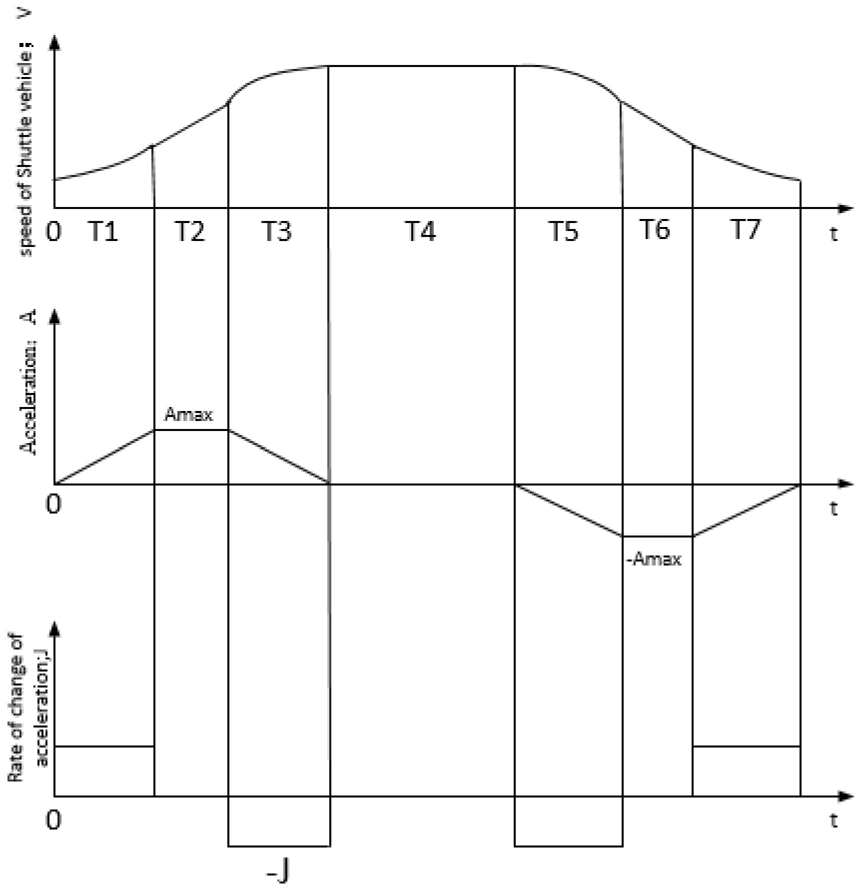

Figure 1. The Figure of the Process of S-Curve of Acceleration and Deceleration

In the face of the whole under 7 paragraph introduction to understand the principle of the algorithm. Let us set the following parameters: $V_{\max}$ is the value of maximum given speed, Unit: m/s; $A_{\max}$ is the maximum acceleration; T_a is the time of getting the speed, $V_{\max}$ with the maximum acceleration, $A_{\max}$. Unit: S; J_1 is the derivative of the acceleration in the section of T1; J_2 is the derivative of the acceleration in the section of T2; V_B is the speed of T1 and T2 cutoff point. Assume the time of the acceleration of motor from 0 to the maximum acceleration is equal to the time of from maximum to 0, We set the time as a characteristic time constant for the system, t_m said. The bigger， the bigger the flexibility of the system, the longer the time to speed up; the smaller the t_m, the smaller the flexibility of the system, the shorter the time to speed up; S-curve regress to a straight line, $t_m = v_{\max}/A_{\max}$, the S-curve is only two sections. So we can get the following relationship:

Maximum acceleration： $A_{\max} = (V_{\max} - 0) \div T_a$.

The derivative of the acceleration in the section of T1: $J_1 = (A_{\max} - 0) \div T_1$.

The derivative of the acceleration in the section of T2: $J_2 = (A_{\max} - 0) \div T_3$.

1) When $t_0 \le t_n \le t_1$, $V_1 = \frac{1}{2} J_1 t_n{}^2$.

2) When $t_1 \le t_n \le t_2$, $V_2 = \frac{1}{2} J_1 t_n{}^2 + A_{\max}(t_n - t_1)$.

3) When $t_2 \le t_n \le t_3$, $V_3 = V_{\max} - \frac{1}{2} J_2 (t_3 - t_n)^2$.

4) When $t_3 \le t_n \le t_4$, $V_3 = V_4$.

5) When $t_4 \le t_n \le t_5$, $V_5 = V_4 - \frac{1}{2} J (t_5 - t_n)^2$.

6) When $t_5 \le t_n \le t_6$, $V_6 = V_5 - J(t_6 - t_5)(t_7 - t_n)$.

7) When $t_6 \le t_n \le t_7$, $V_7 = V_6 - J(t_6 - t_5)(t_7 - t_n) + \frac{1}{2} J (t_7 - t_n)^2$.

Now we set sampling period is ΔT, the initial speed of the sampling period of N+1 is $v(t_n)$,the speed of the end of the sample is $v(t_{n+1})$, as we know:

$t_{n+1} = t_n + \Delta T$, Put the paragraphs of speed curve into discretization, wo can You can get a few simple recursive types:

1) When $t_0 \le t_n \le t_1$, $v(t_{n+1}) = v(t_n + \Delta T) = \frac{1}{2} J_1 t_n{}^2 + J_1 t_n \Delta T + \frac{1}{2} J_1 (\Delta T^2)$. Omit higher-order infinite events: $v(t_{n+1}) - v(t_n) = J_1 t_n \Delta T$.

2) When $t_1 \le t_n \le t_2$, $v(t_{n+1}) - v(t_n) = A_{\max} \Delta T$.

3) When $t_2 \le t_n \le t_3$, $v(t_{n+1}) - v(t_n) = J_2 (t_3 - t_n) \Delta T$.

4) When $t_2 \le t_n \le t_3$, $v(t_{n+1}) - v(t_n) = J_2 (t_3 - t_n) \Delta T$.

5) When $t_2 \le t_n \le t_3$, $v(t_{n+1}) - v(t_n) = J_2 (t_3 - t_n) \Delta T - t_5 \Delta T$.

6) When $t_2 \le t_n \le t_3$, $v(t_{n+1}) - v(t_n) = J_2 (t_3 - t_n) \Delta T - t_5 \Delta T - (t_7 - t_n) \Delta T$.

7) When $t_2 \le t_n \le t_3$, $v(t_{n+1}) - v(t_n) = J_2 \left[(t_3 - t_n - t_5 - (t_7 - t_n)^2 \right] \Delta T$.

In the actual addition and subtraction speed control algorithm, The method of calculating the speed of each interval with real time calculation will take up long time of scanning to make a lot of calculation, The system real-time performance get lower. In general, we use the method of checking list. The method of checking list is to calculate the length of the [0, T1], [T1, T2], [T2, T3], [T3,T4], [T4,T5], [T5, T6], and [T6, T7] seven time interval of all the speed data, and stored in an array to DM area of PLC, Using timing interrupt mode to read the speed data to control the motor running.

4. The Improved Algorithm of S-Curve Acceleration and Deceleration

When the shuttle vehicle starts and brakes, different size of moment of inertia is produced by different weight of goods, the speed of the vehicle will be affected by the inertia, shuttle bus is more heavier, the impact is greater. In accordance with the original algorithm which can adjust the deceleration S-curve, it maybe will not get the required speed, when the shuttle vehicle arrive at the corresponding location, it means that The shuttle bus cannot arrive at the designated position on time, and it may lead to the accident of the shuttle vehicle hit shelves or the collapse of the goods.

In order to facilitate the description, the improved S curve acceleration and deceleration algorithm is given, acceleration and deceleration are similar. The weight of shuttle bus W is measured by weighing sensor, when the shuttle vehicle is at the end of uniform speed, that is when the bus is in S0, the motor controlled by controller starts to slow down in accordance with the S curve plus deceleration algorithm, when the speed is reduced to a minimum, the bus continue to run at the minimum speed, when it is close to the stop position, the shuttle stop is stopped by safety stop sensor.

The premise condition of the application of the improved S algorithm is to consider the inertia of the vehicle and the cargo and the friction between the wheel and the rail. Now we assume a few physical quantities: The gross weight of the shuttle vehicle is M, V is the speed value in the original algorithm, V' is the speed value that considering the shuttle vehicle weight, K is the coefficient of relationship of the value of two kinds of speed before and after improvement, we can obtain the k value through experiments.

Then： $V' = kMV$

In the formula： $kM \le 1$， when we do not consider the inertia of the shuttle vehicle: $kM = 1$

We can be obtain the following relationship formula, We substitute $V' = kMV$ into the algorithm of s-curve acceleration and deceleration.

When $t_4 \le t_n \le t_5$， $V_5' = \left[V_4 - \frac{1}{2}J(t_5 - t_n)^2\right]kM$

When $t_5 \le t_n \le t_6$， $V_6' = \left[V_5 - J(t_6 - t_5)(t_7 - t_n)\right]kM$

When $t_6 \le t_n \le t_7$， $V_7' = \left[V_6 - J(t_6 - t_5)(t_7 - t_n) + \frac{1}{2}J(t_7 - t_n)^2\right]kM$

In the same way, we can be obtain the formula in the phase of acceleration:

$V_1 = k_1 MV$

In the formula: km>=1.

The software flow chart of the control of the deceleration is shown in Figure 2.

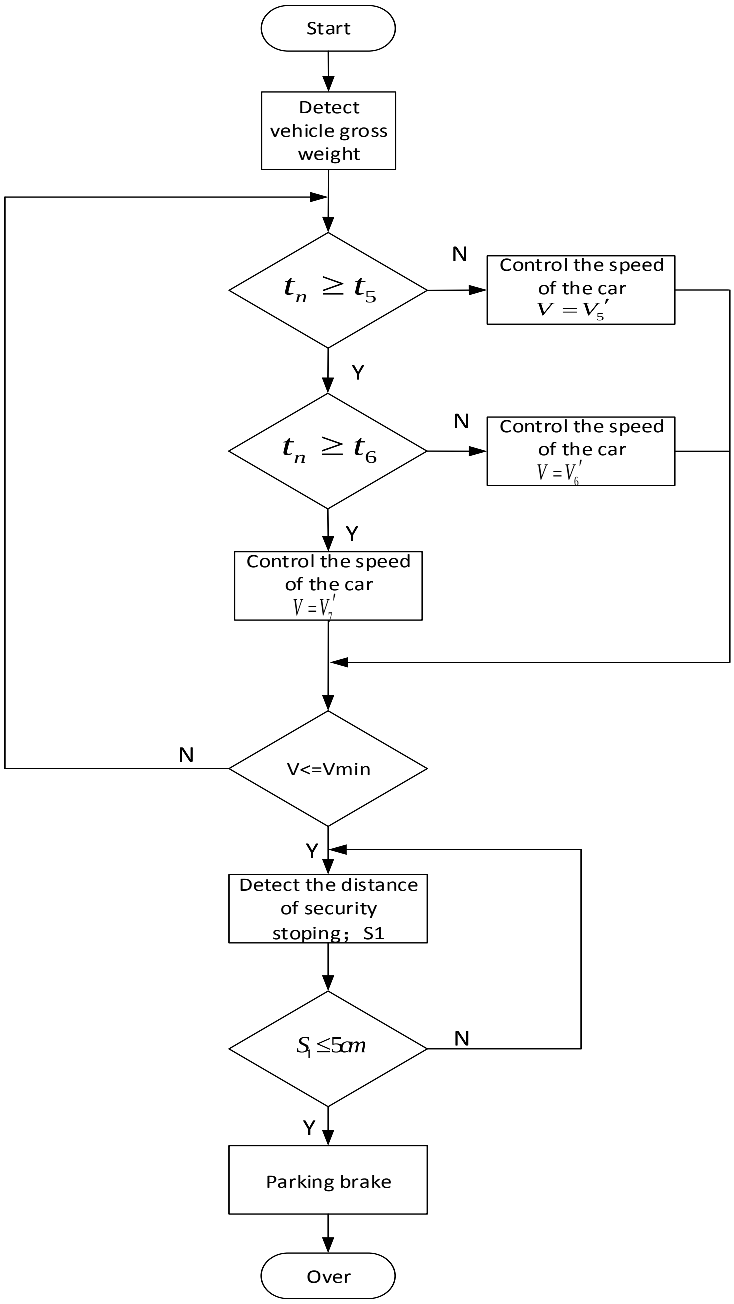

Figure 2. The Software Flow Chart of the Control of the Shuttle Vehicle Deceleration

4. The Analysis of Matlab Simulation Results

In the control of deceleration, We make a Matlab software simulation for the original algorithm of S-curve acceleration and deceleration and the improved algorithm of S-curve acceleration and deceleration [10-11], We can get speed curve of the running of the shuttle vehicle. In the Figure, the horizontal axis is the running time of the shuttle vehicle, unit: s, the vertical axis represents the speed of the shuttle vehicle, unit: m / s. The simulation diagram of the original algorithm and the improved algorithm speed curve is shown in Figure 3.

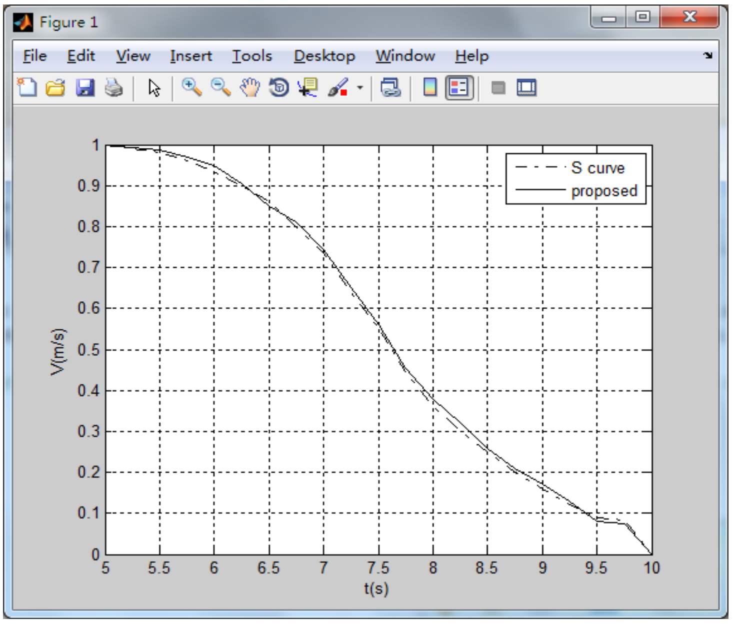

Figure 3. The Simulation Chart of the Speed Curve of the Original Algorithm and the Improved Algorithm

The results of the Simulation can be seen from Figure 3, the speed curve of the original S curve acceleration and deceleration algorithm is almost the same as the speed curve obtained by the S curve acceleration and deceleration algorithm, and the curve of the running speed is very smooth, it ensures that the shuttle vehicle can run smoothly.

The comparison of different load reduction distance is shown in Figure 4, Matlab software simulation of the original S curve acceleration and deceleration algorithm and the improved S curve acceleration and deceleration algorithm. The horizontal axis is the shuttle vehicle gross weight, unit: kg, the vertical axis is the shuttle deceleration distance, unit: cm.

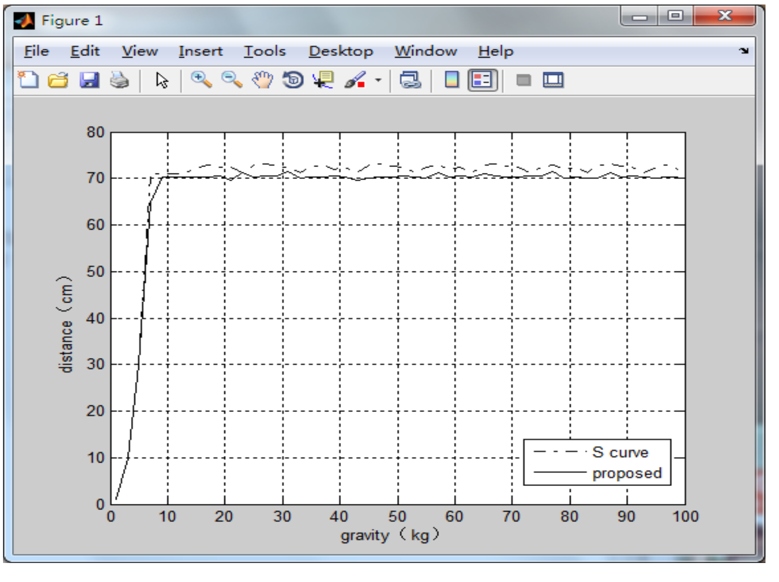

Figure 4. Shows that Shuttle Vehicles Can Run Smoothly Under Various Load Conditions with the Improved S Algorithm, which Provides Protection for the Shuttle's Precision Docking

5. Conclusions

The original S curve acceleration and deceleration algorithm with 7 segment is improved in this paper, the corresponding calculation formula is given. At the same time, in view of the influence of different body weight on the braking distance of the vehicle, the method of improving algorithm is given. MATLAB is used to simulate, the running situation of the S algorithm is compared before and after the improvement. The simulation results show that the improved S curve and deceleration algorithm make the car body run smoothly, the shuttle can be stopped at the same place at different load conditions.

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