Design of Motion Control Software System of Geotextile Paving Trolley for Tunnel Construction

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Abstract. In tunnel waterproofing construction, the method of laying geotextile and waterproof board is generally used. Because the geotextile material is relatively soft, and it is not easy to shape, which brings great inconvenience to the work of construction personnel. Through the analysis of the tunnel waterproofing construction process, based on the tunnel construction geotextile paving trolley, the software system of the trolley motion control system is designed. This system includes the controller program design and the man-machine interface design, and finally cooperates with the hardware system. Debugging verified the system function and the reliability of the equipment.

1. Introduction

A tunnel is an engineering building buried in the ground. It is an important traffic measure for cars. Its water leakage will cause the soil around the tunnel to collapse, which will cause safety problems and cause the existence of soluble hydrogen in materials such as reinforced concrete. The calcium phenomenon reduces the service life of the tunnel[1].

Our country has conducted long-term research and exploration on the problem of tunnel waterproofing. There are three main methods for tunnel waterproof construction in our country: base surface treatment, geotextile hanging, and nail-free laying of tunnel waterproof boards[2]. However, in the research process, there are mainly inequalities in the classification of waterproofing projects, the methods adopted by designers are unreasonable, and the scientific and reasonable arrangements for waterproofing materials, engineering operators and equipment required for the project have not been made[3]. At present, most of the geotextile laying operations are manually laid. There are problems such as high labour intensity, low laying efficiency, large calculation errors, and high potential safety hazards for paving personnel. It is difficult to meet the requirements of tunnel geotextile construction progress, quality and standardized operation[4]. In recent years, many tunnel construction companies have conducted research and implementation of automatic geotextile paving projects, and have achieved many excellent results. Ningxia Communications Construction Co., Ltd. designed a waterproof construction trolley, which can walk automatically, is convenient and fast, greatly reduces labour, is convenient for use in actual projects, and is fast and efficient[5]. In 2018, the geotextile paving trolley developed by China Railway First Bureau Group Construction Machinery Co., Ltd. was added with a hoop paving trolley on the basis of the traditional trolley, which speeded up the work efficiency of geotextile paving and also reduced labour use[6]. According to the technological process of tunnel geotextile construction, this paper studies a software system based on the motion control system of the tunnel geotextile paving trolley, and cooperates with the experiment and debugging of the whole vehicle of the hardware system, which greatly improves the automation of tunnel waterproof construction.
2. System overall scheme design
The geotextile paving trolley for tunnel construction is divided into a motion control system and an automatic paving system. The automatic laying device is installed on the track trolley, and the motion control system drives the trolley to lay the geotextile on the inner surface of the tunnel. The motion control system can drive the trolley to perform lateral and circular motions, and the range of motion is the entire inner surface of the tunnel. The total length of the trolley is 12.5m, and the arc length of the circular track is 50m. The lateral movement axis of the rail trolley is defined as the Y-axis and the circular movement axis is defined as the X-axis. Due to the large span of the two axes, in order to prevent the left and right imbalance when the trolley is traveling, this paper adopts the synchronous control of two servo motors for each axis.

The system structure is shown in Figure 1. Siemens s7-1200PLC is used as the controller[7]. The X-axis and Y-axis each use two servo motors to move synchronously as the driving parts of the walking mechanism, and there are related position feedback signals.

![Figure 1. Structure diagram of motion control system.](image)

2.1. System control process
The system has an automatic operation mode and a manual operation mode. In the automatic operation mode, the system can use sensors and servo controllers to detect the position of the trolley and determine whether the trolley is located at the top of the vault or the bottom of the arch, so as to determine the next forward distance. If the trolley is on the vault, move forward 2m. Otherwise, it will advance 3m and automatically run to the next working cycle. The workflow of the motion control system is shown in Figure 2.

![Figure 2. Work flow chart of motion control system.](image)

3. Control system software design
The motion control system software mainly includes the controller program and the human-computer interaction interface. The controller program design is mainly completed by Portal software[8], and the design of the human-computer interaction interface is completed by Utility Manager[9].

3.1. Controller programming
According to the technological process of tunnel geotextile construction, the system controller program is divided into a horizontal track control module and a circular track control module. Since the lateral
track control program is relatively simple, this article only introduces the automatic control part of the loop track control program.

3.1.1. Axis definition. The portal software integrates the hardware configuration function, which can set the pulse and direction output terminals of the servo motor, acceleration and deceleration time, return to origin mode, etc. According to the control requirements and geotextile construction technology, configure the X-axis and Y-axis, as shown in Table 1.

**Table 1. X-axis, Y-axis parameter setting.**

| Axis name | Basic parameters | Extended parameters |
|-----------|------------------|---------------------|
|           | Signal Type      | Units of Measurement| Maximum Speed (mm/s) | Acceleration Time (s) | Emergency Stop Time (s) | Back to Origin |
| X-axis    | PTO              | mm                  | 33.5                | 2.5                   | 1                       | initiative    |
| Y-axis    | PTO              | mm                  | 75.6                | 2                     | 1                       | initiative    |

In order to make the entire motion control system run more smoothly and smoothly, after many experiments, the acceleration and deceleration time of the X-axis and Y-axis are respectively set to 2.5s and 2s, which effectively avoids the slip and vibration during the operation.

3.1.2. Calculation of the step distance of the hoop track. In order to make the geotextile on the top of the inner surface of the tunnel more closely fit the arch wall, the laying distance between the arch bottom and the top of the tunnel is different. After each laying, steel nails are used to nail the laid geotextile to the arch wall. Therefore, before the construction work, it is necessary to calculate the distance of each step of the rail car in the whole process. In the experiment, the arc length of the tunnel arch wall is 50m, of which the arch bottom at both ends is 30m in total, and the vault top is 20m. According to the geotextile construction technology, the arch bottom is laid at 3m at each step and the vault is laid at 2m at each step. When calculating, set the step count flag step count, step count is automatically incremented by one every time a step is laid, and the calculated distance is stored in the array D (step count) for judging the advance distance of each step. The schematic diagram of the tunnel arch wall and the calculation flowchart of the step distance are shown in Figure 3 and Figure 4.

**Figure 3.** Schematic diagram of tunnel arch wall.
3.1.3. Loop track control program. The circular track is operated in a "semi-automatic mode", that is, after the constructor presses the "next" button on the touch screen, the rail car will move forward on the circular track, and the advance distance is based on the step counter and the array $D$ (step count). After confirming, cooperate with the automatic laying device installed on the trolley and the construction personnel to complete the automatic laying, nailing and other operations, then proceed to the next step of laying. The loop control flow is shown in Figure 5.

**Figure 5.** Control flow chart of circular track.

3.2. Human-computer interaction system screen design

3.2.1. System configuration. The hardware between HMI and PLC is connected through Ethernet interface[10], and the software setting is completed through device configuration. Add the device in the system parameter setting-device list, select s7-1200/s7-1500 (Absolute Addressing) in Siemens AG, and set its IP address in the same network segment as the connected PLC.
### 3.2.2. Variable allocation

In the Utility Manager software, the set variable table must be consistent with the variable table in the PLC. The status indicator lights and buttons use bit variables, and the parameter input and digital display use byte, word, and double word variables according to the data length. The usage of variables is shown in Table 2.

#### Table 2. HMI variable table.

| Variable name | Variable address | Variable type | Remarks |
|---------------|------------------|---------------|---------|
| X_Step count  | MD1000           | REAL          | X-axis current step |
| X_Location    | MD1004           | REAL          | X-axis Real-time location |
| X_Speed       | MD1008           | REAL          | X-axis Running speed |
| X_Home        | M35.0            | BITE          | X-axis Origin signal |
| X_Limit+      | M35.1            | BITE          | X-axis Positive limit |
| X_Limit-      | M35.2            | BITE          | X-axis Negative limit |
| X_Homing      | M35.3            | BITE          | X-axis Back to origin command |
| X_Forward     | M35.4            | BITE          | X-axis forward |
| X_Backward    | M35.5            | BITE          | X-axis backward |
| Y_Step count  | MD2000           | REAL          | Y-axis current step |
| Y_Location    | MD2004           | REAL          | Y-axis Real-time location |
| Y_Speed       | MD2008           | REAL          | Y-axis Running speed |
| Y_Home        | M36.0            | BITE          | Y-axis Origin signal |
| Y_Limit+      | M36.1            | BITE          | Y-axis Positive limit |
| Y_Limit-      | M36.2            | BITE          | Y-axis Negative limit |
| Y_Homing      | M36.3            | BITE          | Y-axis Back to origin command |
| Y_Forward     | M36.4            | BITE          | Y-axis forward |
| Y_Backward    | M36.5            | BITE          | Y-axis backward |

#### 3.2.3. Screen design

As the monitoring and operating equipment of the whole motion control system, the touch screen has the closest contact with the operator. Therefore, the whole human-computer interaction interface should not only be beautiful, but also easy to operate. According to the construction requirements and the characteristics of the construction personnel, this paper designs a human-computer interaction interface based on the Winton touch screen, which mainly includes the car status monitoring screen, the loop track manual control screen, the loop track automatic control screen and the horizontal track manual control screen. Through the above interface, the motion control system can be set, displayed and controlled automatically. The car status monitoring interface is shown in Figure 6.

![Figure 6. Trolley status monitoring interface](image-url)
4. Conclusion

Based on the analysis of tunnel geotextile construction technology, this paper designs the software system of motion control system based on the tunnel geotextile laying trolley. The system mainly includes the controller program designed by Botu software and the human-computer interface designed by utility manager software. Through the application, the motion control system runs normally, can cooperate with the automatic laying device to complete the tunnel geotextile construction operation, reduce the use of manpower, and improve the efficiency and quality of geotextile construction, laying a good foundation for the subsequent automatic nail shooting function.

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