EOL automatic detection scheme for new energy vehicle battery system manufacturing process

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Received: 12 March 2021 / Accepted: 1 May 2021 / Published online: 17 May 2021
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Abstract
As we all know, compared with traditional fuel vehicles, new energy electric vehicles can not only save energy, but also reduce emissions, which is an important direction for future vehicles. However, as the main component of performance, battery performance is highly dependent on temperature, battery life is short, and the range is not ideal. In order to ensure the stability of the heat dissipation structure, an efficient thermal management system must be installed in the battery to ensure that the battery runs at comfortable intervals and prolong its service life. This paper develops a battery temperature management system that combines a water-cooled cycle and an air-cooled cycle. The controller uses MC9S08DZ60 as the main control chip, generates a PWM control signal according to the collected temperature information and error feedback information, and communicates with the compressor, PTC heater, and vehicle system through the CAN network, and the time and temperature information is sent with the battery. The operating status of the components is monitored, and whether to enter the refrigeration cycle, heating cycle, self-circulation, fault cycle, and standby cycle is automatically selected. In recent years, some domestic new energy producers have been launching electronically controlled new energy sources. As the country promulgates the National III emission standard, the new electronically controlled energy will become the main component of the new energy. In order to realize the mass production of electronically controlled new energy, the technical structure of the EOL system must be implemented. This article aims to study the process structure of the EOL system to achieve mass production of new energy through electronic control. Through extensive research and analysis of electronically controlled new energy at home and abroad, as well as the development status of China’s EOL system process, combined with the company’s specific situation, the energy EOL process has been proposed for the construction plan of new electronically controlled new energy.

Keywords New energy vehicle · Battery system · EOL · Automatic detection scheme

Introduction

In many industries, the automobile industry, as an important sector of the national economy, plays an important role in the national economy and has an important responsibility for promoting social development (Rahman et al. 2020). In recent years, with the development of China’s economy and the improvement of people’s living standards, the automobile market has developed rapidly, and the consumption of family cars has continued to grow (Rahmati et al. 2018). In 2016, China’s automobile production and sales exceeded 10 million vehicles, surpassing the USA and becoming the world’s largest consumer automobile market (Rajaee et al. 2019). In 2020, China’s auto production and sales will rank first in the world for two consecutive years. However, in view of the continuous growth of automobile demand driving the rapid growth of GDP, we should see related pollution and energy security issues. Energy and environmental issues have become the main concern of the world in the twenty-first century, especially for the still-developing China (Ramos et al. 2015). Therefore, under the pressure of the coexistence of energy security and environmental pollution, to implement sustainable development strategies, promote energy conservation and emission reduction, and promote the development of new...
energy vehicles to protect new energy vehicles, a solid industry is particularly important and urgent (Regmi et al. 2010). Development and China’s supporting policies, and the industrial development that China should pursue in the next few years are topics worthy of detailed consideration (Remondo et al. 2003). As the country’s emission standards have become more stringent, the production of new energy vehicles of Euro II and below has been discontinued and replaced by new electronic control energy sources with higher emission values from SINOMACH. The end of the production line is an indispensable electronically controlled new energy station in the Guogong II mass production project (Said 1962). The establishment of EOL technology is an unprecedented new technology construction and new technology application for all new energy producers. The construction of a new electronically controlled EOL energy system is related to the construction of new electronically controlled power generation capabilities and is one of the key factors for the survival and development of new energy companies. The research in this article is based on the newly developed electronically controlled new energy, and a new autonomous process is constructed in our manufacturing plant at the same time to ensure the normal mass production and quality specifications of the new energy (Said 1981). The new energy of modern cars has high working pressure and sufficient combustion capacity, and its fuel consumption is about 20% lower than that of gasoline engines. Except for particulate matter, all emissions are lower than those of gasoline engines. As a result, applications are expanding all over the world, and in addition to medium and heavy commercial vehicles, passenger cars and automobiles are also being used more and more (Said 1990). Currently, light commercial vehicles manufactured in foreign countries widely use new energy. Mercedes-Benz, Volkswagen, BMW, Renault, Volvo, and other well-known European brands all use this new energy (Sameen et al. 2019).

**Development of the new energy automobile industry**

**Introduction to the current situation of the new energy vehicle market**

From the concept of new energy vehicles to the introduction of new energy vehicles, several generations of efforts have been made. In the twenty-first century, with people’s concern about the environment and the deep concern about the energy crisis, new energy vehicles have made great progress (Sandford 1929). As far as the global market is concerned, according to the sales data of electric vehicles, global new car sales in 2016 were 315,400, as shown in Fig. 1.

In terms of annual growth rate, the global growth rate of new energy vehicles was the highest in 2017, at 74.06%, while 2018 was the slowest year in 5 years, at only 41.05%. The growth rate in 2020 is 64.88% better than the growth rate of the previous year (Sandford 19). This was also the first time that the annual global new car sales exceeded 2 million that year. Table 1 lists the ten most important models for global new car sales in 2019.

Among them, Tesla’s Model S for new energy vehicles produced in the USA ranked third with a sales volume of 31,623, and was made in China.

BYD Thai Automobile Co., Ltd. ranked third from the bottom with 14,747 sales and was the only Chinese model to enter the list that year.

In the past 5 years, the world’s new energy vehicles have developed rapidly, and the market structure has also undergone tremendous changes. Table 2 lists the ten most important models of global new car sales (Vorpahl et al. 2012).

The most popular model in 2020 is the Tesla Model 3, with annual sales of 145,846 units. The 2016 sales champion Nissan Leaf ranked third with an annual sales volume of 87,149 units. If we compare the sales of 61,207 cars in 2016 with the data in 2020, the model will rank first in terms of sales in 2016, but it only ranked fourth in the 2020 list. It can be seen that the global new energy vehicle market is developing rapidly. In the past five years, the annual sales growth rate
dropped to 34.70%, and the annual new car sales increased to 507,026 units.

Figure 2 shows that the government’s determination to develop new energy vehicles is increasing day by day, and consumers’ acceptance of new energy vehicles is increasing day by day.

In 2018, car sales were 3.48 times the annual sales, and new energy vehicles were 1,256,000 vehicles, which was 16.80 times the 2016 annual sales.

In the past 5 years, the annual sales of new cars in different countries/regions have doubled. In 2016, sales in the USA were 3.04 times that of the country, and sales in Japan were 5.03 times that in 2018. In 2018, Germany was only the second-largest country after China. The sales volume in 2020 exceeds the sales volume in 2016 by 10.86 times (Yilmaz 2010).

Countries also show great differences in growth rates, which may reflect the different development and production rates of new energy vehicles between countries. Figure 3 shows the annual sales growth rate of each country from 2018 to 2020.

Sales ratio is the proportion of the annual use of new energy vehicles in the total sales of the above four countries. Table 3 lists the market share of new vehicles from 2014 to 2020.

Figure 4 clearly shows the changes in the growth rate of the four new car market shares in the four countries from 2016 to 2020. In addition to the zero growth in 2016, China’s share of the new energy vehicle market has also grown relatively strongly in other years. The growth rate in 2016, 2017, and 2018 exceeded 150%, reaching 300% in 2016. Except for the 100% increase in the US new car market share in 2016, it has not doubled in any year since then. There was a negative growth in 2016, and the growth rate of the new car market share was −12.50%. From 2016 to 2020, the growth rate of

| Rank | Brand                   | Sales in 2020 |
|------|-------------------------|--------------|
| 1    | Tesla Model 3           | 145,846      |
| 2    | BAIC New Energy EC series | 90,637      |
| 3    | Nissan Leaf             | 87,149       |
| 4    | Tesla Model S           | 50,045       |
| 5    | Tesla Model X           | 49,349       |
| 6    | BYDTE PHEV              | 47,452       |
| 7    | JAC IEV E/S             | 465,986      |
| 8    | BYD e5                  | 46,251       |
| 9    | Toyota Prius PHEV       | 45,686       |
| 10   | Mitsubishi Outlander PHEV | 41,888      |

Figure 2 Annual sales of new cars in major countries/regions in the world from 2016 to 2020.

Figure 3 Annual sales growth rate of major countries from 2018 to 2020.

![Table 2](image)
Japan’s new energy vehicles in the domestic market has declined (Youssef et al. 2014a).

The spatial distribution of new energy automobile industry bases-taking China as an example

At present, China’s new energy vehicle manufacturing companies are mainly concentrated in four provinces: A, B, C, and D in Eastern China; E in Central China; F in Southern China; and G and H in Northwestern China (Youssef et al. 2014b), in the southwestern provinces of China, as shown in Fig. 5.

Since China puts forward the “energy-saving and new energy” strategy, the government has always attached great importance to the development and industrialization of new energy (Zaidi et al. 2015). By promoting and supporting national policies, all parts of China have actively responded to the R&D, demonstration, and promotion strategies of energy-saving and new energy vehicles, as shown in Table 4.

An important feature of China’s automobile industry is the cluster development of industrial clusters, and China’s new energy automobile industry is no exception. The influence of industrial agglomeration is obvious geographically. The Pan-A-B-C real estate industrial cluster, the Yangtze River Delta industrial cluster, and the Pan-Pearl River Delta industrial cluster have been established (Zabihi et al. 2018). There are six new cluster areas in the automotive energy field, including industrial clusters, western industrial clusters, central industrial clusters, and northeastern industrial clusters, as shown in Fig. 6.

Influencing factors of the spatial distribution of the new energy automobile industry

Research and manufacturing base

From the perspective of the spatial distribution of the new energy vehicle industry, it has been accumulated on the basis of the production of traditional fuel vehicles. As new energy vehicles represent an upgrade and breakthrough in the traditional fuel vehicle industry, some traditional fuel vehicle manufacturers are putting technology and patents in their hands. Therefore, in order to maximize this benefit, they often build new energy vehicle production facilities in areas closer to the original production facilities of conventional fuel vehicles. For example, the FAW group has opened a new energy vehicle production plant in its headquarters in Changchun. Geely Automobile has established new energy vehicle factories in province A, Dongfeng Automobile in B, and Chery Automobile in C.

Table 3 New car market share in four countries from 2014 to 2020.

| Time | China | USA | Japan | Germany |
|------|-------|-----|-------|---------|
| 2014 | 0.04  | 0.20| 0.30  | 0.10    |
| 2015 | 0.10  | 0.40| 0.50  | 0.10    |
| 2016 | 0.10  | 0.70| 0.60  | 0.20    |
| 2017 | 0.40  | 0.80| 0.70  | 0.40    |
| 2018 | 1.00  | 0.70| 0.60  | 0.70    |
| 2019 | 1.40  | 1.00| 0.50  | 0.70    |
| 2020 | 2.20  | 1.20| 1.00  | 1.60    |

Fig. 4 The growth rate of the market share of new energy vehicles in four countries from 2016 to 2020.

Fig. 5 Construction of China’s new energy vehicle manufacturing base.
Technology and knowledge spillover

In addition to the above-mentioned specialized investment, services, labor, and other basic factors such as R&D and manufacturing, technology and knowledge dissemination have also played an active role in generating new energy in the automotive industry. The automobile industry has always been a high-tech industry, and vehicles with new energy have put forward higher requirements on various production and information technologies.

Local policy guidance

The new energy automobile industry is a high-tech industry, and forward-looking industrial policy guidelines are very important. In addition to the unified planning and development of the new energy industry across the country, the concentration of the new energy automobile industry in the region depends to a large extent on the support of the local authorities for the industry. These support measures are mainly reflected in land gains, tax relief, and market access.

Proximity to the consumer market

Proximity to potential large supermarkets is also an important factor when the company builds its factory. The company hopes that the production base will be able to expand to the largest consumer market as much as possible.

At present, the main areas of consumption for new energy vehicles in China are mainly areas with relatively developed economies. This is due to the fact that given the high level of economic development, the locality has sufficient funds to invest in public facilities.

Empirical research on the agglomeration factors of China’s new energy vehicles

Table 4 National top ten new car sales in 2018 (unit: ten thousand vehicles, %)

| Area | Sales (ten thousand) | Pure electric proportion of sales (%) | Proportion of plug-in hybrid sales (%) |
|------|----------------------|---------------------------------------|---------------------------------------|
| A city | 8.42 | 47.50% | 52.50% |
| B city | 8.05 | 24.50% | 75.50% |
| C city | 6.27 | 58.20% | 41.80% |
| D city | 6.25 | 95.80% | 4.20% |
| E city | 5.64 | 64.80% | 35.20% |
| F city | 5.25 | 98.90% | 1.10% |
| G city | 3.78 | 93.00% | 7.00% |
| H city | 3.35 | 73.70% | 26.30% |
| I city | 2.56 | 99.50% | 0.50% |
| G city | 2.53 | 98.50% | 1.50% |

Fig. 6 Distribution map of China’s new automobile industry cluster
Find the concentration coefficient of each province, as shown in Table 5.

Model building

This article is groundbreaking and has almost no data. Therefore, this article only discusses the general direction and chooses a simple multiple regression model for analysis, as calculated in formula (2):

\[ F = \beta_0 + \beta_1x_1 + \beta_2x_2 + \cdots + \beta_5x_5 + \mu \]

2

Use statistical software to perform regression and obtain the data shown in Table 6.

The sample size of the analysis model is small, and the number of industrial companies exceeding the declared size in each province still has a significant impact on the location of new energy vehicle companies, and its standard ratio is the largest. Therefore, it can be assumed that regional R&D bases and production bases are very important to branches, and location selection is also particularly important. Companies are more likely to establish factories in locations with fully supportive industrial services and industrial assets, in anticipation of the sharing of public services, labor, auxiliary industries, and self-produced materials.

The per capita disposable income of residents, the average expenditure of industrial enterprises on R&D exceeding the specified amount, the number of related activities, and the number of cars owned per capita are very similar. We can compare their standard ratios to study their impact on the layout of new energy vehicles.

### EOL automatic detection system design for battery system manufacturing process

#### EOL automatic test system platform system structure design

**Design requirements and difficulties of automatic test system**

The automatic test system is an intelligent test system used in all aspects of battery testing. It must be highly integrated, intelligent, and stable, and the entire test process must be carried out in a safe and closed environment. Test results can be calculated and stored according to actual requirements. The entire execution process requires complex tool design, positioning accuracy, safe loading and unloading, and fast host response. The positioning accuracy required by the entire system is ±1 mm.

**System composition of automatic test platform**

Many new automatic power battery test platforms have been designed in this article, including AGV intelligent vehicles, imaging systems, flexible fixtures, four-axis robots, safety inspection rooms, test cabinets, and top computers. The battery and indoor environment are monitored throughout the process. Figure 7 below shows the operation diagram of the battery test system.

1. Logistics system

   The AGV transportation system provides transportation for the battery, and supports and fixes the battery. When the handheld device puts the battery on the table of the AGV, the AGV waits in the unloading area. The logistics trolley transfers the battery to the test station according to the distribution of the goods and the interaction with the PLC information. After the test is completed, the trolley transports the battery to the next part of the material.

2. Positioning system

   The positioning system consists of an AGV positioning system and a vision compensation system. The positioning system basically completes the flexible coordination of high- and low-voltage docking connectors. The positioning AGV provides accurate positioning with almost no errors. Vision compensation positioning is mainly used to compensate for the cumulative errors caused by design, tool settings, and AGV positioning.

3. Host

   The host displays the status of the information received from the PLC on the screen and can download

| Province | Concentration factor | Province | Concentration factor |
|----------|----------------------|----------|----------------------|
| A        | 0.56                 | Q        | 6.11                 |
| B        | 1.67                 | R        | 2.22                 |
| C        | 0.00                 | S        | 1.11                 |
| D        | 0.00                 | T        | 3.33                 |
| E        | 0.56                 | U        | 7.78                 |
| F        | 0.00                 | V        | 3.89                 |
| G        | 0.56                 | W        | 2.22                 |
| H        | 0.00                 | X        | 0.00                 |
| I        | 0.56                 | Y        | 3.89                 |
| J        | 0.56                 | Z        | 2.22                 |
| K        | 10.00                | a        | 0.00                 |
| L        | 10.56                | b        | 0.56                 |
| M        | 1.67                 | c        | 0.00                 |
| N        | 5.00                 | d        | 5.56                 |
| O        | 12.78                | e        | 5.00                 |
| P        | 3.33                 |          |                      |
instructions to manually control the operation of the device. Higher-level computers can also monitor and calculate test data in real time through CAN communication, which will be described in detail in the following article.

4. Security inspection room

The safety test room is designed to test batteries in a safe environment. Figure 8 shows the safety door.

Flexible adaptive gripper design

The reliable connection of high- and low-voltage test plugs is a prerequisite for checking the safety of battery charging and discharging. For automated test systems, the four-axis robotic arm must be carefully designed to ensure accuracy, flexibility, reliability, and stability.

1. The gripper is equipped with a flexible pneumatic correction mechanism, which has a certain adjustment angle when docking the high and low-pressure grippers. The docking position will be automatically adjusted when inflated to enhance the adaptability of the mechanism.

2. The high- and low-voltage plugs of the fixture are designed to be movable inertia, aligned through the positioning pin holes to guide the plug connection. Taking into account the position deviation of the AGV carriage and the calculation error of the visual analysis, the above-mentioned mechanical structure design can effectively improve the error resistance. The gripper is designed according to functional requirements, and the control structure is designed to be flexible. The specific design is shown in Fig. 9.

Tool design

The system is a series of tools developed for product design. It is mainly used for the design of AGV meters. The AGV workbench is used to fix and support the battery and complete the flexible mating of high- and low-voltage docking connectors. The bottom of the table is an 8-mm-thick steel plate, and the positions of brackets extend from the table to fix the battery in place. The height of each positioning column changes according to the geometry of the battery. The front part of the AGV table is equipped with two hollow lugs for fixing the high- and low-voltage plugs. The PVC board is attached to the top of the table to prevent the battery and AGV table from wearing out. The tool design model is shown in Fig. 10.

Positioning strategy

The intelligent station positioning method is a prerequisite for the normal operation of any station. It realizes the flexible coordination of the high-voltage and low-voltage plugs of the battery workstation (Fig. 11).

Vision compensation positioning mainly uses visual inspection and analysis functions for precise positioning. After the vehicle positioning is completed, the PLC outputs signals to make the robot move along the four axes.

EOL program design

Functional requirements for electronically controlled new energy EOL

As shown in Fig. 12, the structure of the electronically controlled new energy EOL system mainly includes new energy autonomous station ECU data flashing, ECU error code reading and erasing, and online fine-tuning of new energy
parameters, making new energy more efficient. The staff is responsible for writing data records into the control unit, deleting error codes in the control unit, adjusting the power supply for new energy, and storing various data and data sets in the database server.

After the controller writes the calibration data, the EOL tool software must be used to read and clear the controller fault code, and then install the controller on a new power supply. After installing the electronic wiring harness to the new power supply, place the new electronic control unit on the test bench and fix and connect the appropriate wires. If the test detects that the “new energy failure” indicator light is on, please use the “fault diagnosis tool” to read the new “energy failure code,” determine the information about the failure and the cause of the new energy, and take appropriate measures and corrective measures to correct the failure, replace the new energy, and clean the ECU about the wrong information in the circuit memory. The scheme and composition of the electronically controlled new energy EOL and the research design and structure of the EOL process are shown in Fig. 13.

**EOL station construction**

The construction of the electronically controlled EOL station for new energy is designed to serve production (Fig. 14). It provides technical and hardware guarantees for a smooth and autonomous process and the transmission of electronically controlled new energy. The new electronically controlled energy flows into the production line smoothly. Before the new energy enters the test workshop, the ECU will read and clear the error code so that one can quickly install the new energy on the test bench for a new energy efficiency test. If the new energy efficiency meets the requirements of the new energy test procedure, the machine can be easily removed. If the new energy efficiency is unqualified, after confirming that the new energy component has not failed, the new energy efficiency parameters may operate. Install online until the new energy efficiency is evaluated. Finally, the new energy parameters will be displayed in the new energy ECU memory again.
Research and realization of fault diagnosis function

During the test, the new electronic control energy usually fails. Determining how to read the new energy ECU information through the electronic control and how to find the new energy failure helps us analyze the cause of the failure and guides us to troubleshoot and solve the problem; therefore, it can be shut down without new energy barriers, one of the main research areas of our EOL system.

Research and application of electrical control cable control

The electronically controlled new energy electronic control system includes control devices, sensors, actuators, and electronic control wiring harnesses. Among them, the electronic control wiring harness is composed of two parts: the new power wiring harness and the automobile wiring harness. Checking the quality of the electrical control power wiring harness is also an important part of the EOL system. In order to test the quality of the electrical control wiring harness, new energy cannot be limited to testing its appearance. Considering the importance of the wiring harness to the electrical control system and the characteristics of the wiring harness circuit, the wiring harness should be checked.

Test bench structure

The new electronic control energy must be tested on the test bench. In addition to installing control equipment with the latest energy calibration data, a new energy electronic control harness with electronic control functions must also be installed, so this should be a test equipped with an electronic control device station. The design and installation of wiring harness, the modification of test bench console and the modification, and inspection and maintenance of various gas, oil, and water systems to are needed meet the new electrical test requirements.

System software development technology

OPC technology

OPC is an industry standard that contains a complete set of interfaces, properties, and methods for process control and industrial automation systems. The communication between the upper-level PC and the lower-level computer’s PLC is implemented using OPC technology.

DLL technology of expansion card

In 16 PCI-1762 optically isolated outputs, this input channel is very suitable for digital inputs in noisy environments or where drift may occur. In the host program, add a link to the DLL of the card driver, and then call the corresponding function in the DLL of the card. The card is used to control the opening and closing of the relay.
Serial communication technology between PC and battery tester

RS-232 is limited to point-to-point communication between the PC serial interface and the device. In the circuit, the RS-232 communication method uses a simple three-wire connection: Txd, Rxd, and ground. Instrument end and PC end Txd, cross Rxd, and ground the wires are connected together.

PC programming

The above computer software is written in C# in the VS environment, which is an object-oriented visual environment for rapid application development. The system uses OPC technology, DLL technology for expansion cards, RS232 and ADO.NET serial communication technology, etc., which can realize the interaction with the lower computer PLC, switch external circuits, control equipment, and store test data. It automatically controls the ideal development environment.

System test and result analysis

Test requirements

The automatic test system is a completely intelligent test platform, specially designed for the current battery test process, with a low degree of automation and poor recording and analysis functions. The equipment integration method can realize barcode binding, automatic test start, and automatic test result analysis.

The battery module detection system has a humanized interface, convenient operation, fast response, and accurate test results. The block diagram of the system software is shown in Fig. 15.

System initialization After running the program, initialize the card and system parameters, including the initialization of the PCI card slot position, the initialization of the battery tester parameters, the initialization of the OPC tag, etc.
evaluation. This method realizes the overall intelligence and automation of the entire work process, so as to reduce the number of operators and improve test efficiency. The test scope includes battery box and related accessories and BMS system.

1. Connect the test harness
2. Security check
3. The program is flashing
4. Compile and check logistics data
5. Static and wake-up current
6. Check battery parameters and current
7. BMS balance function test
8. Fault signal test and HVIL test
9. Measurement of BMS accuracy
10. Test the high-voltage circuit of the entire vehicle
11. Impulse test
12. Capacity test

The battery test system uses HVU, Hall sensors, and other components for initial testing. It uses two internal networks and one external network of the CAN bus, which are mainly...
used to calculate the SOC of the battery and calculate the capacity. In addition, an independent protection system is added to independently protect the battery.

1. Temperature and humidity test
2. Insulation test
3. Voltage detection

Assumption formula (3) is written below:

$$K = \frac{R_{n2}}{R_{n2} + R_{n1}} = \frac{R_{(n-1)2}}{R_{(n-1)2} + R_{(n-1)1}} = \ldots = \frac{R_{2}}{R_{2} + R_{1}}$$

(3)

Then, through the resistor divider method, formula (4), formula (5), and formula (6) are obtained:

$$U_n = \frac{R_{n2}}{R_{n2} + R_{n1}} U_n = kU_n$$

(4)

$$U_{n-1} = \frac{R_{(n-1)2}}{R_{(n-1)2} + R_{(n-1)1}} U_{n-1} = kU_{(n-1)}$$

(5)

$$U_n = U_{n-1} - U_{n-1} = \frac{R_{n2}}{R_{n2} + R_{n1}} U_{n-1} - \frac{2.4414}{k} D_n - D_{(n-1)}$$

(6)

4. Current favorites

The current in this article is measured using a Hall current sensor. The measured current is measured according to the principle of magnetic field compensation.

5. Gathering resistance

Calculation method:

Set the sine wave as in formula (7):

$$U1(\omega t) = A \cos \omega t$$

(7)

The voltage signal of Keng battery response is as shown in formula (6):

$$U2(\omega t) = B \cos(\omega t + \theta)$$

(8)

Assuming that the test current causes a phase difference in the working voltage, formula (9) can be obtained:

$$U(\omega t) = K \times U1(\omega t) \times U2(\omega t) = KAB \cos(\omega t + \theta) = 0.5KAB[\cos \theta + \cos(2\omega t + \theta)]$$

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$$U_n = U_{n-1} - U_{n-1} = \frac{R_{n2}}{R_{n2} + R_{n1}} U_{n-1} - \frac{2.4414}{k} D_n - D_{(n-1)}$$

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(9)

A low-pass filter is needed to filter the alternating current, as in formula (10):

$$U1(\omega t) = A \cos \omega t$$

(10)

Formula (11) is obtained by measuring the internal resistance through the AC method:

$$R = \frac{B \cos \theta}{I}$$

(11)

$$I$$ is the maximum value of the signal of the direct current source of alternating current, and formula (12) can be obtained:

$$R = \frac{2A}{KAI}$$

(12)

In formula (12), $$K$$, $$A$$, and $$I$$ are known quantities, the A/D sample is $$u$$, and the resistance $$R$$ can be obtained by division.

System operating parameters and results

Visual positioning accuracy experiment

The program used to connect the high and low pressure in the pairing cycle realizes the multiple acquisition of the point coordinate value of the four-axis flexible gripper motion control system, thereby obtaining the repeatable positioning accuracy of the four-axis flexible gripper drive.

For experimental process, choose an AGV in charge of a smart car, move the 4-axis flexible drive from the original position of the workpiece to the mating position of the high-voltage connector, then return to the original position of the workpiece, and repeat the cycle 30 times and write data.

The recorded data is the $$X$$-, $$Y$$-, and $$Z$$-axis coordinate values and the $$R$$-axis angle value of the transmission point. The error value is obtained from the average value of the coordinate. The experimental results are listed in Table 7.

In the experiment, the average $$X$$-coordinate of the driving point of the four-axis robot is 114.618 mm, and the average $$Y$$-axis is 321.829 mm. The $$Z$$-axis does not change when driving, so the $$Z$$-axis average value will not be calculated. According to Table 7, the average $$R$$-axis angle is 89.5120. The average error of the coordinate value is less than ±0.5 mm, and the error of the angle value is less than ±0.0500.

According to the above data analysis, the repositioning accuracy of the four-axis robot drive motion control system is ±0.5mm.
to point B, where B is the assembly point, and the two digital brake calipers are locked in the X- and Y-directions of the reference point AGV moving direction. Repeat the process 20 times and write down the data.

The recorded data is the value of two digital calipers connected to connection point B, and the error value is obtained from the average value of the coordinates. The experimental results are shown in Table 8.

In this series of experiments, the average value of the X-axis of the attachment point is 23.339 mm, and the average value of the Y-axis is 31.263 mm. The error of the X- and Y-coordinates is small.

Based on the analysis of the above data, the repeat positioning accuracy of the AGV smart car will be mm.

| Sequence | X    | Y    | ΔX   | ΔY   |
|----------|------|------|------|------|
| 1        | 23.65| 30.73| 0.061| -0.833|
| 2        | 23.52| 30.94| -0.069| -0.623|
| 3        | 23.74| 31.56| 0.151| -0.003|
| 4        | 23.37| 31.38| -0.219| -0.183|
| 5        | 23.67| 31.47| 0.081| -0.093|
| 6        | 22.92| 31.35| -0.669| -0.213|
| 7        | 23.68| 31.55| 0.091| -0.163|
| 8        | 23.6 | 30.78| 0.011| -0.783|
| 9        | 23.51| 31.46| 0.079| -0.103|
| 10       | 23.49| 30.7 | 0.071| -0.863|
| 11       | 23.46| 31.32| -0.129| -0.243|
| 12       | 23.63| 31.34| 0.041| -0.223|
| 13       | 22.79| 31.23| -0.799| -0.053|
| 14       | 22.72| 30.98| -0.869| -0.583|
| 15       | 22.85| 31.76| -0.739| 0.197|
| 16       | 22.6 | 31.24| -0.179| -0.323|
| 17       | 22.22| 30.86| -0.369| -0.703|
| 18       | 22.45| 31.36| -0.239| -0.203|
| 19       | 22.88| 31.44| -0.709| -0.123|
| 20       | 23.52| 31.53| -0.269| -0.033|

To point B, where B is the assembly point, and the two digital brake calipers are locked in the X- and Y-directions of the reference point AGV moving direction. Repeat the process 20 times and write down the data.

The recorded data is the value of two digital calipers connected to connection point B, and the error value is obtained from the average value of the coordinates. The experimental results are shown in Table 8.

In this series of experiments, the average value of the X-axis of the attachment point is 23.339 mm, and the average value of the Y-axis is 31.263 mm. The error of the X- and Y-coordinates is small.

Based on the analysis of the above data, the repeat positioning accuracy of the AGV smart car will be mm.

| Sequence | X    | Y    | ΔX   | ΔY   |
|----------|------|------|------|------|
| 1        | 23.65| 30.73| 0.061| -0.833|
| 2        | 23.52| 30.94| -0.069| -0.623|
| 3        | 23.74| 31.56| 0.151| -0.003|
| 4        | 23.37| 31.38| -0.219| -0.183|
| 5        | 23.67| 31.47| 0.081| -0.093|
| 6        | 22.92| 31.35| -0.669| -0.213|
| 7        | 23.68| 31.55| 0.091| -0.163|
| 8        | 23.6 | 30.78| 0.011| -0.783|
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| 10       | 23.49| 30.7 | 0.071| -0.863|
| 11       | 23.46| 31.32| -0.129| -0.243|
| 12       | 23.63| 31.34| 0.041| -0.223|
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| 17       | 22.22| 30.86| -0.369| -0.703|
| 18       | 22.45| 31.36| -0.239| -0.203|
| 19       | 22.88| 31.44| -0.709| -0.123|
| 20       | 23.52| 31.53| -0.269| -0.033|

Charge and discharge test experiment

Analyze the records of charging and discharging experiments: During the experiment, the test cabinet will perform battery charging and discharging tests, run the LABVIEW program, open the Dicaron device test file, test 20 batteries, and record the data.

Record the internal resistance of the battery pack, internal DC resistance, battery temperature difference, battery voltage drop, and battery capacity data. The experimental results are listed in Table 9.

The result of this set of experiments is that the internal DC resistance R is less than 170 mS/m², the temperature difference is less than 10°, the voltage difference between the two ends of the battery is less than 0.70 V, and the battery capacity is less than 130 Ah. It can be seen from the table that the test data of AA battery does not match the overall test result. After checking and analyzing the battery, this was caused by the interruption of the battery copper bus connection.

Conclusion

In China, the production and sales of new energy vehicles are the world’s top priority, and their technical level needs to be improved. In 2018, global new car sales were 247, an increase of 64.88% over the previous year. China’s new car sales
accounting for the share of global new car sales increased from 23.70% in 2016 to 62.23% in 2020, surpassing the USA, and ranking first in the world in 2015, and has remained so far. Domestic car sales declined in 2018, and new energy vehicle sales exceeded this trend, reaching 12.56 million vehicles. From the perspective of sales structure, the proportion of all-electric vehicle sales in total sales has increased by 78.39% year by year. In recent years, it has been a major distributor of new energy vehicles in China. Triple material batteries accounted for 58.17% of the total battery shipments in 2018, and are the main battery types selected by various manufacturers. This article is based on the current temperature control program used in car batteries to control peripheral components, and develops appropriate conditions for cooling, heating, and heat storage functions. The summary and innovation are as follows: (1) The control method of each component, the BTMS controller hardware circuit, is equipped with a suitable control circuit to control the temperature, and realizes the effective control of the components, so that the battery can work in its working state. (2) The BTMS management software has formulated an appropriate strategy for the possible battery temperature. When the actual battery temperature reaches the set cycle temperature, it will automatically enter the cycle to realize automatic intelligent control of the battery pack temperature. Creatively adopt a closed and recyclable temperature management system to ensure the compatibility of cooling, heating, and thermal protection functions, effectively solve the problem of battery internal temperature imbalance, control the temperature of the internal thermal environment of the battery, and allow rapid charging at low and high temperatures. With the rapid development of new energy batteries and modern battery pack assembly, AGV, imaging, and PACK inspection processes, this article focuses on the current battery pack inspection requirements to ensure high efficiency, safety, and security. On the issue of stable performance, relevant domestic and foreign literature, and reference materials have been studied, and an automatic test system has been established. In this paper, through the precise positioning of AGV and the interaction between the robot and the imaging system, the flexible robot grip design, the key technology of the positioning system and the elasticity of the docking connector are deeply studied and analyzed. The dual positioning of complete high- and low-voltage docking equipment focuses on solving the problem of high precision requirements. According to the test requirements and test principles, the test process, and method are designed to achieve effective and comprehensive PACK battery test, and to further improve the intelligence and balance of the system.

### Funding
This work was funded by the following: (1) Natural Science Basic Research Program of Shaanxi Province: Ecological Benefit Evaluation and Multi-objective Optimization of Automobile Industry Chain Based on Life Cycle Assessment Theory (2017JQ7003); (2) Humanities and Social Sciences Youth Fund of Ministry of Education:

| Serial number | DC internal resistance (mΩ) | Cell temperature difference (ΔT) | Single pressure difference (ΔV) | Battery capacity |
|---------------|-----------------------------|---------------------------------|-------------------------------|-----------------|
| 1             | 150 mΩ                      | 3°                              | 0.053 V                       | 115AH           |
| 2             | 140 mΩ                      | 4°                              | 0.052 V                       | 116AH           |
| 3             | 147 mΩ                      | 6°                              | 0.050 V                       | 113AH           |
| 4             | 164 mΩ                      | 6°                              | 0.052 V                       | 112AH           |
| 5             | 162 mΩ                      | 9°                              | 0.044 V                       | 110AH           |
| 6             | 146 mΩ                      | 8°                              | 0.056 V                       | 125AH           |
| 7             | 148 mΩ                      | 3°                              | 0.042 V                       | 121AH           |
| 8             | 149 mΩ                      | 3°                              | 0.046 V                       | 121AH           |
| 9             | 154 mΩ                      | 1°                              | 0.048 V                       | 123AH           |
| 10            | 152 mΩ                      | 7°                              | 0.048 V                       | 124AH           |
| 11            | 144 mΩ                      | 2°                              | 0.063 V                       | 125AH           |
| 12            | 147 mΩ                      | 5°                              | 0.064 V                       | 115AH           |
| 13            | 160 mΩ                      | 15°                             | 0.061 V                       | 213AH           |
| 14            | 140 mΩ                      | 5°                              | 0.060 V                       | 115AH           |
| 15            | 150 mΩ                      | 4°                              | 0.058 V                       | 117AH           |
| 16            | 157 mΩ                      | 3°                              | 0.056 V                       | 112AH           |
| 17            | 168 mΩ                      | 2°                              | 0.059 V                       | 115AH           |
| 18            | 153 mΩ                      | 1°                              | 0.047 V                       | 122AH           |
| 19            | 146 mΩ                      | 5°                              | 0.060 V                       | 121AH           |
| 20            | 140 mΩ                      | 3°                              | 0.067 V                       | 118AH           |
Ecological Benefit Evaluation of Automobile Industry Chain Oriented to “Made in China 2025” Plan (16YJCZH008); (3) Natural Science Basic Research Program of Shaanxi Province: Identification of Dangerous Driving Status for Motor Coach Based on Environmental Perception Technology (2018JQ5142); (4) Humanities and Social Sciences Youth Fund of Ministry of Education: Research on Recycling Management of Automobile Products Based on Performance Evaluation of Resource, Energy and Environment (18YJCZH110); (5) Fundamental Research Funds for the Central Universities in China: Identification of Dangerous Driving Status for Motor Coach Based on Multi-source Information Fusion (30010228106).

Declarations

Conflict of interest The authors declare that they have no competing interests.

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References

Rahman, et al. (2020) Multiscale groundwater level forecasting: combining new machine learning approaches with wavelet transforms. J. Water Resour 14(2020):103595
Rahmati O, Naghibi SA, Shahabi H, Bui DT, Pradhan B, Dashre A, Sardooi E, Samani AN, Melesse AM (2018) Groundwater-spring potential modelling: comprising the capability and robustness of three different modeling approaches. J Hydrol 555:248–261. https://doi.org/10.1016/j.jhydrol.2018.01.037
Rajaei T, Ebrahimi H, Nourani V (2019) A review of the artificial intelligence methods in groundwater level modeling. J Hydrol 572:336–351. https://doi.org/10.1016/j.jhydrol.2018.12.037
Ramos AM, Sarmiento LF, Trujillo MG, Mancias JP, Santos AC (2015) Linear discriminant analysis to describe the relationship between rainfall and landslides in Bogotá, Colombia. Landslides 13:671–681. https://doi.org/10.1007/s10346-015-0593-2
Regmi NR, Giardino JR, Vitek JD (2010) Modeling susceptibility to landslides using the weight of evidence approach: western Colorado, USA. Geomorphology 115:172–187
Remondo J, González A, De Terán JR, Cendrello A, Fabbrini A, Chung CJ (2003) Validation of landslide susceptibility maps: examples and applications from a case study in Northern Spain. Nat Hazards 30(3):437–449
Said R (1962) The geology of Egypt. Elsevier Publishing Company, Amsterdam, New York, p 377
Said R (1981) The geological evaluation of the River Nile. Springer, Verlag, New York, p 151
Said R (1990) The Geology of Egypt. S.A, Balkema, Rotterdam, Brookfield, p 731
Sameen MI, Pradhan B, Lee S (2019) Self-learning random forests model for mapping groundwater yield in data-scarce areas. Nat Resour Res 28:757–775. https://doi.org/10.1007/s10346-019-9416-1
Sandford KS (1929) The Pliocene and Pleistocene deposit of Wadi Qena and of the Nile Valley between Luxor and Assiut. Quart J Geol Soc. London 25p
Sandford KS (1934) Palaeolithics in Egypt and the Nile Valley in Upper and Lower Egypt. Univ Chicago Orient Inst Pub 3:1–131
Vorpahl P, Elsenbeer H, Märker M, Schröder B (2012) How can statistical models assist to define driving factors of landslides? Ecol Model 239:27–39
Yilmaz I (1989) The effect of the sampling strategies on the landslide susceptibility mapping by conditional probability (CP) and artificial neural network (ANN). Environ Earth Sci 60:505–519
Youssef AM, Al-Kathery M, Pradhan B (2014a) Landslide susceptibility mapping at Al-Hasher Area, Jizan (Saudi Arabia) using GIS and Boolean logic. J Afr Earth Sci 111:156–169. https://doi.org/10.1016/j.jafrearsci.2015.07.008
Zaidi FK, Nazzal Y, Ahmed J, Naeeem M, Jafari MK (2015) Identification of potential artificial groundwater recharge zones in Northwestern Saudi Arabia using GIS and Boolean logic. J Afr Earth Sci 111:156–169. https://doi.org/10.1016/j.jafrearsci.2015.07.008