U.P.B. Sci. Bull., Series D, Vol. 86, Iss. 4, 2024 ISSN 1454-2358

APPLICATION PRACTICE OF INTELLIGENT ALGORITHM AND DIGITAL TWIN IN ELECTROMECHANICAL EQUIPMENT

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In order to explore the specific application methods of intelligent algorithm and digital twin technology in the field of mechanical and electrical equipment, a mechanical and electrical experiment platform with the background of Gomoku man-machine chess and a digital twin system corresponding to mechanical and electrical systems are constructed. The focus is to explore the process of intelligent algorithm enabling controller for efficient drive control and data communication of mechanical and electrical systems. The real-time data mapping between electromechanical system and twin system is realized to achieve the purpose of real-time monitoring and management of electromechanical system. The actual test shows that the platform successfully realizes the fast data processing and communication, and realizes the "virtual and real synchronization" between the physical system and the twin system in the concept of digital twin, which provides a practical example and innovative thinking for the application of intelligent algorithm and digital twin technology in electromechanical equipment.

Keywords: Intelligent Algorithm, Digital Twins, Electromechanical Equipment, Programmable Logic Controller

1. Introduction

In intelligent manufacturing and automation equipment, the control of electromechanical equipment is increasingly dependent on complex automation systems driven by motors. However, in high-speed, dynamically changing environments, these systems often face the challenges of real-time data processing

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and decision-making. For example, the traditional cutting simulation software is limited to the trajectory simulation of the tool, and can not fully consider the size and shape of the workpiece, if the workpiece is held beyond the set range, it is possible to collide, and even cause the workpiece to shift. In order to avoid this problem, the motor control system must make accurate strategy and processing in a very short time, in which real-time data acquisition, data mapping, feedback mechanism and real-time execution are key factors.

Gobang man-machine playing equipment is a comprehensive practical case of electromechanical equipment. Modern man-machine chess devices have made significant progress in both algorithm and hardware aspects. Algorithm research is primarily reflected in the design and optimization of algorithms. Traditional heuristic search algorithms such as Alpha-Beta [1] pruning and Monte Carlo Tree Search (MCTS) [2] have been replaced by advanced algorithms like deep learning and reinforcement learning. With the development of deep learning technology, more and more research has begun to explore methods based on neural networks, such as deep reinforcement learning. Deep learning methods have been gradually applied to the field of object detection and recognition [3], which can also be used for the recognition of chess pieces and chessboard objects, and even for the calculation of game strategies. Peizhi Yan et al [4]. have further improved the performance of Gomoku AI based on pure neural networks by mixing deep convolutional neural networks with deep learning. Silver David et al [5]. demonstrated the enormous potential of deep learning in complex board games such as Go using this method. The research of electromechanical structure is mainly reflected in the continuous progress and evolution of hardware platform. Giuliano Fabris et al [6]. achieved the execution of picking up and placing chess pieces by coupling collaborative robots with artificial intelligence systems. Pozzi Luca et al [7]. used a 7-degree-of-freedom robotic arm to alternate between players represented by white or black chess pieces.

As gaming algorithms and hardware continue to improve, the control complexity of such devices is gradually increasing. First of all, as the game strategy becomes more complex, the requirements for device response speed and execution accuracy also increase. The control system not only needs to process various sensor data, but also needs to analyze and execute complex control instructions in real time to maintain efficient and accurate synchronization between the collected data and the actuator. Secondly, the actual working environment and conditions of the physical equipment are often unpredictable, and there may be problems such as sensor failure, data delay or physical component wear, resulting in the control system being unable to adjust in time, affecting the stability, reliability and rapidity of the equipment.

Therefore, the limitations of traditional control methods are gradually exposed, which are mainly reflected in the following aspects: first, it increases the difficulty of real-time monitoring and adjustment; Second, failure detection and predictive maintenance capabilities are insufficient; Third, the transmission and mapping of data flows in complex systems are prone to delays or errors. In view of these situations, the introduction of digital twin technology becomes crucial, especially its data mapping capabilities, can help solve these problems.

Digital twinning technology involves the precise digital replication of real electromechanical systems. It not only includes the physical structure and component attributes of electromechanical systems but also simulates their operational states, dynamic behaviors, and other dynamic characteristics [8]. Leveraging this capability allows for real-time monitoring and management of potential faults and issues during the operation of electromechanical equipment. The application scope of digital twinning technology is extensive. In the field of electromechanical devices, Christina Lat sou et al [9]. aim to coordinate the reusability and scalability of existing digital twinning frameworks through the development of unified concepts and processes. Magyar Péter et al [10] explore and anticipate the study of process parameters for welding specimens within a created test system. Jun feng et al [11] integrate traditional wheeled vehicle control systems with digital twinning technology, establishing a framework for control system fault diagnosis and maintenance and developing a fault detection method. Muhammad Hamza Zafar et al [12] provide a systematic review of the collaborative interaction between cooperative robots and digital twinning. Gasiyarov Vadim R et al [13] validate the rationality of the virtual configuration concept method in industrial electromechanical complexes through virtual debugging of rolling mill transformations.

In summary, most of the existing research focuses on the feasibility analysis and design optimization of the manufacture of electromechanical physical devices using digital twin technology, especially the validation of device performance through virtual models in the pre-manufacturing stage. However, in the actual operation of the equipment, especially in the real-time monitoring and fault diagnosis of the real-time drive and control process of intelligent electromechanical equipment, the research is slightly insufficient. In particular, the research of data bidirectional mapping and feedback mechanism in electromechanical equipment is not deep enough.

This paper mainly discusses from the following aspects: Firstly, discusses how to realize real-time and fast data processing by Gobang intelligent algorithm to drive the control mechanism to complete the motion control process; Secondly, based on the data mapping relationship between twin devices and physical devices, digital twin technology is used to realize bidirectional data mapping and data communication, so as to ensure the effective flow of information between the two systems. Finally, the application of digital twin technology in real time monitoring of Gobang physical equipment is analyzed, and its importance in optimizing control and fault diagnosis is emphasized. Through this comprehensive example, the potential of digital twin technology to improve the intelligence level of electromechanical equipment is demonstrated.

The actual test of the Gobang man-machine playing device shows that the constructed twin system can reflect the running state of the real device in real time, realize the "virtual and real synchronization" between the twin system and the physical system, and fully demonstrate the important role of digital twin technology in real-time monitoring and bidirectional data mapping [14].

This proves the feasibility of applying intelligent algorithm and digital twin technology to electromechanical equipment and realizing its effective control. Extending to other electromechanical equipment, such as the similar problem of workpiece processing mentioned above, the introduction of digital twin technology can generate a global model of the device when the workpiece is moving, and monitor the position relationship between the workpiece and the tool in real time. In this way, when the workpiece is at risk of impact, the twin system can make precise strategic adjustments in a very short time, issue an alarm and actively stop the operation of the equipment before the collision, avoiding damage.

2. System design scheme

Fig. 1 shows the overall structure of the electromechanical equipment, and the structure is simplified as much as possible on the basis of satisfying the Gomoku man-machine game. It is mainly divided into the following modules.

Supply Module: It's role is to supply chess pieces of the corresponding color according to the choice of the operator or AI.

Pieces Retrieval Module: It's role is to grab the pieces supplied by the Supply Module, and transport the pieces to the corresponding point with the X /Y Axis Slide Module.

Checkerboard Module: It's role is to fix the real Checkerboard and drop pieces above it.

X/Y Axis Slide Module: It's role is to drive the Piece Retrieval Module and Checkerboard Module to move to the specified position, and transport the pieces to different ranks and points.

After verification and analysis, the electromechanical equipment can meet the design requirements of real-time data acquisition and communication, and "virtual and real synchronization" based on digital twin technology. Due to the limited computing capacity of the device's own control processor such as PLC (Programmable Logic Controller), the platform uses the PC (Personal Computer) as the core processor, and the PC sends position control instructions to the PLC, and the PLC drives and controls the movement of the electromechanical system according to the instructions of the PC. This platform uses Alpha-Beta pruning algorithm, and there are many researches on the strategy of this algorithm, so this article will not elaborate.

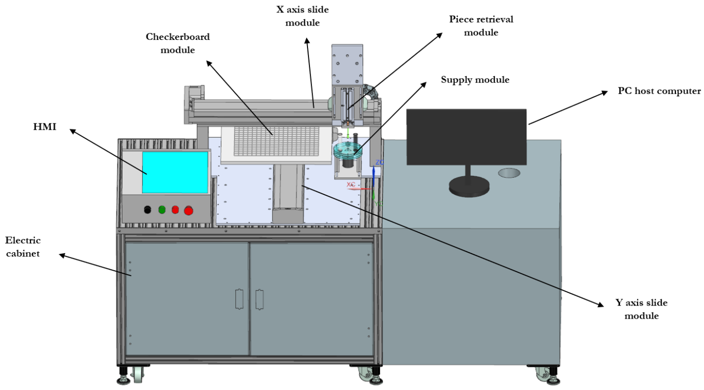


Fig. 1. Electromechanical equipment model

The controller PLC accepts the PC host computer's row, column values and other chess pieces data, and drives the electromechanical actuator to the specified position through the pulse frequency and quantity control drive device. The mechanical and electrical equipment physical system has the following three functions.

First, Receive instructions: receive the row, column and other data of the PC host computer, and convert it into the corresponding chessboard position in the mechanical and electrical equipment. Second, Position control: Drive the corresponding actuator to supply the corresponding color chess pieces according to the instructions of the PC host computer, and accurately control the transport of chess pieces to the specified position of each component. Third, Information feedback: Obtain motion status and position information from each component of the electromechanical equipment through sensors or other data acquisition methods and feed it back to the PC host computer.

The data structure of the platform is shown in Fig. 2. PC sends control command data to PLC, including the color, position information and confirmation information of the chess pieces of the current operator or AI. After receiving the instruction sent by PC, PLC executes the corresponding control task; the motion state, completion signal and sensing data of the actuator are fed back to the PC. At the same time, the static information and dynamic characteristics such as operating state and dynamic behavior of the electromechanical system are mapped to the digital twin virtual system in real time, which provides the operator with real-time and safe monitoring and management of the motion state and chess situation of the Electromechanical equipment.

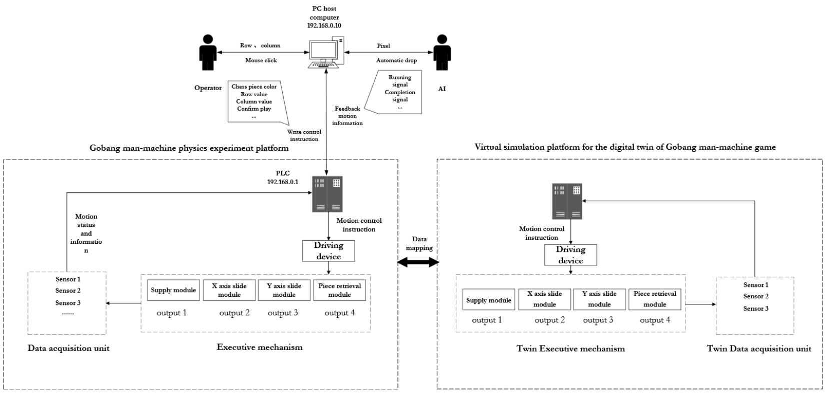


Fig. 2. Data structure relationship

3. Implementation of algorithm transformation control

3.1 Coordinate conversion

According to the functional design requirements, as shown in Fig. 3, the size of the checkerboard adopted is 15×15, and the operator operates on the virtual checkerboard to control the action of the physical equipment. The virtual checkerboard and the real checkerboard coordinate system are in the same direction, and the starting points of the two checkerboards are located in the upper left. The system design initializes the zero-back operation to ensure the origin position of the two coordinates of the system. The virtual checkerboard spacing is 45PX; the true checkerboard spacing is 20mm, and the true checkerboard coordinate zero point position is (-7.68mm, 76.89mm), depending on the origin sensor position of the two axes.

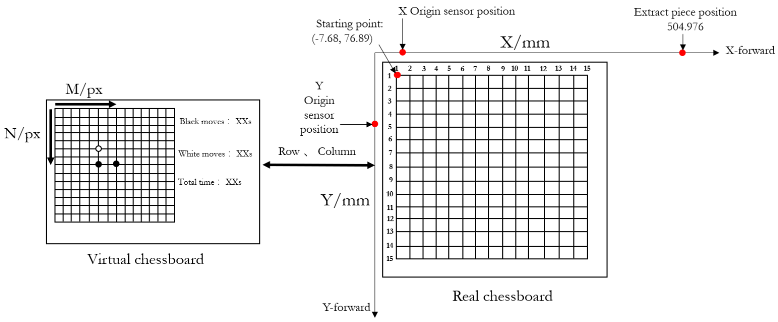


Fig. 3. Checkerboard correspondence

The position data between the virtual checkerboard points and the real checkerboard points are converted between the world coordinates and pixel coordinates with the line values as the medium, and the calculation formula is shown in formula (1) - formula (4).

$$X = x_{offset} + (B - 1) * \Delta x \quad (1)$$

$$Y = y_{offset} - (A - 1) * \Delta y \tag{2}$$
$$M = m_{offset} + (B - 1) * \Delta n \tag{3}$$
$$N = n_{offset} + (A - 1) * \Delta m \tag{4}$$

Where:

M, N: pixels in the horizontal and vertical directions of the PC host computer interface;

X, Y: the horizontal and vertical distances on the real board;

A, B: row and column values;

Offset: indicates the offset;

3.2 Decision transformation

When detecting that there is a mouse click on the checkerboard, that is, after the operator drops, as shown in Fig. 4, the operator's drop information is converted into the column position and stored in the checkerboard array through formula (1) -formula (4). After AI obtains the opponent's column position, it calculates through the algorithm module and obtains the column position that AI should follow. Then the row coordinates under itself are converted into pixel coordinates and the lower right corner of the pixel is the center to draw a circular chess piece of the corresponding color, that is, to achieve AI.

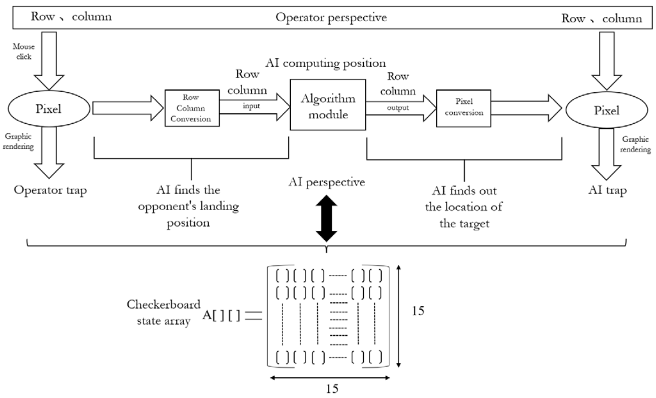


Fig. 4. Algorithm module input and output

Array-based manipulation provides a simple and efficient way to implement board games. As shown in Fig. 5, in a complete game, 0 represents no chess piece, 1 represents white chess pieces, and 2 represents black chess pieces. The real-time tracking and analysis of chess game state is realized by reading, changing and comparing array values. By continuously reading the array values, you can know the current state of each position on the board in real time, including whether there are pieces and what color pieces are; By changing the value of the array, you can simulate the behavior of the drop, and place a new chess piece on the board at the specified position; By comparing the array values, you can further determine the winner by examining the distribution of pieces in each row, each column, and on the diagonal.

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	2	0	1	0	0	1	0	0	0	0
0	0	0	0	1	1	2	0	1	1	0	0	0	0	0
0	0	0	0	0	2	2	2	1	0	0	0	0	0	0
0	0	0	0	2	2	2	1	2	0	0	0	0	0	0
0	0	0	0	2	2	1	0	0	1	0	0	0	0	0
0	0	0	0	1	2	2	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 5. Checkerboard state

3.3 Decision control

In a round of new game, as shown in Fig. 6, the operator first holds the move, and the AI realizes the automatic move after five steps of processing. Every black and white piece cycle, Algorithm program must judge whether to win or lose, and if the win or lose is established, Algorithm program will jump out of the current game cycle. At the same time, the decision results of the algorithm, namely row value, column value, chess pieces information, etc. are transmitted to the PLC controller synchronously. After obtaining the data, the PLC immediately drives the electromechanical structure to transport the corresponding chess pieces to the specified position, and feedbacks the motion signal and completion signal of the electromechanical executive structure to the PLC and PC step by step.

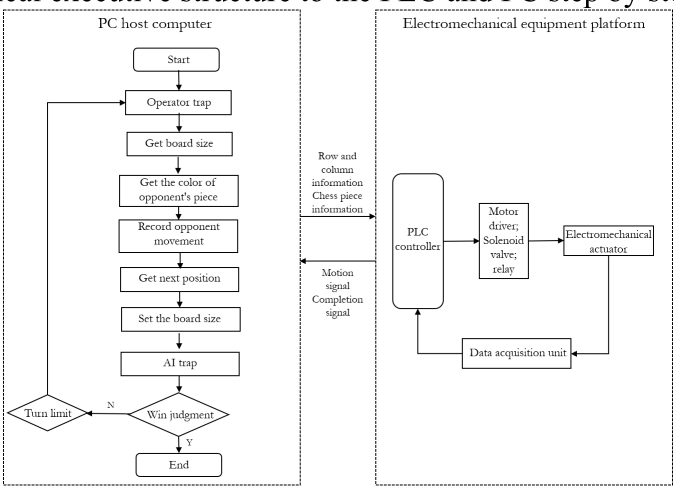


Fig. 6. Control and feedback process

4. Digital twin system construction

4.1 Physical unit definition

Mechanical and electrical equipment physical system includes mechanical structure, controller PLC, sensor and actuator and other parts. As shown in Fig. 7, in the hardware structure of the electromechanical equipment, the system adopts S7-1200 series PLC to connect the PC host computer and the electromechanical executive structure, and performs the hardware configuration of the system in TIAPortal-V16 [15].

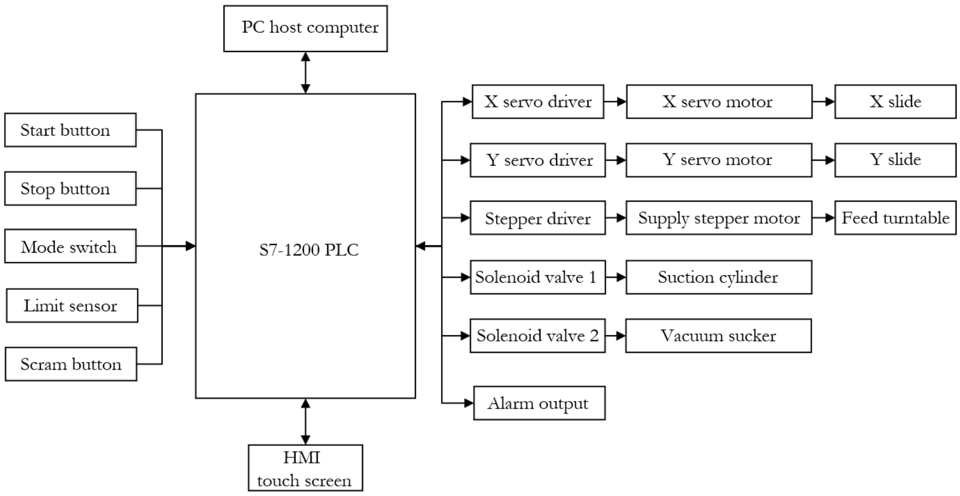


Fig. 7. Physical system hardware structure

Considering the accuracy requirements of checkerboard positioning, servo motors are adopted and limit switches are added to each servo motor and cylinder to limit and protect their positions. Part of I/O distribution is shown in Tab. 1 [16]. Depending on the number of I/O, the platform uses Siemens 1200 series PLC as the intermediate controller.

Tab. 1 Partial I/O Allocation

Address	Function Description	Address	Function Description
I0.0	X-axis Positive Limit	Q0.0	X Motor Pulse
I0.1	X-axis Negative Limit	Q0.1	X Motor Direction
I0.2	X-axis Origin	Q0.2	Y Motor Pulse
I0.3	Y-axis Positive Limit	Q0.3	Y Motor Direction
I0.4	Y-axis Negative Limit	Q0.4	Standby
I0.5	Y-axis Origin	Q0.5	Standby
I0.6	Telescopic Cylinder Upper Limit	Q0.6	Chess Cylinder
I0.7	Telescopic Cylinder Lower Limit	Q0.7	Suction Switch
I1.0	On Inspiration	Q1.0	Rotary Motor Pulse
I1.1	Rotary Motor Limit	Q1.1	Rotary Motor Direction

4.2 Virtual unit definition

There are motion constraints and behavior logic among each model device in the virtual unit. In order to realize the digital mirror of the physical unit, it is necessary to build a digital twin model under multi-dimensional conditions. It creates a virtual model that is highly similar to and dynamically related to physical objects, processes or systems in the physical world by integrating physical models, sensor data, operating records and other information [17]. According to the construction dimension of the twin model, the twin model is modeled from four dimensions: geometric physics, attribute information, behavior logic and constraint rules.

(1) Definition of geometric physics and attribute information model.

Geometric physical model is a model that visually describes the physical entity layer. The attribute information model models the attribute information possessed by the physical entity layer. Through NX MCD, the basic properties, configuration information and connection properties of the device are added to the virtual model, as shown in Fig. 8, and the basic objects of the electromechanical device are endowed with rigid body and collider properties. The generation of black and white chess pieces is generated through rigid objects.

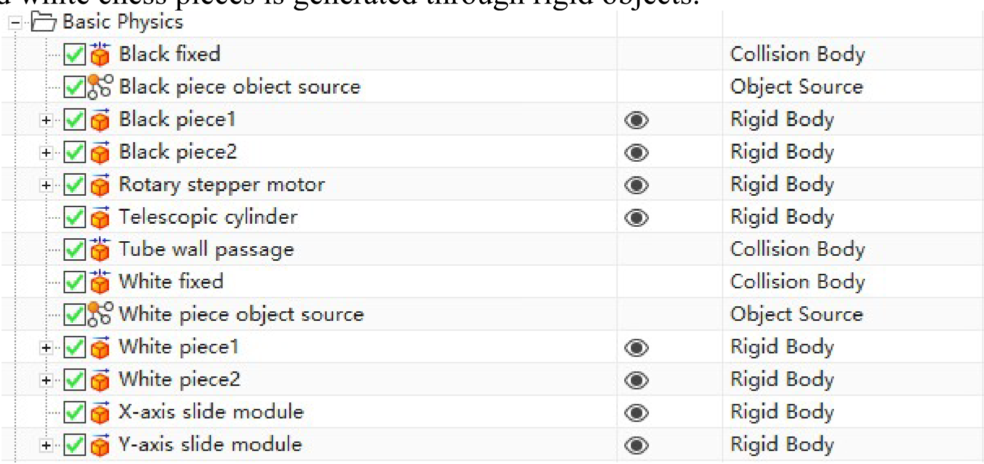


Fig. 8. Basic electromechanical object definition

(2) Behavior logic and constraint rule model definition

The behavioral logic model describes the logical behavior of the physical entity layer. The logical behavior in the physical entity layer mainly includes the action behavior of the equipment and the logical behavior of the system to control the moving mechanism. According to these logical behaviors, the kinematic model and the behavioral logical model are established respectively for the virtual model. Constraint rule model models the constraint rules that the physical entity layer needs to follow in the process of movement, including process constraint rules, process constraint rules, decision rules and so on. As shown in Fig. 9, the position and speed control of the motor are defined according to the true motion range of the physical equipment, and the corresponding constraints are imposed on the motor.

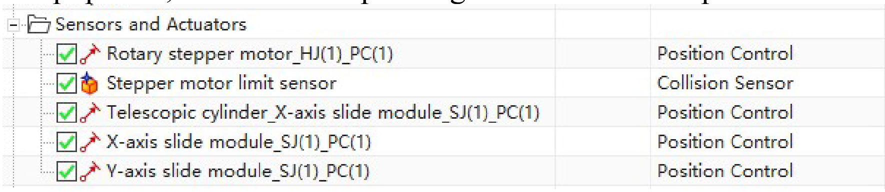


Fig. 9. Position control definition

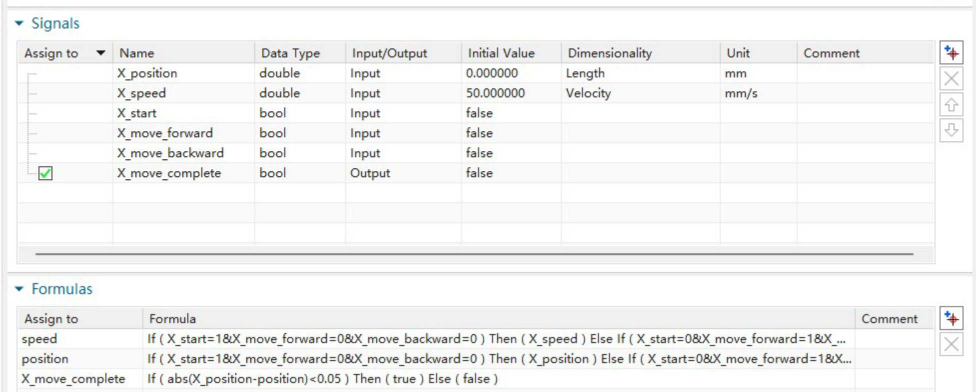
In the physical system, the motor and cylinder actions are usually controlled by PLC signals, and in the same twin system, the twin motor and cylinder actions are also controlled by signal control, and finally the data interaction between the two is realized through the physical system signals and the twin system signals. As shown in Fig. 10, the control signals of each motor and cylinder are added to the signal adapter. As well as the limit signal and data signal of each motor and cylinder, the corresponding value is written by PLC and the control signal action is driven.

Fig. 10. Signal adapter definition

Taking the motion of the drive control X-axis servo motor as an example, as shown in Fig. 11, the control signals and data signals of the X-axis servo motor are defined, including position, speed, start, forward and reverse dotting, positioning completion, etc. The Y-axis servo motor is similar to the X-axis servo motor and is defined by the same method.

Through continuous collection and analysis of data from physical device sensors, control systems and other sources, such a large amount of real-time data is used to control the action of the twin system by means of signals, so as to build a model that can reproduce or simulate the behavior of physical devices in real time in the digital space [18], and finally build the twin system of the platform.

The twin system can reflect the state, behavior and performance of its corresponding entity in real time or near real time, ensuring that the large amount of real-time data (such as position, speed) generated by the electromechanical system can be transmitted to the twin system in real time, and can be accurately reproduced in the model. This kind of real-time data mapping enables the twin system to reflect the real time state of electromechanical system, and provides strong support for monitoring, diagnosis, prediction and optimization.



Signals

Assign to	Name	Data Type	Input/Output	Initial Value	Dimensionality	Unit	Comment
	X_position	double	Input	0.000000	Length	mm	
	X_speed	double	Input	50.000000	Velocity	mm/s	
	X_start	bool	Input	false			
	X_move_forward	bool	Input	false			
	X_move_backward	bool	Input	false			
☑	X_move_complete	bool	Output	false			

Formulas

Assign to	Formula	Comment
speed	If (X_start=1&X_move_forward=0&X_move_backward=0) Then (X_speed) Else If (X_start=0&X_move_forward=1&X_...	
position	If (X_start=1&X_move_forward=0&X_move_backward=0) Then (X_position) Else If (X_start=0&X_move_forward=1&X...	
X_move_complete	If (abs(X_position-position)<0.05) Then (true) Else (false)	

Fig. 11. Axis class signal definition

5. Data communication process

5.1 Connection between PC and PLC

As shown in Fig. 12, when PC host computer reads and writes PLC through S7server. PC will read all the data of the current communication block when reading PLC; when instructions are written, they are written in bytes, and some instructions in the data block are Bool, using hexadecimal encoding, and only occupy 1/16 bits of a byte. Improper instruction structure of the data block may cause instruction overwrite or multiple write situations when instructions are written.

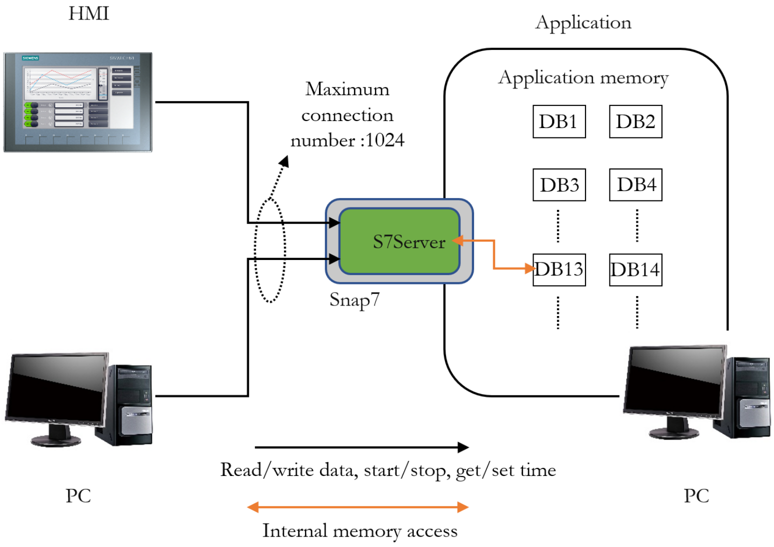


Fig. 12. Read-write PLC

In the whole process, the command execution confirmation mechanism is adopted, as shown in Tab. 2, which is the communication instruction defined within the PLC [19].

Tab. 2 Communication instruction

	Name	Data Type	Function Description
PC host computer instruction	Initial Start	bool	Each shaft returns to the specified position and the cylinder resets
	Row Value	int	Checkerboard line number
	Column Value	int	Checkerboard column number
	Select Pieces	int	1: White piece; 2: Black piece;
	Pieces Confirm	bool	Confirm drop of the Pieces
	Initial Stop	bool	Shaft and cylinder return to original stop
Feedback instruction	Initial Running	bool	The device is being initialized.
	Initialization Complete	bool	indicates that the reset is complete
	Pieces Moving	bool	The piece is moving
	Completion Flag Bit	bool	The piece has been moved

After receiving instructions from the PC host computer, PLC not only performs the corresponding operations, drives the device to complete the corresponding actions, but also returns a feedback information to the PC host computer, and transmits the motor motion to the PC, indicating that the instructions have been correctly received and processed, so that it is ready to issue new instructions. The communication addresses of the PC host computer instructions and feedback instructions are optimized in the structure of the data block, as shown in Tab. 3.

Tab. 3 Instruction Communication Address

Instruction Name	Address
Pieces Moving	DB13.DBX30.0
Initial Running	DB13.DBX30.1
Pieces Move Complete	DB13.DBX30.2
Initialization Complete	DB13.DBX30.3
Column Value	DB13.DBX32.0
Row Value	DB13.DBX34.0
Select Pieces	DB13.DBX36.0
Initial Start	DB13.DBX38.0
Initial Stop	DB13.DBX38.1
Pieces Confirm	DB13.DBX38.2

5.2 Connection between PLC and servo system

The servo system of the electromechanical equipment adopts position control mode, as shown in Fig. 13. PLC sends pulses to the servo driver, uses pulse frequency to control speed, and uses pulse number to control position.

The number of pulses per revolution of the servo motor state in the Electromechanical equipment is 3200 and the load displacement per revolution is

10mm. Assuming that the motion needs to be controlled to 12 rows and 15 columns, the true motion distance between X axis and Y axis can be calculated according to formula (1) - Formula (4) as X: -232.656mm, Y: -143.11mm, and positive and negative indicate the direction of motion. Then PLC sends corresponding pulse instructions and direction instructions to the servo drives of X axis and Y axis respectively. Similarly, the servo drive will also send the corresponding number of pulses to the PLC to feedback the position and speed of the servo motor [20]. The process of reading and writing data blocks and sending pulses is repeated throughout the whole game until the end of the game.

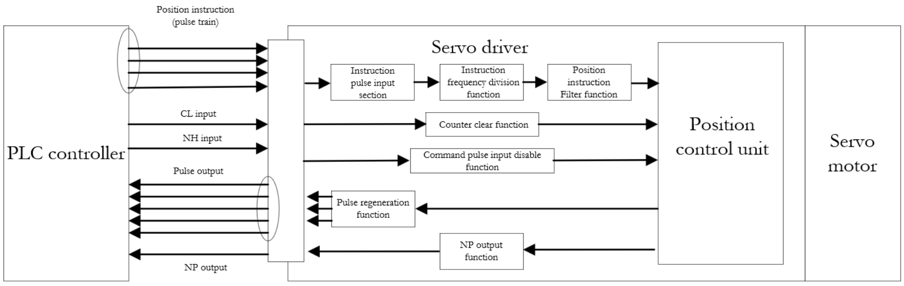


Fig. 13. PLC and Servo

5.3 Connection between physical system and twin system

With a unified and non-proprietary software interface, OPC has a powerful data exchange function in automation engineering and is widely used in server and client architecture and process control. KEPServerEX (From then on it is called KEP software) is a communication service software that can realize various data request services on the client side, support online scheduling, easily connect to the server side, and realize OPC server scheduling and communication. In this paper, the OPC Data Access interface is built by KEP Software, and the real-time data communication between the physical system client and the twin system client is realized in this way.

5.3.1 OPC DA configuration

As shown in Fig. 14, the Gogo electromechanical equipment is directly connected to the OPC DA server through PLC, and its physical system will generate a large number of real-time position, speed, signal and other data through the feedback and detection of sensors and control systems during movement. After the OPC DA server collects a large number of such data from the physical system of the electromechanical equipment, the OPC DA server will collect a large number of such data. The collected data is converted into a standard format and transmitted to the twin system. After receiving the real-time data collected by the OPC DA server, the twin system uses the data to update its state and model in real time, so that it accurately reflects the current state of the physical device.

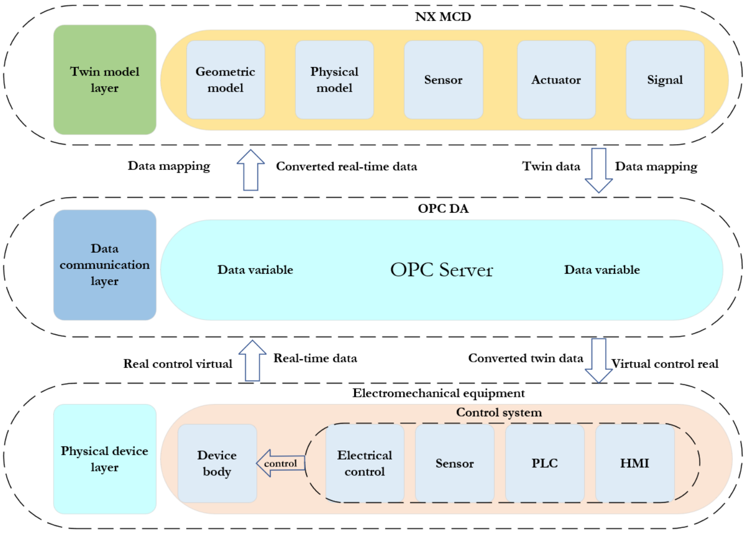


Fig. 14. OPC server configuration

Depending on the OPC data access interface used, set the relevant connection parameters and enable Date Collection; the driver is Siemens TCP/IP Ethernet; the channel is assigned as Kep_signal. The PLC model and ID are S7-1200 and 192.168.0.1.

The variables configured in the OPC DA server are shown in Fig. 15, including the variable name, variable address, data type, and scan rate. To facilitate the accurate mapping of large amounts of real-time data generated by physical and virtual systems, variable names in the OPC DA server are consistent with the signal names previously configured in the MCD. The variable address in the OPC DA server is consistent with the address of the PLC control variable and the status monitoring variable. The data type is adjusted according to the specific variable content, and the scan rate is set to 100ms.

Tag Name	Address	Data Type	Scan Rate	Scaling
X_start	M20.0	Boolean	100	None
X_move_complete_signal	M20.1	Boolean	100	None
X_movejog_forward	M20.2	Boolean	100	None
X_movejog_backward	M20.3	Boolean	100	None
Y_start	M30.0	Boolean	100	None
Y_move_complete_signal	M30.1	Boolean	100	None
Y_movejog_forward	M30.2	Boolean	100	None
Y_movejog_backward	M30.3	Boolean	100	None
White_position	M62.0	Boolean	100	None
Black_position	M62.1	Boolean	100	None
Sensor_position	M62.2	Boolean	100	None
White_position_signal	M62.3	Boolean	100	None
Black_position_signal	M62.4	Boolean	100	None
Sensor_position_signal	M62.5	Boolean	100	None
Telescopic_cylinder_upper_limit	M101.3	Boolean	100	None
Telescopic_cylinder_lower_limit	M101.4	Boolean	100	None
Sucker_cylinder_running	M101.5	Boolean	100	None
Telescopic_cylinder	M200.6	Boolean	100	None
Sucker_cylinder	M200.7	Boolean	100	None
X_position	MD22	Float	100	None
X_speed	MD26	Float	100	None
Y_position	MD34	Float	100	None
Y_speed	MD38	Float	100	None
X_movejog_speed	MD42	Float	100	None
Telescopic_cylinder_speed	MD58	Float	100	None
Turntable_speed	MD64	DWord	100	None

Fig. 15. Partial variable tag

5.3.2 Data mapping

In the framework of digital twin, the motion behavior of the device in the virtual space is driven by real-time data to ensure that the digital twin model can accurately reflect the state of the execution unit. In order to achieve this, firstly, the acquisition of real-time motion data is the key. These data are derived from the real execution unit, covering the real-time position, speed, acceleration and other information of the device, and are used to drive the corresponding behavior of the moving mechanism in the virtual environment. This real-time flow of data ensures the accuracy of the digital twin, enabling it to respond in real time to changes in actual operations.

Secondly, by storing and analyzing the collected data, a two-way interactive data transmission channel is established to provide necessary information for the device model in the virtual space. This channel not only transfers data from the real device to the virtual model, but also feeds the virtual model's control instructions back to the physical device for real-time monitoring and adjustment.

Finally, by connecting virtual units to real devices through industrial Ethernet, physical properties can be mapped effectively, thus achieving the ultimate goal of digital twins. In this connection, the motion accuracy and response speed of the motor are affected by the mapping mechanism between the game strategy and the real-time feedback data. Data mapping involves several key data types, including design data, control data and operation process data.

(1) Design data: including the physical entity and virtual unit data of mechanical and electrical equipment, such as the geometry, position, size and other information of each sub-model in the virtual unit, the surface situation of the chess pieces on the board in the physical entity, the shape of the chess actuator, rod length and other data.

(2) Control data: includes specific instructions to execute the game strategy, such as motor speed, motor direction, piece type, point position, etc. This data is mapped to the physical control system through real-time transmission and directly drives hardware execution. This process requires not only precise instruction delivery, but also latency and data loss to allow for smoother operation.

(3) Operation process data: including the current position, speed, acceleration and other physical state data of the motor, as well as real-time position induction data on the chessboard. This data is mapped back to the twin system to adjust game strategies and correct device actions in real time, thus ensuring closed-loop control of the entire system.

As shown in Fig. 16, the variable tags established in the respective servers, devices, and channels are added to the MCD client in the MCD External Signal configuration menu. The variable name, data type, and I/O type of the added variable tag are displayed visually in the tag bar. The update time, that is, the data scanning period of the two-node cluster system, is 0.1s, the same as the scanning rate set in the OPC server parameter.

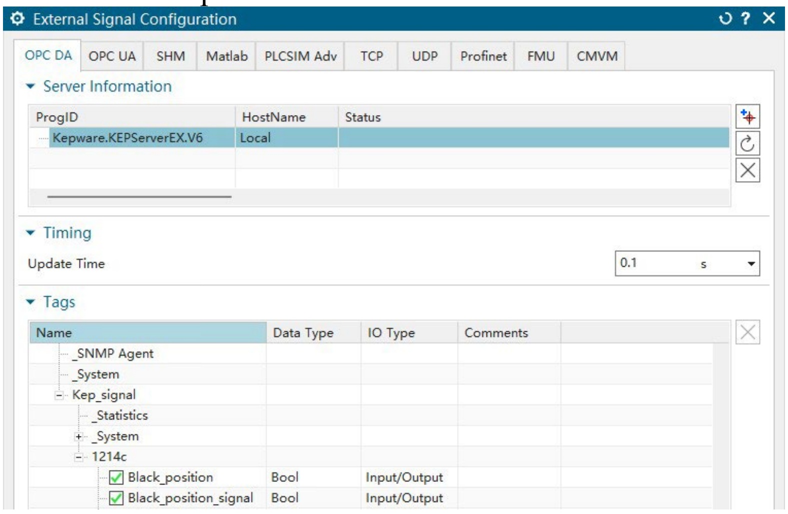


Fig. 16. External signal configuration

After configuring all internal signals, external signals and OPC servers, select the configured OPC DA server and corresponding external signals from the MCD Signal Mapping menu, as shown in Fig. 17. Automatic mapping cannot exclude some signal mapping errors. The names and data directions of the mapped internal and external signals are shown below. All real-time data mapping channels between the physical system and the virtual system have been set up.

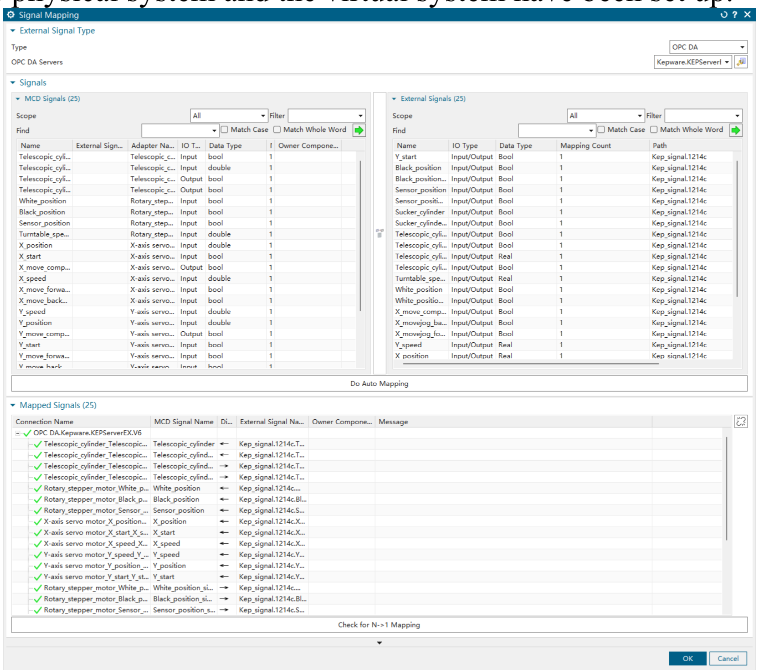


Fig. 17. Signal mapping

Taking the real-time data of X-axis servo motor positioning position as an example, it represents the absolute positioning position of the servo motor in the physical device and the motion control position of the virtual servo motor in the virtual model. The data interaction between the two is realized through the third variable established by the OPC server, that is, the "X-axis position" whose address is MD22, as shown in Fig. 18. The PLC in the physical unit is connected to the OPC server variable by register address addressing, and the motion control position variable in the virtual model in MCD is connected by name addressing. When the variables in the physical device change, the variable with the address MD22 in the OPC server also changes, and the variable corresponding to the "X-axis position" in the virtual model also changes; When the X-axis position variable in the virtual model changes, the variable corresponding to the name "X-axis position" in the OPC server also changes, and the variable with the address MD22 in the corresponding physical device also changes.

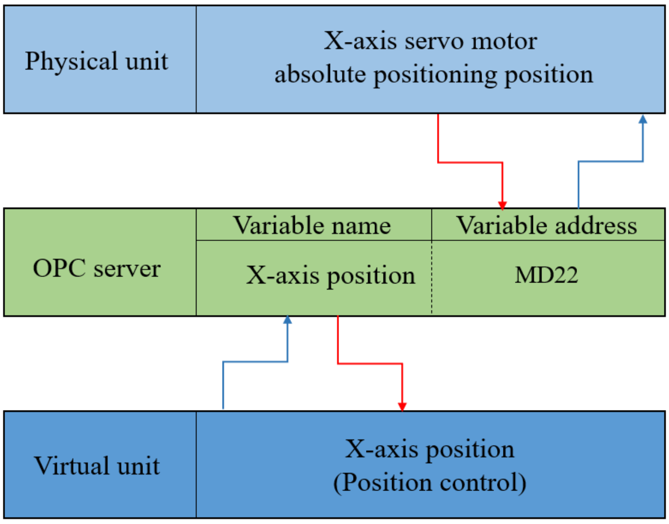


Fig. 18. X-axis position data map direction

This bidirectional data mapping ensures virtual and real synchronization between physical devices of twin devices. In the control layer, the control signal is transmitted to the physical device in time through data mapping to ensure the efficient execution of device actions and game strategies. At the same time, the sensor feedback data is analyzed in real time and mapped back to the twin model to help monitor and adjust the operating state of the device and ensure the operating accuracy. Through this mapping mechanism, the interaction between the physical device and the digital twin becomes more accurate, can respond quickly to policy adjustments, and improves the efficiency and reliability of the entire system through the feedback mechanism, which ultimately provides an important guarantee for the action execution of the electromechanical device.

6. Application test and conclusion

6.1 Testing

Use KEP Software's connection test tool to test whether the connected OPC server can read and write data correctly [21]. When all marked variable signals show good, it means that the physical system and the virtual system are successfully connected through the OPC DA server and can conduct real-time data interaction.

The test process is shown in Fig. 19. Both the operator and the algorithm AI can guide and control the movement of the electromechanical system, and the virtual twin system also synchronizes the movement, achieving "virtual-real synchronization" between the two systems. After the virtual checkerboard is placed on the PC host, the platform can realize fast data processing and communication, and the real checkerboard and double checkerboard can be placed in the specified position according to the instructions of the PC host. The operator can also control the movement of the real device by pausing or stopping the virtual model movement. When the gas path supply of the device is artificially removed, the gas path of the mechanical and electrical device is simulated to be faulty, and the corresponding virtual body also stops running.

Through the visual interface, you can find out where the fault occurs, instead of looking for it in the real device. This means that consistent and synchronized results can be obtained both in the actual operation of the electromechanical system and in the virtual environment of the dual system. The accurate mapping of real-time data verifies the feasibility and effectiveness of the application of intelligent algorithm and digital twin technology in electromechanical equipment, and provides a safer and more intuitive expression for the operation monitoring and fault diagnosis of electromechanical equipment.

Fig. 19. Test procedure

5.1 Conclusion

Through the construction of electromechanical experiment platform and its twin system, the concrete application methods of intelligent algorithm and digital twin technology in electromechanical equipment are successfully practiced, which provides a new idea for the research and practice in related fields. For example, in the machine tool processing or other automation equipment mentioned in the previous article, when the real equipment fails, the digital twin will reflect the status of the equipment in real time, and the equipment will stop working. Operators do not need to go to the actual site to find the problem one by one, because this may bring some subsequent dangers, especially in some more dangerous working environments such as high temperature steel mills and chemical workshops. By monitoring the stagnation of the twin, the operator can more easily locate the fault. At the same time, the corresponding parts of the digital twin are stopped, the fault points are displayed visually, the fault data of the equipment is mapped to the twin system in real time, and the monitoring data of the state of the twin model is helpful to guide the maintenance process of the equipment. Reduce troubleshooting time and improve maintenance efficiency. The main conclusions are as follows.

(1) In this way, the electromechanical equipment can quickly realize equipment control according to the decision situation under the guidance of the algorithm.

(2) Based on the control requirements of electromechanical equipment, different algorithms can be tested on the electromechanical equipment to evaluate their effects and feasibility, obtain control algorithms that meet the requirements, and then optimize control decisions.

(3) The application of digital twin technology enables operators to understand the operating status and movement process of equipment in a safe and intuitive way in real time, and plays an example role in the operation monitoring and management of real electromechanical equipment.

The follow-up work of this study is as follows: Firstly, the applicability of different intelligent algorithms can be deeply studied to further improve the decision-making ability and response speed of the device; Secondly, the application scenarios of digital twin technology can be expanded to explore its implementation effect in more complex electromechanical systems. Finally, interdisciplinary research can also be carried out with other fields to promote the further development of intelligent and digital mechanical and electrical equipment.

Acknowledgments

This work was supported by the Key Science and Technology Project of Yunnan Province (202402AE090027); Education Foundation of Yunnan Province (2024Y610).

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