Theory and Practice of Science and Technology
2025, VOL. 6, NO. 9, 7-12
DOI: 10.47297/taposatWSP2633-456901.20250609

Research on Intelligent Interactive Control of Agricultural Tractors from the Perspective of Man-Machine Collaboration

Tingzheng Bai[1], Lisha Ma[1], Daiyuan Wang[2]

[1]Beijing Union University of the Arts, Beijing, 100101, China

[2]Beijing Pandora Audio-Visual Technology,Service Co., Ltd., Beijing, 100083, China

ABSTRACT
To address industry pain points of low interaction efficiency and high operational complexity in agricultural tractor control interfaces. Taking walking tractors as an example, this study constructs an intelligent control architecture that includes working devices (plows) and functional accessories (Electric Sunshade Canopy) by applying the reverse engineering method, starting from system requirements and based on the Pandora Box server. The system utilizes Widget Designer for customized graphical interfaces and implements Modbus Protocol to control remote I/O modules managing power output shafts and shade motor logic. Through virtual simulation models, this research demonstrates innovative pathways for transferring media control technologies to agricultural machinery, providing a conceptual prototype for smart farming equipment development with significant reference value for engineering applications.

KEYWORDS
Hand-guided tractor; Pandora's Box Server; Reverse engineering; Virtual simulation model

1 Introduction

While China has emerged as a global leader in agricultural machinery manufacturing with world-class production volumes, its overall manufacturing capabilities remain relatively modest, placing it in the mid-to-lower tier of the international industry. However, an increasing number of enterprises and institutions are now prioritizing innovation-driven strategies, significantly boosting R&D investments to advance agricultural equipment technology. The book *"Digitalization and Intelligent Design of Agricultural Machinery"* systematically explores core technologies and architectural frameworks for applying digitalization and intelligence in engineering design. Through detailed case studies of seeders and combine harvesters [1-3], it elaborates on specific design technologies and solutions, thereby vividly demonstrating the critical importance of innovation in agricultural machinery development.

Currently, China has made significant strides in agricultural digitalization. To address grain sowing challenges, the research team led by Yu Feiyang, Li Hongshuang, Lü Shuaiqi, and Zhang Hengguo developed a cell-wheel grain seeder. This innovative device features a working mechanism, structural design, and electronic control system, with prototype testing demonstrating precise quantitative seeding capabilities to enhance efficiency [4]. Meanwhile, Zhao Zhiwei, Sun Wei, and Wu Jianmin's team designed a hand-guided corn stalk harvester for mechanized harvesting of dryland corn stalks. Their comprehensive analysis of the machine's structure, operational principles, and key components showed field trials met agronomic requirements, indicating promising application prospects [5]. In hilly terrain potato harvesting, Pang Jinchao, Jiang Jinlin, and Wang Gongpu's team created a compact hand-guided potato harvester. Field tests confirmed its structural integrity and suitability for small-scale operations [6]. These three teams have collectively driven agricultural mechanization innovation by developing specialized equipment for diverse crop harvesting and sowing challenges, effectively addressing farmers' practical needs in modern farming practices.

As the flagship hardware in Christie's Pandora Box series, the Christie Pandora Box Server integrates advanced rendering technology with intuitive media display control functions to create a professional solution with robust media processing and display capabilities. Currently, this system has been successfully implemented in two major themed projects at Beijing Fantasy Wave Science Fiction Exploration Museum: the immersive games "Space Rescue" and "Space Dinosaur Base". Through the Pandora Box Server's custom control design tools, full-process interactive control has been achieved. Additionally, in the collaboration between Christie and Australian production company Dead Puppet Society for their new drama "The Wider Earth", the Pandora Box Player, Manager, and custom control design tools formed the core technical support. This cross-domain application fully demonstrates the Pandora Box System's comprehensive advantages in device control and scene management, further highlighting its exceptional control capabilities.

Current manual tractors suffer from low intelligence levels, resulting in subpar user experiences and harsh operating conditions that increase safety risks and driver fatigue. By developing an intelligent control system based on the Pandora's Box Server, we can manage both the tractor's working mechanism (plow) and functional attachments (sunshade). This innovation not only reduces driver fatigue and enhances safety but also pioneers a new approach to tractor intelligence. Starting with controlling two distinct types of agricultural machinery—working mechanisms (plows) and functional attachments (sunshades)—this system expands the application scope of Pandora's Box Servers, offering a fresh solution for smart agriculture.

2 System requirements analysis

Scenario-oriented system requirements analysis

By employing reverse engineering methodology, we initiate system requirements analysis for agricultural tractor control systems through Pandora's Box Server implementation. This scenario-driven approach begins with top-level design requirements and task scenario design, while enhancing requirement alignment through stakeholder communication to uncover user needs [6-7]. The scenario model requires systematic organization and design from multiple perspectives including stakeholders, usage scenarios, operational methods, transmission principles, and bidirectional feedback mechanisms. As illustrated in Figure 1.

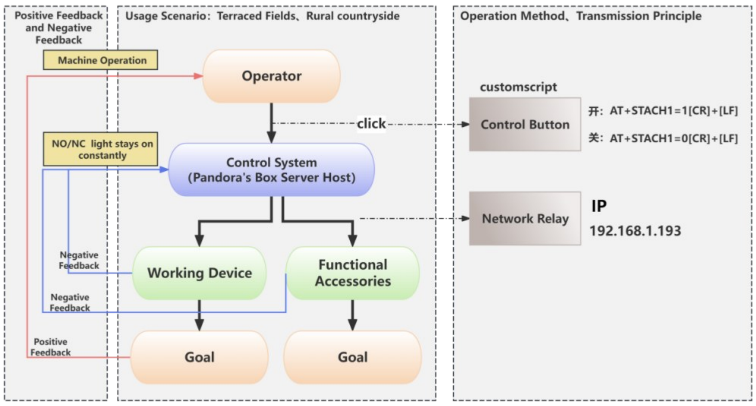

Figure 1 Control system operation scenario model

(1) Stakeholders: In this study, farmers as agricultural production entities serve dual roles as both the most direct stakeholders and end-users, bearing vital interests in both safety and economic benefits. First, farmers expect tractors to be easier to operate, more efficient, and less labor-intensive while reducing driving fatigue. They also require reliable performance in complex operational scenarios such as small-scale farmland management in mountainous and hilly terrains to ensure their safety. Second, digital integration can enhance agricultural productivity by reducing time and labor costs.

(2) Application Scenarios: Hand-guided tractors are typically deployed in small-scale farmlands, particularly in mountainous and hilly areas with complex terrain. These machines can be equipped with plows to till the soil. However, two critical issues exist: First, due to the irregular shape and limited size of plots, frequent turning and route adjustments by hand-guided tractors significantly reduce operational efficiency. Moreover, on steep slopes, the unstable center of gravity may cause rollovers, posing safety risks to operators. This study investigates safety measures for field operations through the Pandora's Box service system that controls the plow attachments, effectively reducing operational hazards. Second, the lack of enclosed compartments exposes crops to weather conditions during transportation. For instance, rainwater can damage agricultural products, causing financial losses for farmers. To address this, the research implements control of functional accessories (Electric Sunshade Canopy), ensuring safe crop transportation during rainy weather while enhancing farmers' comfort during agricultural activities.

(3) Usage Guidelines: When operating a hand-guided tractor, farmers should first shift the gear selector to neutral and fully depress the clutch pedal to ensure complete disengagement before use. For tractors equipped with gear lock mechanisms, the clutch must be released before shifting. Starting the tractor with the gear not in neutral or the clutch not fully depressed may cause sudden forward movement or backward sliding, potentially endangering operators and bystanders while damaging the transmission system. To address these operational risks, our intelligent system has replaced traditional manual controls with smart automation.

(4) System Transmission Principle: The operator triggers the control button ("custom script") by clicking to activate its function. This button essentially contains program code, with the activation command being "AT+STACH1=1[CR]+[LF]" and the shutdown command "AT+STACH1=0[CR]+[LF]" ("AT" indicates greeting, "STACH" denotes channel, "1" controls activation/deactivation, "[CR]" represents carriage return, and "[LF]" signifies line break). The control button then transmits commands to the Pandora Media Server. Through Modbus RTU or TCP protocols via RS485 bus (or RJ45 Ethernet interface), the server sends control signals to remote I/O modules (digital output type) for operating device and functional accessory control. These remote I/O modules achieve remote control/data transmission through network connections (IP addresses vary but follow standardized formats; this study uses IP address 192.168.1.193) to support the entire control system operation. The left section displays forward and reverse feedback: Reverse feedback: If system connection is normal, the "NO" and "NC" indicators on the remote I/O module remain illuminated; Forward feedback: Mechanical components maintain normal operation.

3 Analysis of software and hardware system conditions

3.1 Software system conditions

The foundation of software system conditions lies in the Pandora Magic Box server host and Pandora Software Encryption Dog. When these two prerequisites are met, the Widget Designer is required to customize control design tools. This software primarily focuses on creating and designing various widgets within graphical user interfaces (GUI). Its greatest advantage lies in its intuitive interface, allowing users to conveniently arrange components, set styles, and define interactive functions to build personalized interfaces tailored to specific needs. This enables operators to perform tasks more intuitively while reducing operational complexity.

3.2 Hardware system conditions

In addition to the aforementioned requirements, the system must include a display unit, remote I/O module (DO), neutral and ground wires, network cable, Somfy electric sunshade umbrella, Dongfanghong power output shaft, Pengxiang gear-shifting mechanism, and power supply. Through systematic research, the rationale for hardware selection has been established, including quantity specifications, available conditions (power and voltage parameters), and comparative analysis of pros and cons as detailed in the table below.

Name of hardware device	quantity	Eligibility	Analysis of advantages and disadvantages
Remote I/O Module (DO)	1	Support Modbus RTU/TCP protocol RS485 or RJ45 interface Output voltage: 5V/12V/24V DC voltage	Remote control through standard industrial protocol, support multi-device networking, strong anti-interference capability (RS485 differential signal)
Electric sunshade	1	Voltage: 24V and below Power: below 50W Meet the control requirements of remote I/O modules	Good product quality and performance Good compatibility with control equipment: easy to integrate, stable and reliable
Power output shaft (John Deere 904)	1	Voltage: 12V Power: 81 horsepower Meet the control requirements of remote I/O modules	Good compatibility with tractors Reliable and durable Easy to operate control
Pengxiang brand shifting mechanism	1	Voltage: 24V Meet the control requirements of remote I/O modules	Good signal compatibility The electrical parameters are well matched
Monitor	1	Window system	Compatible with communication protocols
Neutral & Live Wires	N	Meet the control requirements of remote I/O modules	Facilitates precise control, troubleshooting and maintenance

4 Simulation of overall architecture scheme and system design

4.1 Overall design idea

Principle of Operation for Hand-Operated Tractor Plow: The engine serves as the power source, with its crankshaft generating rotational force. When the clutch pedal is released, power is transmitted to the gearbox via the clutch. The gearbox adjusts the gear ratio through its shifting mechanism, delivering appropriate power to the drive shaft. This shaft then transfers power to the working device (plow) to operate it. Pressing the clutch pedal cuts off power transmission from the crankshaft to the gearbox, facilitating operations like shifting gears. As shown in section 1 of Figure 4.

Pandora Control Principle: The system operates through the Pandora Magic Box server, which sends control signals based on predefined programs in the Widget Designer customization tool or user commands. These signals are transmitted via the Modbus TCP protocol to a remote DO-type I/O module, triggering internal relay contacts (with capacity ⩾ power output shaft load current) to control circuit connectivity. For high-power equipment like power output shafts, additional intermediate relays or contactors with power amplification are required. After contact activation, the connected device circuits can be switched between open and closed states, enabling remote control through the DO module as shown in the lower section of Figure 4.

4.2 Analysis of functional modules and system design of hand-guided tractor

First, the scheme for the working device (plow) is derived by combining the control principles of both:

(1) Control of the working device (plow) rotation and stop: In hand-guided tractors, the power output shaft serves as

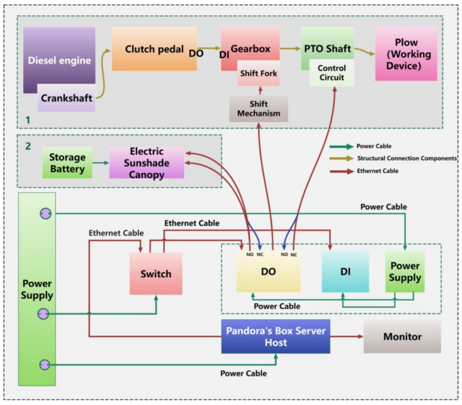

Figure 2 Overall simulation architecture based on Pandora Box Server

the critical component transmitting power from the gearbox to the plow. The remote I/O module (DO) communicates with the ECU via Modbus RTU protocol. When the server sends the AT+STACH1=1 command, the module outputs a 12V DC signal to the ECU's start pin to activate the shaft rotation. Conversely, sending AT+STACH1=0 commands disconnects the circuit for shutdown control. Signals are transmitted through shielded twisted pair cables (RS485 bus) to ensure anti-interference capability. Combined with programming instructions from Pandora's Widget Designer software, this system achieves precise operation. (2) Gearshift adjustment control for the working device (plow): Advanced hand-guided tractors feature a mechanical hybrid shifting system integrating an electronic control unit (ECU) with mechanical shift components. The remote I/O module (DO) can be connected directly to the ECU to enable control. Implementation method of system design for working device (plow): The system primarily consists of two components: first, controlling the rotation and stopping of the working device (plow) via the power output shaft; second, gear position adjustment control. The system design encompasses both hardware and software aspects. On the software side, the initial step involves verifying relay connectivity: In the computer, configure the remote I/O module's IP address to 192.168.1.193 through parameter configuration software to enable remote control or data transmission. Right-click the computer's —— Start button, select "Terminal Manager", and ping the IP address 192.168.1.193. If numerical responses are displayed, the relay connection is confirmed. Next, access the Widget Designer software and connect it to the server's ID for code programming. For hardware selection, this study employs John Deere 904 power output shaft. As this shaft operates on 12V voltage, a DO-type remote I/O module supporting 12V DC power is chosen. The RS485 bus connects to the ECU of the power output shaft. After receiving Modbus commands from the server, the module outputs 12V control signals to the ECU's start/stop pins, achieving precise control over the power output shaft's operation. Secondly, the control scheme is derived from the operation principle of functional accessories (Electric Sunshade Canopy); The electric sunshade umbrella features a motor-driven system where forward and reverse rotation of the motor control its extension and retraction. This motor operation is managed through an electronic control circuit, which can be implemented by connecting a remote I/O module (DO) via network cables. Based on this configuration, we developed a comprehensive simulation architecture diagram utilizing the Pandora's Box Server. As shown in Figure 4,

5 Research on application of virtual simulation model simulation scenario analysis

5.1 Virtual simulation model

Figure 3 presents the virtual simulation model of the intelligent retrofitting solution for the Pandoora Magic Box server-

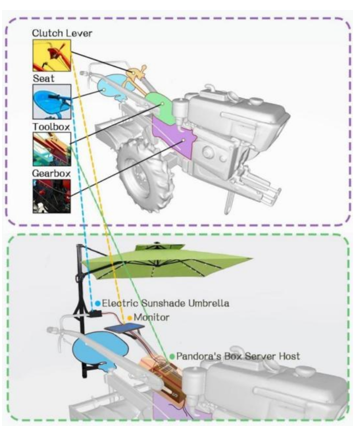

Figure 3 Virtual simulation model based on Pandora box server

equipped hand-guided tractor, with detailed component layouts and functionalities as follows: 1. Operating Area: The clutch lever retains its position in the traditional hand-guided tractor's control console, preserving basic mechanical functions. The transmission, as the core component of the original mechanical system, achieves gear shift coordination with the Pandoora system through an Electronic Control Unit (ECU). A display integrated on the front pillar in front of the seat shows the control interface and real-time feedback. 2. Intelligent Retrofit Module: The Pandoora Magic Box server replaces the original tool box, serving as the central control hub. Remote I/O modules (DO) establish communication with power output shafts, shift mechanisms, and electric sunshades via concealed internal wiring, enabling 24V/12V DC circuit control and supporting IP address 192.168.1.193 for remote signal transmission. 3. Functional Accessories: The electric sunshade, mounted above the driver's seat using the rear seat support as a pivot, is powered by a Somfy-brand 24V low-power motor and achieves one-touch opening/closing control through the Pandoora system.

The system's interactive logic features an integrated display interface with customizable control buttons (including operation start/stop, sunshade switch, and gear adjustment functions). Through the Widget Designer tool, graphical interaction is achieved. Operator commands are processed by the Pandora server and executed via a remote I/O module (combining DO/DI modules) for control and feedback: The server sends DO commands to control devices while reading DI inputs (e. g., NO/NC contact status) into Modbus registers, enabling real-time interface updates. Feedback signals are transmitted back through the Modbus RTU protocol via RS485 bus. This design achieves spatial reconfiguration (replacing traditional toolboxes with servers) and functional integration (placing displays on the front pillar in front of the seat), building upon conventional mechanical structures to create an intelligent agricultural equipment system that combines operational control and environmental regulation [8-9].

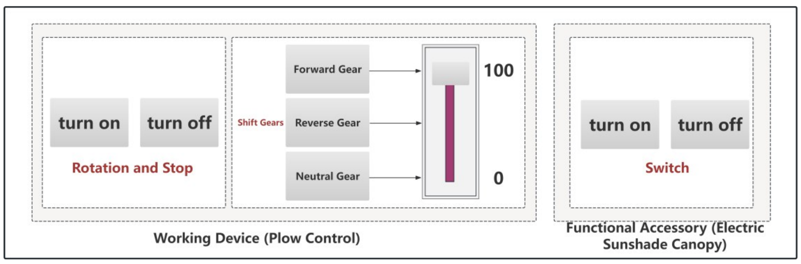

Figure 4 Button interface design based on Pandora server

The structured control interface based on the custom control design tool, as shown in Figure 4, is divided into three functional zones: (1) The left "Working Mechanism (Plow Control)" section features an "On" and "Off" button to control the plow's rotation and stop, enabling operation start/stop functions; (2) The central "Gear Shift" zone contains "Forward", "Reverse", and "Neutral" options. Linked through arrow indicators with a scale bar (0-100) on the right panel, this section provides interactive tractor gear adjustment control; (3) The right "Functional Accessories (Electric Shade Canopy)" section includes an "On" and "Off" button specifically for operating the electric shade canopy. This zoned design clearly presents the operational logic of plow controls, tractor gear shifting, and canopy switching, ensuring intuitive and clear user interaction.

5.2 Virtual scenario and application effectiveness analysis

To demonstrate the practical value of intelligent control systems based on the Pandora Magic Box server in agricultural production, this study analyzes the role of intelligent control systems in two typical scenarios through virtual simulation. Scenario 1: Precision farming in hilly terrain. This complex agricultural landscape, widely distributed across southern China's hilly regions, presents challenging soil conditions and limited arable space. Traditional manual tractors face operational complexities and rollover risks. The system achieves refined control via the Pandora Magic Box server, optimizing operations through: Users can preset gear positions for the transmission mechanism via the interface, which automatically adjusts the tractor's start-stop and gear settings to minimize operational errors and enhance efficiency. Scenario 2: Cargo protection during rainy transportation. Agricultural product transport in rainy seasons imposes additional demands on manual tractors. Traditional open-loading methods often cause cargo dampness, increasing farmers' economic losses. The system integrates an electric sunshade mechanism for flexible adjustment: Users can instantly deploy or retract the canopy through the interface, adapting to weather conditions for optimal protection.

While the analysis demonstrates high feasibility in system design, practical implementation may encounter three key challenges: First, signal transmission latency – remote I/O modules may experience interference in complex environments, compromising system responsiveness. Second, terrain adaptability limitations – current control logic primarily targets common hilly terrain, requiring further optimization for diverse environments like mountainous and sandy areas. To address these challenges, future improvements could include: adopting high-performance remote I/O modules to enhance signal stability and real-time performance; implementing AI-powered terrain recognition and path planning algorithms to boost system adaptability in complex terrains; and continuously refining functional modules through user feedback from surveys and field trials to better meet practical needs.

6 Conclusions

This study investigates a conceptual design framework for a hand-guided tractor based on the Pandora's Box Server, exploring the cross-domain application potential of media control technology in agricultural machinery. By integrating digital media with agricultural equipment, the research achieved breakthroughs in designing a collaborative control architecture between power output shafts and electric sunshades. A remote I/O module communication solution utilizing the Pandora's Box Server and Modbus Protocol was proposed, with real-time command transmission performance and user interface rationality verified through virtual simulation models. Although no physical simulations or experimental data were collected, the theoretical advantages in reducing operational complexity and enhancing safety were demonstrated through scenario-based analysis. The research provides innovative technical solutions for intelligent agricultural machinery, offering valuable methodologies for future digital transformation of farm equipment. Future work will focus on hardware reliability testing and control algorithm optimization to validate the practicality of the proposed system.

About the Author

1. Tingzheng Bai, Current Master's student in Academy of Art at Beijing Union University, research interests: digital media design, interaction design.

2. Lisha Ma, Lecturer (Ph. D.) in Academy of Art at Beijing Union University, research interests: industrial design, intangible cultural heritage protection.

3. Daiyuan Wang, Legal Representative at Beijing Pandora Audiovisual Technology Service Co., Ltd, Technical Field: software and hardware multimedia technology.

References

[1] He Yuanling, Xing Zebing, Hou Huaming, et al. Development Status and Prospects of Intelligent Agricultural Machinery Equipment (English) [J]. China Agricultural Science and Technology Herald, 2019,21(06):8-19.

[2] Guo Yuanyi. Current Status and Development Trends of Agricultural Mechanization Technology [J]. Contemporary Agricultural Machinery, 2024(07):28+30.

[3] Liu Dong. Application of Digitalization and Intelligence in Agricultural Machinery Engineering Design [J]. China Agricultural Resources and Regional Planning, 2023,44(07):48+65.

[4] Yu Feiyang, Li Hongshuang, Lü Shuaiqi, et al. Design of a Hollow-Drill Grain Sowing Machine [J]. Mechanical Design, 2024,41(S1):103-108.

[5] Zhao Zhiwei, Sun Wei, Wu Jianmin, et al. Design of a Hand-guided Corn Straw Harvester [J]. Agricultural Machinery Research, 2015, 37(11): 100-103.

[6] Li Junhua, Shen Keyu, Xu Yuan, et al. Research on Age-Friendly Design of In-Vehicle Human-Computer Interaction Interfaces [J]. Packaging Engineering, 2023,44(14):145-151+169.

[7] Zhang Ran, Li Yuan, Wang Hao, et al. Research on Scenario-Oriented Radar System Model Design and Simulation Methodology [J]. Journal of Graphics, 2024,45(02):284-291.

[8] Wu Jianbin, Zhang Jingyuan, and Zhang Linghao. Research on Interaction Design for Situational Awareness-Based In-Vehicle Infotainment Systems [J]. Packaging Engineering, 2018,39(16):189-196.

[9] Wang Xiaoli, Li Chunqing, Gu Ying. The Mechanism of Institutional Logic's Impact on the Initiative of Participants in Digital Interaction Platforms —— A Case Study Based on Intelligent In-Vehicle Systems [J]. Engineering Management Science & Technology Frontiers, 2024,43 (01):89-96.