Enhancing Operational Efficiency and Accuracy: A Usability Study of HMI Design for Apple Sorting Systems

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Abstract: ***In the rapidly evolving landscape of industrial automation, human-machine interface (HMI) design plays a pivotal role in the development of control systems, significantly influencing operational efficiency, user experience, and system maintainability. This paper presents a comprehensive HMI design scheme tailored for an automatic apple sorting system, which integrates advanced automation components such as frequency converters, pneumatic cylinders, programmable logic controller (PLC) units, and sensors. The proposed HMI design encompasses four critical modules: the operation interface, which provides a visually intuitive and user-friendly platform for system control; I/O input and output management, ensuring seamless data exchange between the system and external devices; and PLC system diagnosis, enabling real-time monitoring and troubleshooting of system components. The design philosophy emphasizes clarity, aesthetics, and user-centric functionality, offering a streamlined operation process that aligns with end-user requirements. Furthermore, the modular architecture of the HMI facilitates convenient maintenance and future upgrades, thereby enhancing the system's adaptability and longevity. Experimental validations demonstrate that the proposed HMI design not only improves the overall performance of the automatic apple sorting system but also reduces operational complexity and training time for users. This study contributes to the broader field of industrial automation by providing a scalable and effective HMI solution that can be adapted to similar applications.***

Keywords: Human-machine interface; PLC; Configuration software.

1. INTRODUCTION

A well-designed human-machine interface allows users to grasp the operation method intuitively, reduces learning costs, and creates a comfortable interactive experience. Reasonable menu layout and shortcut-key settings help users complete tasks efficiently; clear instructions and operating procedures minimize misoperation. It can adapt to different user needs, offering advanced functions for professionals and facilitating system maintenance and upgrades. The modular design of the software interface simplifies functional updates and fault repairs, satisfying users' pursuit of aesthetics and ease of use, and enhancing satisfaction and loyalty [1].

The apple automatic sorting system consists of a frequency converter, cylinders, a PLC controller, sensors, and other components. First, apples are conveyed to the sorting machine's belt, then pass through sensor detection and are classified according to size, weight, color, defects, and other features. Next, the PLC controller compares these data with preset classification rules and controls the cylinders to extend or retract, automatically sorting the apples into the corresponding outlets for packaging. On top of the basic sorting function, this design adds a three-color indicator light, emergency stop and reset, speed-regulation system, manual/auto switchover, HMI user management, and encrypted program download. After completing the HMI design, the system is run and debugged. The program is compiled, simulated, and downloaded to the PLC, ensuring the TP1200 is correctly connected to the network IP. Simulation is started and the HMI simulation interface is opened. Gao and Gorinevsky (2018) initially explored probabilistic methods for grid balancing in this context [1]. This work was subsequently expanded by Gao, Tayal, and Gorinevsky (2019), who applied probabilistic planning to minigrids [2]. Further developing these concepts, Gao and Gorinevsky (2020) formulated a probabilistic modeling framework for optimizing resource mix, which was published in IEEE Transactions on Power Systems [3]. Concurrently, advancements in other domains leveraging complex models have emerged. Chen et al. (2023) proposed a generative, text-guided 3D vision-language pretraining method for unified medical image segmentation [4]. In finance, Su et al. (2025) introduced an anomaly detection and early warning system for financial time series using a WaveLST-Trans model [5], while Zhang et al. (2025) developed MamNet, a hybrid model for network traffic forecasting and frequency analysis [6]. The application of deep learning in green finance was demonstrated by Zhang, Li, and Li (2025), who focused on carbon market price forecasting and risk evaluation [7]. Research at the intersection of vision and language continues to be prolific, as seen in the work of Peng et al. (2025) on 3D Vision-Language Gaussian Splatting [8] and Zhang et al. (2025) on dynamic cross-attention for fine-grained image captioning in advertising [9]. The optimization and security of large language models (LLMs) are also critical areas of investigation. Wen et al. (2025) presented a dynamic data filtering framework for fine-tuning LLMs [10], and Weng et al. (2025) proposed SecureGen, a framework to enhance security in text-to-image models [11]. Furthermore, several studies have focused on leveraging LLMs for text assessment, including Zhao et al.'s (2025) LLaM-ScoreNet for automated text quality evaluation [12] and Zhang et al.'s (2025) work on maximizing scoring divergence in automated essay assessment [13]. Huang et al. (2025) enhanced document-level question answering using multi-hop retrieval-augmented generation with LLaMA 3 [14]. The broader innovative applications of large models in computer science were discussed by Zhang et al. (2025) [15]. Beyond AI core technologies, Fang (2025) designed a cloud-native microservice architecture for cross-border logistics [16], and Wang and Bi (2025) introduced a hierarchical adaptive fine-tuning framework for multi-task learning in large-scale models [17]. In the financial sector, Cheng et al. (2025) developed FinStack-Net for financial fraud detection using ensemble learning [18]. Finally, Yang (2024) applied computer-assisted methods to communicative competence training in cross-cultural English teaching, bridging technology and pedagogy [19].

2. HMI–PLC COMMUNICATION CONNECTION

In the human-machine interface design [2-4] of this apple automatic sorting system, Siemens $S7-1500$.

The PLC is suitable for large-scale control systems, offering more I/O interfaces and abundant analog channels to meet all system requirements. After creating the PLC station S7-1500 and the HMI station TP1200 in TIA Portal V17, the communication link between the two stations is established. PN/IE Ethernet communication is adopted; subnet addresses for Interface 1 and Interface 2 are set to 192.168.0.1 and 192.168.1.1 respectively, while the HMI interface subnet address is set to 192.168.0.2. After the communication settings are complete, the serial port is closed; the communication connection is shown in Figure 1.

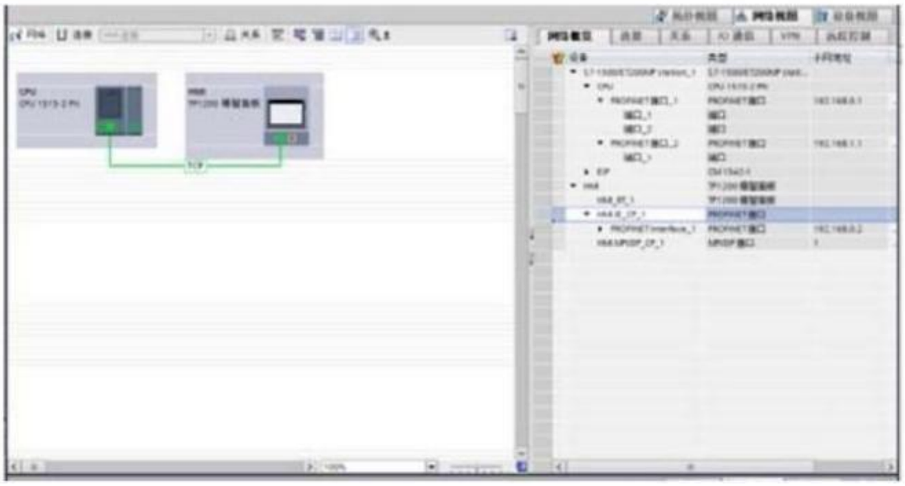

Figure 1: S7-1500 and HMI Station Connection

Figure 2: Download Encryption

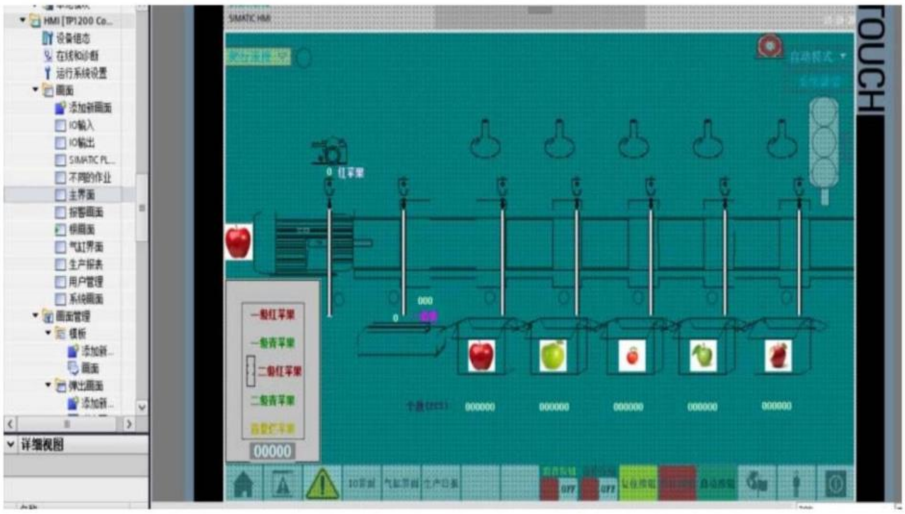

Figure 3: Main Screen

3. DOWNLOAD TO DEVICE

To prevent inadvertent on-site operations from altering the program code, this design introduces a download encryption feature. This prevents non-developers from making arbitrary changes, which could cause system failures, increase the difficulty of repairs for engineers, and reduce production efficiency. Encryption ensures that only authorized developers can modify the program code, improving system stability and maintainability, as shown in Figure 2.

4. HMI SCREEN CREATION

4.1 Screen Layout

In the HMI_TP1200, I0 inputs, I0 outputs, SIMATIC PLC system diagnostics, and various operator interfaces (mainly the main screen, alarm screen, root screen, cylinder interface, production report, user management, and system screen) were created. These settings are shown in Figure 3.

4.2 Interface Design

During screen operation, the motion status of each station, the I0 input/output status, and production completion should be displayed [5]. Therefore, this design adds an I0 interface, a cylinder interface, and a production interface to the sorting screen. The specific designs are as follows: the I0 input interface is shown in Figure 4, the I0 output interface in Figure 5, the cylinder interface in Figure 6, and the production daily report interface in Figure 7.

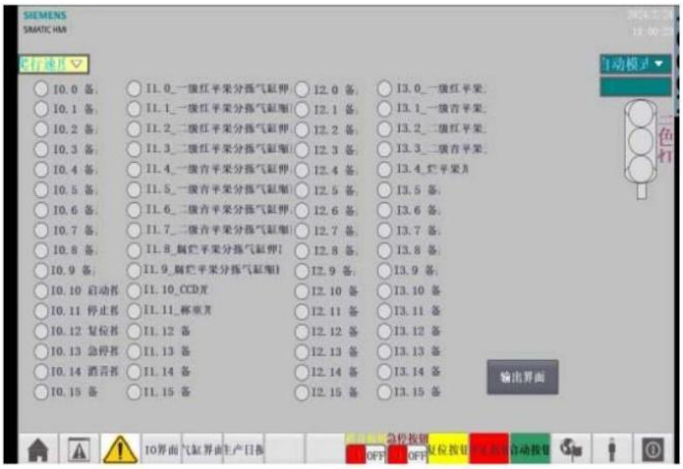

Figure 4: I0 Input Screen

Figure 5: I0 Output Screen

Figure 6: Cylinder Interface

Figure 7: Daily Production Report

4.3 User Management Design

In actual production, operators follow a fixed account-and-password management system; only employees specifically assigned to operate the equipment are granted access, preventing untrained staff from causing accidental operation. This permission management system aims to ensure operational safety and correctness. See Figure 8 for details. 4 Conclusion

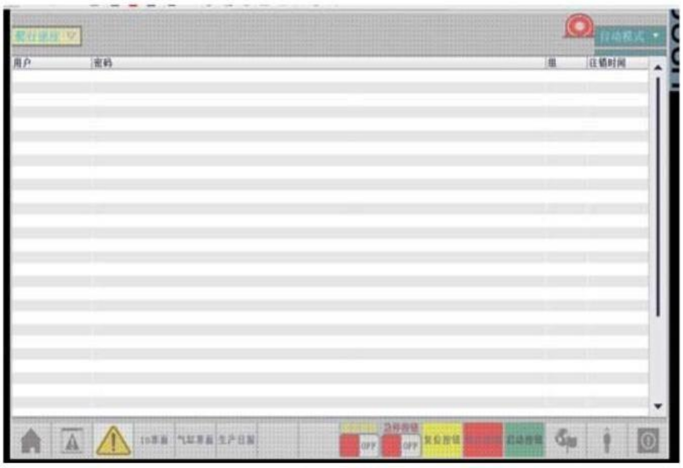

Figure 8: User Management

The HMI design of this apple automatic sorting system includes I0 inputs, I0 outputs, SIMATIC PLC system diagnostics, as well as distinct operation interfaces such as the main screen, alarm screen, root screen, cylinder interface, production report, user management, and system screen. It enhances user experience, improves system usability, and boosts product competitiveness.

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