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INTERACTION AND FEEDBACK LOOPS IN USER INTERFACE FOR DIGITAL ENGINEERING DESIGN

Abstract. *Digital engineering design relies on interaction and feedback loops to support user engagement and improve workflows. Interaction in user interfaces (UI) allows designers to adapt interfaces to user and context requirements, analyze system data, and provide visible feedback. This approach fosters an immersive and responsive design environment, especially in industrial use cases. Feedback loops, visual, auditory, or haptic, provide insights into system behavior, potential errors, and impact of design adjustments. User-system interaction is studied using various methods, including real-time observation, system logs or analytics tracking, and developing user thought process models. These methods focus on context-rich data from real-world settings, allowing for iterative improvements and refinements in user-centered design. Interaction systems are not limited to a single input or output device but often provide multiple ways of interaction or manipulation.*

Standard components in innovative system interactions include sensors for data collection, actuators for response execution, processing units for data analysis, communication modules for connectivity, and user interfaces for seamless interaction. The interaction design process includes software in the preliminary stages, hardware and digital devices, and a CPU or other smart-emended device. The user-to-system interaction process involves input, processing, and output. The user inputs through devices like keyboards, touchscreens, or sensors. The system interprets this input, processes it using algorithms, and determines an appropriate response. After processing, the system provides the user output. Feedback is then provided, completing the loop and enabling further interaction. This iterative process fosters effective communication between the user and the system. In industrial applications, this process occurs within device limitations and context. The application layer, chatbot system layer, and LLM models layer are three stages of user interaction activity classification in intelligent systems. The application layer provides user-facing interfaces, while the chatbot system layer facilitates interaction with the system's logic. The LLM layer enhances interaction quality and system intelligence by processing user input and generating relevant responses.

Keywords: *digital system design, user interface, computer engineering, design engineering, design*.

Introduction. In digital engineering design, interaction and feedback loops are essential components that support dynamic user engagement, enabling iterative refinement and user-centered improvements in complex workflows. Interaction in user interfaces (UI) for digital system design enables designers to adapt digital interface to the user and context requirements, analyze relevant system data, and provide system feedback which is immediately visible to the user. This approach is curtailed for fostering an immersive and responsive design environment within the industrial use case context. At the same time interaction and feedback loops, allows users in real-time, provide and receive tangible response to the relevant input. Well-designed interaction on loop can help guide user in reinforcing action and assist with system optimization tasks. These loops promote informed decision-making, facilitate creative experimentation, and support rapid iteration, all crucial for achieving high-quality engineering outcomes. Overall, these loops are essential for a successful digital engineering design process. The relevant feedback response mechanisms, which can be visual, auditory, or even haptic, enable a more intuitive and efficient design process by offering insights into system behavior, potential errors, and the impact of design adjustments. By integrating robust interaction and feedback loops, digital engineering interfaces promote informed decision-making, facilitate creative experimentation, and support rapid iteration, all of which are critical in achieving high-quality engineering outcomes.

Analysis of research and publications. In digital engineering design, interaction, and feedback loops are essential components that support dynamic user engagement, enabling iterative refinement and user-centered improvements in complex workflows. Interaction in user interfaces (UI) for digital system design allows designers to adapt digital interfaces to the user and context requirements, analyze relevant system data, and provide system feedback that is immediately visible to the user. This approach is curated to foster an immersive and responsive design environment within the context of industrial use cases. At the same time, interaction and feedback loops allow users to provide and receive tangible responses to the relevant input. Well-designed interaction on the loop can help guide the users in reinforcing action and assist with system optimization tasks. The appropriate feedback response mechanisms, visual, auditory, or even haptic, enable a more intuitive and efficient design process by offering insights into system behavior, potential errors, and the impact of design adjustments. By integrating robust interaction and feedback loops, digital engineering interfaces promote informed decision-making, facilitate creative experimentation, and support rapid iteration, all of which are critical in achieving high-quality engineering outcomes.

Purpose. The main goal of this article is to study relevant approaches in the user-system interaction process while presenting a novel concept of an intelligent interaction loop system.

Methods. To study user-system interaction, researchers utilize various methods that can be broadly classified based on their approaches and objectives. Amon the most relevant are several key methodologies that study user behavior, context of interaction, model situations and predict future actions, as well as help model user and system response to certain events. Researchers observe users interacting with the system in real-time, either in a controlled environment or a natural setting, to capture authentic interactions and behaviors. User interactions are tracked through system logs or analytics, which record actions, time spent, errors, and other metrics for later analysis. Researchers develop models of user thought processes to predict behavior and interaction outcomes. Users verbalize their thoughts while interacting with the system, providing insight into cognitive processes and problem-solving strategies. These methods fall under qualitative field studies, emphasizing context-rich data from real-world settings. By combining several research methodologies, researchers can achieve a comprehensive understanding of user-system interaction from multiple perspectives, allowing for iterative improvements and user-centered design refinements. A brief overview of the main methods and their classifications is provided in Table 1.

Table 1

User-system interaction Classification*

Interaction system	**System components**	**System data**	**Use cases**
Direct controls	Mechanical device Text screen Voice and sound devices Visual display	Signal data Reach text data Graphical materials	Factory controls Digital surveillance system Device or system status control
Smart parametric system	Web or local application parameter control Events classification and response templates Parameters controls System state surveillance	Digital parameters Data base – events, system status, devices Digital surveillance data Device specific data Historical (events) data	Smart automated house IoT Smart car or transportation system controls Decision support or predictive modeling system

Special device or context –based interaction	Input device Output device Digital computational unit Communication and network unity	Spatial and GPS data Sensors and camera data Visualization Data	Virtual, Augmented or Mixed Reality Special suits UAV and robotics systems Another misc. Smart device

* prepared based on author work and public research data [1-7]

Figure 1 categorizes three major interaction processes – direct user and system input, usage and environment-relevant context system, and intelligent data-driven AI-enabled systems. As a general rule, user-to-system interactions do not occur in a limited laboratory-like environment; rather, they happen in real-time under the influence of many surrounding factors and events that can alter or affect the interaction process. Interaction systems themselves are not limited to a single input or output device – such as a screen, text input, or sound output. Instead, they usually provide several ways of interaction or manipulation, or in some cases, there is a specific input device for part of the international process (Figure 2).

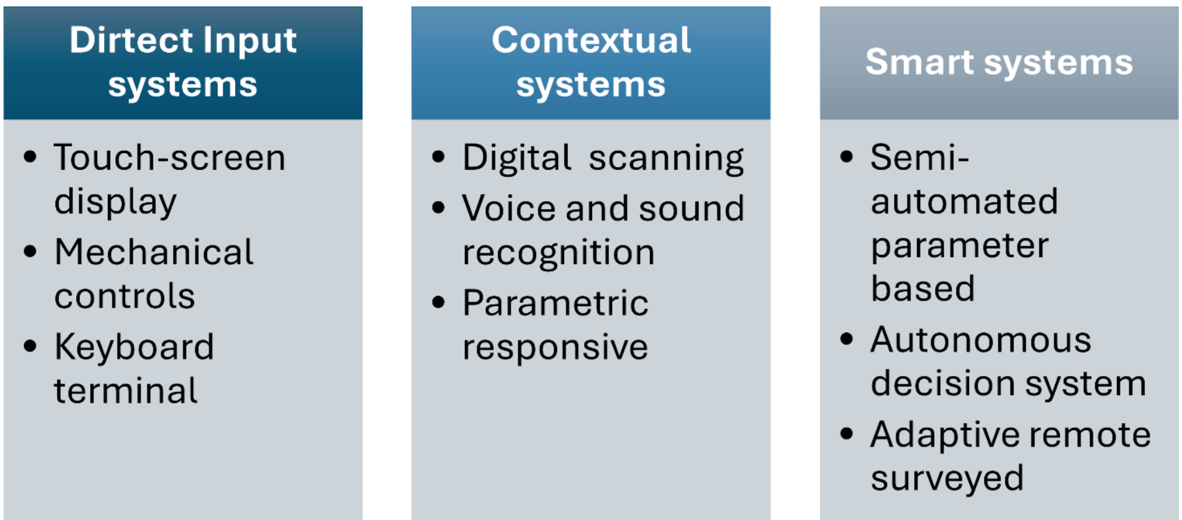

Fig. 1. **Digital Interaction systems classification [1-4]**

Fig. 2. **Example of mixed mechanical and digital control system**

Example of software functions used for human to machine interaction within the scope of systems classification in Table 1 and Figure 1:

- Data-preprocessing (data);
- SignalConvert(input signal, output type);
- GUI_Render(screen, data);
- Text_Render(text, coordinates),
- Feedback-Type(input, output, type);
- Notification(device, message, type);
- ParametersSetup(system, data, type).

Commonly used components in innovative system interactions include sensors for data collection, actuators for executing responses, processing units for data analysis and decision-making, communication modules for connectivity, and user interfaces for facilitating seamless interaction and control between users and the system. Table 2 outlines the critical software, hardware, and systematic level of components that constitute the interaction design process. Software is generally used in the preliminary stages to make and design the relevant systems and their user interface. At the same time, hardware and digital (analog in some cases) devices make the system, coupled with CPU or any other smart-emended device.

Table 2

List of commonly used components in the context of smart systems interaction*

Type	**Description** (examples)	**Common usage**
Software	3D CAD 3D Modeling UI and UX design 2D Graphical Design Application software	User Interface Design User Interaction modeling Input and output data Digital modeling
Hardware	Sensor screen Mechanical Input/output	Direct interaction Direct response

	Digital input/output Special sensors and camera	Interaction data Testing and control
Special systems	Spatial recognition Embedded CPU/GPU Haptic or motion response Other misc. Input/output devices	Data processing Autonomous behavior

* prepared based on author work and public research data [1-7]

Results. There are three overall stages of the user-to-system interaction process or loop. This process involves input, processing, and output. The user provides input through interaction devices such as keyboards, touchscreens, or sensors. This stage captures user intentions or commands. At the interaction loop (or action processing stage), the system interprets the input, processes it using algorithms, and determines an appropriate response based on its logic or innovative system processing modules. After processing the action and relevant event, the system provides the user output. The system delivers feedback or results to the user, often via visual displays, auditory signals, or physical actions, completing the loop and enabling further interaction. This iterative process ensures a dynamic exchange, fostering effective user and system communication.

Figure 3 illustrates key components of user-to-system interaction in industrial applications with various electronic devices, input terminals, and potential system-to-user responses. A user conducts certain activities or desires to accomplish the goal; the interaction occurs within the limitations of the devices and context provided. The intelligent systems take the user input as some signal, convert it into relevant systems data format, and fire a related action (function). The system processes the events in queues, breaking each system-relevant action into jobs with a data package attached. Once the processing is completed, the system will choose the most appropriate response feedback type and initiate it with the user. These steps are combined into what is called an interaction loop.

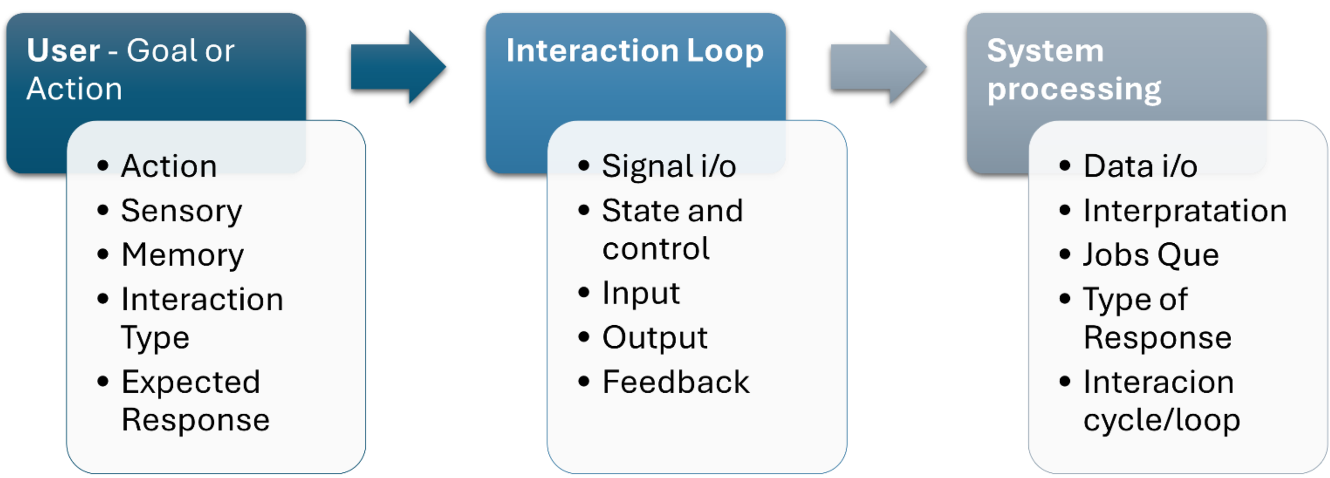

Fig. 3 **Three stages user to system interaction components**

A software conceptual representation of the user-system interaction loop can be visualized as a cyclic process, as shown in Figure 4. The user side represents the interface where the user interacts with the system. Inputs can come from keyboards, mice, touchscreens, voice commands, or sensors. The action cycle loop captures and interprets the user input. This section involves data validation, preprocessing, and translating the input into a format the system can process. System processing and the feedback loop are the primary subsystems, where input data is processed using algorithms, rules, or particular data rulesets to determine appropriate responses or activity. Afterward, the system's main module converts the system's decisions into outputs, such as visual feedback (e.g., GUI updates), auditory responses, or actuator commands. At the end of the current interaction cycle (loop #n), the system output module presents the relevant event to the user through the interface, providing feedback and enabling further input, thus completing the loop. The presented interaction cycle facilitates continuous interaction, allowing iterative refinement and adaptive responses in user-system communication.

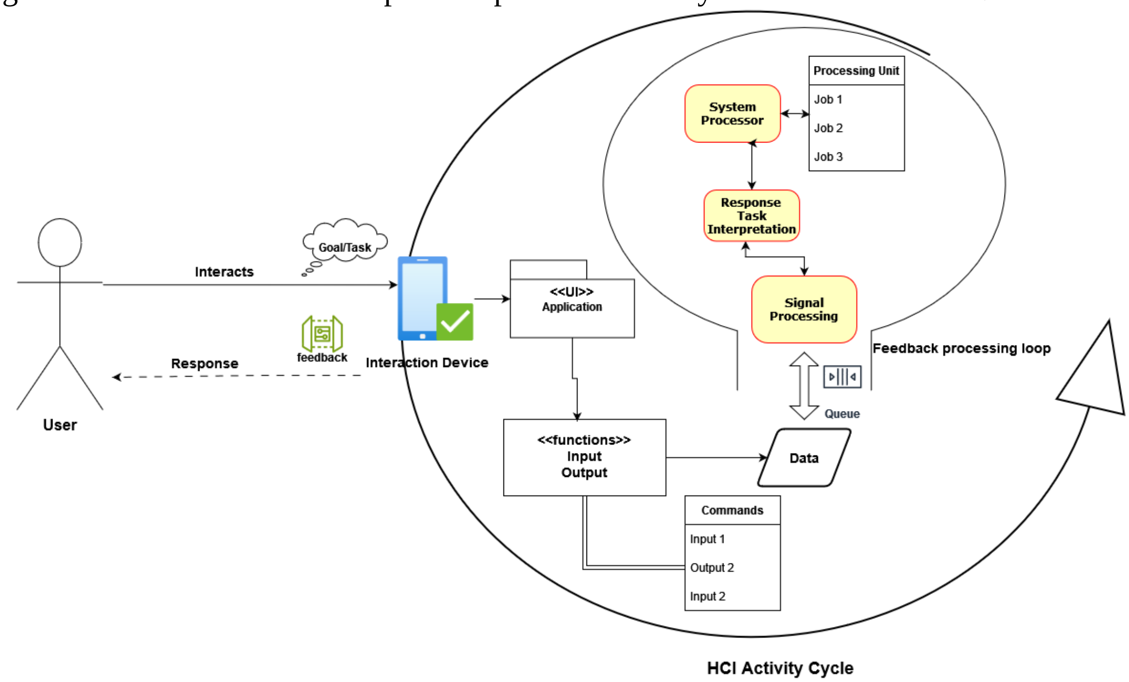

Fig.4. **User system interaction loop**

The application layer, Chatbot system layer, and LLM models layer are three stages of User interaction activity classification and components in the case of intelligent systems (Figure 5). The Application Layer serves as the user-facing interface in a smart system, providing tools, features, and functionality for users to interact with the system. It includes graphical user interfaces (GUIs), voice command modules, and other interaction mechanisms tailored for user convenience and accessibility. The Chatbot System Layer acts as the intermediary, facilitating interaction between the user and the system's underlying logic. It handles natural language understanding (NLU), dialogue management, and response generation, enabling conversational interfaces that simulate human-like interactions. The LLM Layer provides advanced language understanding and generation capabilities. It processes user input, interprets context, and generates coherent, contextually relevant responses. This layer leverages pre-trained models like GPT or similar to enhance interaction quality and system intelligence.

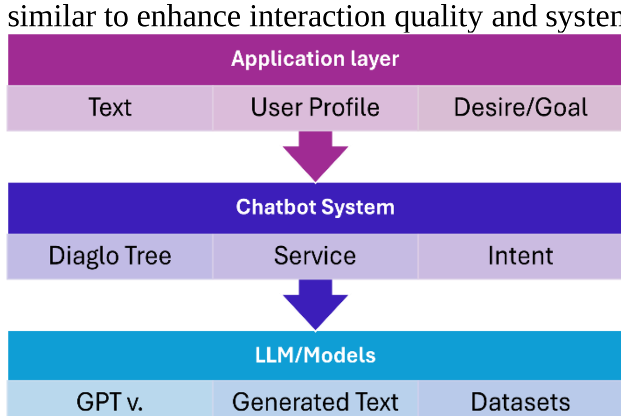

Fig. 5. **User interaction activity classification and components in case of smart systems**

Table 3 shows the classification of user interaction activity in intelligent systems. Components (system actors) make up each of the pertinent systems. Together, these elements allow for smooth communication and flexible reactions in intelligent systems.

Table 3

Interaction Process*

№	Interaction Stage	Description	Components Actors
1	**User Perception System Action mapping**	Users input data through sensory or interaction devices (e.g., text input, voice commands, gestures).	Input Devices: Sensors, keyboards, microphones, touchscreens, etc.
2	**Event Processing**	The system interprets, analyzes, and processes the input using algorithms, AI models, or decision-making logic.	Processing Units: CPUs, GPUs, AI processors for data analysis and decision-making. Communication Modules: Wi-Fi, Bluetooth, IoT protocols for data exchange.
3	**System Action User response**	The system provides output (e.g., visual, auditory, or physical responses), completing the interaction and enabling feedback for the next iteration.	Output Devices: Displays, speakers, actuators for feedback delivery. User Interface: GUI, chatbots, voice assistants for user interaction.

* prepared based on the author's work

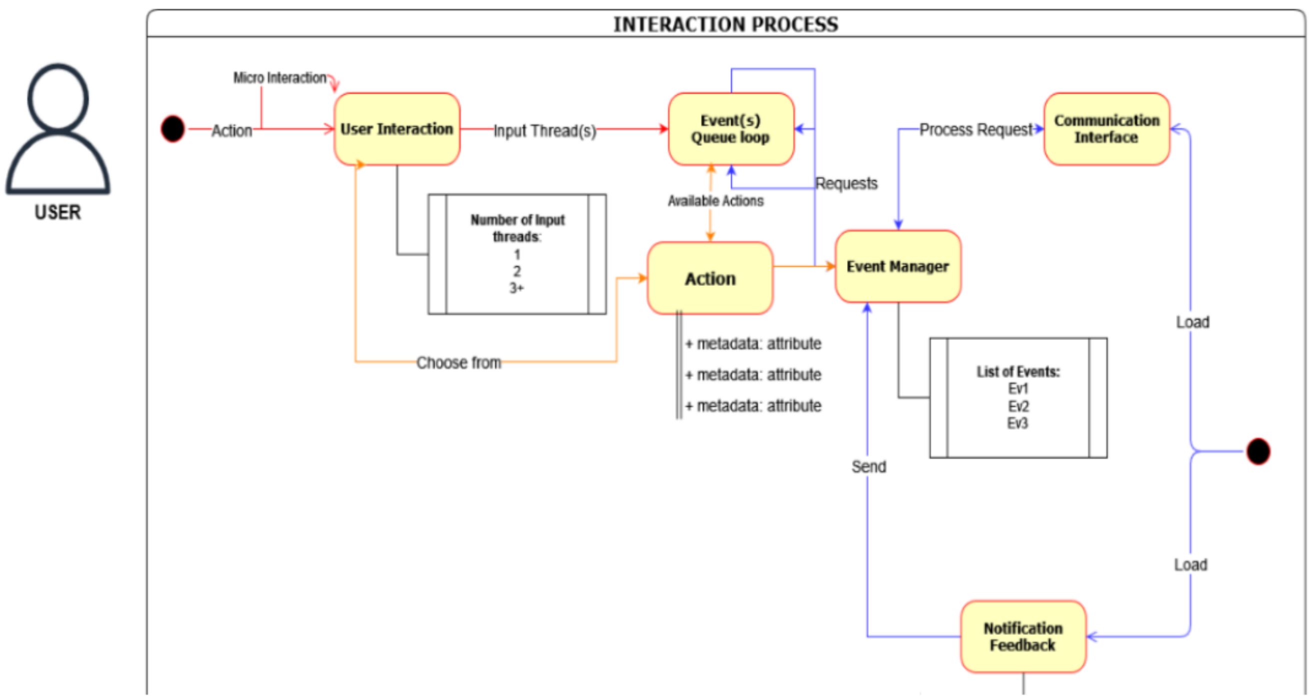

Fig. 6. **Sample user-smart system interaction process – main systems, data and activities**

Sample sequential algorithm for typical user-system interaction and feedback in context of smart processing (Figure 6 and Table 3):

1. User goal translates into system-relevant action;
2. Digital system proccess and classicifes relevant user actions;
3. Special function matches relevant action with system pre-defined event;
4. Event is beisng process in order FIFO;

5. When the queue moves to next event – action function is being called, and it gets all the related metadata associated with this event (action);
6. System GUI or another UI-specific function is being called based on current Action;
7. User received relevant feedback based on Action and UI function;
8. The loop continues until further specified;
9. In case of halt or pause of user action and if there are no predefined rules for automated event processing, systems goes into stand-by mode of shuts down.

Discussion. In a typical user-smart system interaction process, a user's intent is captured when they initiate an action via an input device, such as a touchscreen, voice command, or sensor. The data processing unit of the system processes this input and interprets the request using rule-based logic, artificial intelligence (AI) models, or decision-making algorithms. It retrieves and analyzes pertinent data from sensors, system databases, or outside sources. An output device, such as a display, speaker, or actuator, is then used to deliver the system's generated response or action. Data collection, processing, decision-making, and feedback distribution are essential tasks in this loop coordinated by networked subsystems such as the application interface, communication modules, and intelligent control units. This iterative process ensures adaptive and context-aware responses to user needs. The presented smart interaction system loop can be used to develop more responsive, context aware and smart behavior prediction systems in future.

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СИСТЕМИ КОРИСТУВАЛЬНИЦЬКОЇ ВЗАЄМОДІЇ ТА ЗВОРОТНОГО ЗВ'ЯЗКУ В ІНТЕРФЕЙСІ КОРИСТУВАЧА ПРИ ПРОЕКТУВАННІ ЦИФРОВИХ СИСТЕМ

Аннотація. *Цифровий інженерний дизайн ґрунтується на циклах взаємодії та зворотного зв'язку для підтримки взаємодії з користувачами та покращення робочих процесів. Цикл взаємодії в інтерфейсах користувача (UI) дозволяє дизайнерам адаптувати інтерфейси до вимог користувача та контексту, аналізувати системні дані та забезпечувати видимий зворотний зв'язок. Цей підхід сприяє створенню захоплюючого та адаптивного середовища дизайну, особливо в промислових випадках використання. Цикли зворотного зв'язку, візуальні, слухові або тактильні сенсори, дають уявлення про поведінку системи, допомагають виявити потенційні помилки в роботі та адаптивно коригувань с=ситеми-елементи дизайну.*

Взаємодія користувача і технологічної системи вивчається за допомогою різних методів, включаючи спостереження в реальному часі, системні журнали або відстеження аналітики, а також розробку моделей розумового процесу користувача. Ці методи зосереджені на контекстно-розширених даних із реальних налаштувань, що дозволяє ітеративно вдосконалювати та уточнювати дизайн, орієнтований на користувача. Системи взаємодії не обмежуються одним пристроєм введення або виведення, але часто забезпечують кілька способів взаємодії або маніпуляцій. Стандартні компоненти інноваційної взаємодії систем включають датчики для збору даних, виконавчі механізми для виконання відповіді, блоки обробки для аналізу даних, комунікаційні модулі для підключення та інтерфейси користувача для безперебійної взаємодії. Процес проектування взаємодії включає програмне забезпечення на попередніх етапах, апаратні та цифрові пристрої, а також центральний процесор або інший інтелектуальний пристрій.

Процес взаємодії між користувачем і системою включає введення, обробку і виведення. Користувач вводить дані за допомогою таких пристроїв, як клавіатура, сенсорні екрани або датчики. Система інтерпретує цей вхід, обробляє його за допомогою алгоритмів і визначає відповідну реакцію. Після обробки система видає на вивід користувача. Після цього забезпечується зворотний зв'язок, що завершує цикл і забезпечує подальшу взаємодію. Цей ітеративний процес сприяє ефективній комунікації між користувачем і системою. У промислових програмах цей процес відбувається в межах обмежень пристрою та контексту. Прикладний рівень, системний рівень чат-ботів і рівень моделей LLM – це три етапи класифікації активності взаємодії з користувачем в інтелектуальних системах. Прикладний рівень забезпечує інтерфейси, орієнтовані на користувача, тоді як системний рівень чат-ботів полегшує взаємодію з логікою системи. Рівень LLM підвищує якість взаємодії та інтелект системи, обробляючи введені користувачем дані та генеруючи відповідні відповіді.

Ключові слова: проектування цифрових систем, інтерфейс користувача, комп'ютерна інженерія, дизайн програмних систем, дизайн.