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Research Article

Interactive Product Design System Based on Intelligent Space Decomposition Technology and Internet of Things Technology

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In order to improve the effect of interactive product design, this paper combines intelligent space decomposition technology and Internet of Things technology to construct an interactive product design system. Moreover, this paper applies the interactive signal transmission technology to the interactive product design to improve the real-time information transmission quality of the interactive product. In addition, this paper selects the appropriate filter as the hardware foundation of the system, proposes the overall concept of digital constant ratio timing, and provides sufficient theoretical support for the analog-digital mixing and digital processing links involved in the system. Finally, this paper constructs a system model and combines the experimental research to verify that the interactive product design system based on the intelligent space decomposition technology and the Internet of Things technology can effectively improve the product design effect.

1. Introduction

From the perspective of users' cognition, analyzing the process of users' cognition of the semantic elements of the product can determine the important parts of the product. The three modes of sensory channel, effect channel, and feedback channel are analyzed, respectively. The sensory channel is the primary way for users to recognize and collect information about a product. Moreover, it is the processing of the aesthetic image of product symbols and often conveys information semantics to users through the external manifestations of the product such as product shape, color, material, and other elements in a certain packaging form. The main purpose of design is to allow users to effectively perceive and identify products [1]. The effect channel is the way for users to understand the acquired semantic information of the product, and the processing of the interpretation of the product symbol function. The effect channel here includes touch and voice, and touch can be divided into a touch screen and physical buttons. The task decomposition method is used to decompose the tasks, and the control methods are selected and executed according to different task links and effectively combined with the user's behavior characteristics. The design process studies the user's behavior, and the user can choose the touch mode, sound level, and voice decibel according to their physiological characteristics and psychological trends [2]. The feedback channel is the further processing and thinking of the information by the user, and the processing of the symbolic association of the product symbol. It means that the user implements an operation password on the product, and the product makes some information output and information feedback accordingly. Moreover, the user's brain response to the feedback of each step of the product is mainly thinking and memory [3].

Simply put, interaction design is the design and definition of the behavior of artifacts, environments, and systems, and the appearance elements that convey this behavior. Interaction design first plans and describes the way things behave, and then describes the most effective form of communicating that behavior. Specifically, interaction design is about creating new user experiences with the purpose of enhancing and augmenting the way people work, communicate, and interact [4]. Reference [5] describes interaction design as "the design of human communication and interaction space." From the user's point of view, interaction design is a technique of how to make products easy to use, effective, and enjoyable. It is committed to understanding target users and their expectations, understanding how users behave with each other when interacting with products, and understanding "people" its own psychological and behavioral characteristics, and at the same time, it also includes understanding, enhancing, and expanding various effective interaction methods. Interaction design also involves multiple disciplines and communication with people from multiple fields and backgrounds. Interactive product design is different from product design in the traditional sense. Product design in the traditional sense is related to design elements such as function, structure, human factors, form, color, environment, as well as the technologies, methods, and means of realization of functions used, and it is the design that indirectly affects the end user of the product. Interactive product design emphasizes the interaction between the user and the product system, the functions and technologies that support the behavior, and the information expression and emotion of both parties, which directly affects the design of the end user of the product [6].

Interaction design is not the same as human-computer interaction. It is an emerging discipline developed on the basis of human-computer interaction. The crystallization of the fusion of disciplines. Interaction design means that the design should pay attention to the interaction between people and products, and consider the user's background, experience and feelings during operation, so as to design products that meet the end user [7]. Human-computer interaction mainly refers to the interaction between human and computer, which is "about the design, evaluation, and realization of interactive computing systems for people to use, and is a science that studies the main phenomena related to this aspect." The main application areas of HCI are mostly related to computer science, focusing on the user interface of software systems, and the research purpose is to solve the usability and ease of use of software systems supported by complex computing technology. Also for software systems, people often confuse interaction design and interface design, thinking that interaction design is interface design, especially when understanding the interaction with software products. In fact, the interface is a static word. When designing the interface, we care about the interface itself, that is, the components, layout, and style of the interface, to see if they can support effective interaction [8]; at the time, we pay more attention to the interaction between the product and the user behavior and the interaction process. Summarize the difference between interaction design and interface in one sentence: interface design is concerned with static appearance, while interaction design is concerned with dynamic process [9].

Usability is a basic and important indicator of interaction design. Usability goals are about meeting specific usability standards, which can be divided into goals such as effectiveness, efficiency, security, usability, generality, ease of learning, and ease of memory. It is an overall evaluation of usability and a quality indicator to measure whether a product is effective, easy to learn, safe, and efficient from the user's point of view [10]. User experience is a subfield of the field of experience design. It applies to the product of the system and interaction model, it will affect the user's understanding of the device or system. This field is devoted to influencing all aspects of user and product interaction [11].

Interaction design advocates the basic point of view of system theory to run through the entire design and believes that the design process itself is a system, and its various links and elements are closely related to each other. The actions are taken in the scenario [12]. A system is a whole composed of a set of interacting or interdependent elements. According to the definition of the system, the interactive product design system is a system composed of four basic elements: people, human behavior, the scene when the product is used, and the technology integrated with the product [13]. Interaction design is the design of interactive systems. For the design of tangible products, the theoretical and practical significance of the interactive system can be understood as follows: place the product to be designed in the interactive system, use the theory and principles of interactive system design to guide the product design, and combine the entire interactive design system composed of multiple elements. As an organic whole, the properties and functions of the constituent elements are analyzed in the product design process to determine a suitable solution, and finally, achieve the design goal [14].

Leisure-oriented activities: In the field of product design, styling mediates factors and aesthetics. Product design is the integration of function and human factors into a good-looking shape. Their purpose is to solve a specific design problem and aim to provide a solution to human needs. Therefore, a product provides a specific function or set of functions, rather than being a "generalist." Opportunities to provide useful information are numerous and interactive aspects do play a role, but they are usually limited to the operation of mechanical or electrical products [15]. The usability aspect of the product focuses on traditional human factors (such as product design to fit the human body or "where should I turn this knob if I operate it"). To sum up, the application fields of traditional consumer products are different, and consumer products in a specific application field have specific functions [16].

Different from traditional products, interactive products in the category of large products have three unique elements: shape, function, and interaction. Among them, the modeling elements include the forms and materials in the traditional product elements, and the modeling generally includes three parts: the control interface, the feedback module, and the basic modeling. The functional elements are also extended from the physical functions of traditional products to the functions at the user's emotional and physical levels [17]. As a unique element of interactive products, interactive elements refer to the way the product interacts with users and the software design involved in the product, which are important factors that determine and reflect the innovation of the product and user satisfaction. At the same time, the three are interconnected, which is embodied in (1) the modeling language prompts the user to interact, and the modeling itself is a function; (2) the function of the product is realized through the process of interaction, and the mode of interaction determines part of the modeling; and (3) different functions require specific interaction methods and modeling features. The difference from traditional product design is that the design needs to determine the modeling details and the realization method of functions around the user's interactive experience process. The "user-centered" design principle is particularly prominent in interactive product design [18].

This paper combines intelligent space decomposition technology and Internet of Things technology to construct an interactive product design system to improve the effectiveness of product interaction design in the e-commerce era and to satisfy the user experience.

2. Interactive Signal Transmission Technology

2.1. Timing Technology. Time measurement is the measurement of the time information of the detector output signal, and it is usually the time interval between a measured signal and the reference signal (Δt_0). A time measurement system has to solve two problems:

(1) Time detection: The timing discriminator circuit determines the time of appearance of the signal and provides a trigger logic signal. (2) Time measurement: The physical time interval between the measured signal and the reference signal is converted into discrete digital data by the time-to-digital conversion circuit.

Leading edge timing is one of the most intuitive timing methods. The analog pulse signal directly output by the front-end detector is input to a fast discriminator with a fixed threshold. When the rising edge of the signal exceeds the threshold, it outputs a logic pulse as a timing signal output. It is shown in Figure 1.

V_{input} is the input signal, the leading-edge timing circuit is a fast discriminator, the threshold value is V_{th}, and the timing circuit outputs the timing logic signal V_{output} at the time of T_{th}. T_{th} is the trigger delay time, and the size of T_{th} is closely related to the threshold level V_{th} and the rising/falling rate of the input signal.

The threshold of the leading-edge timing is fixed, so for input signals of different amplitudes, the timing delay time is different, as shown in Figure 2.

The leading edge of the input signal is approximately regarded as a linear rise, which can be expressed by the following relationship [19]:

$$V_i(t) = \begin{cases} -\dfrac{V_m}{t_m} t, 0 \leq t \leq t_m, \\ -V_m, t > t_m. \end{cases} \quad (1)$$

The signal amplitude is V_m, and the peak time is t_m. When it enters the discriminator with the threshold value V_{th}, the amplitude reaches the threshold value, and the trigger time t_{th} is:

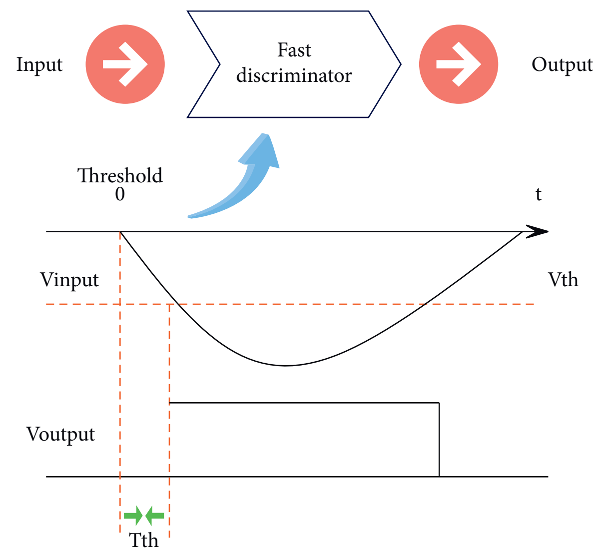

FIGURE 1: Schematic diagram of leading-edge trigger timing.

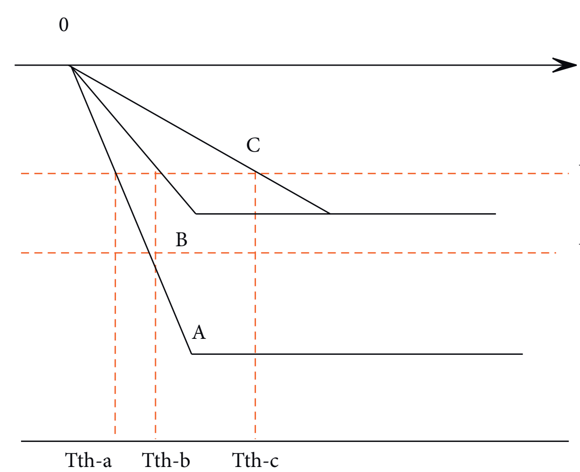

FIGURE 2: Amplitude walk effect and rise time walk effect.

$$t_{th} = \frac{V_{th}}{V_m} t_m. \quad (2)$$

In Figure 2, input pulses A and B have the same peak time but different amplitudes. For example, with a scintillator detector, if the species of the detected particles are the same, the output pulse rise time is the same, but the input amplitude is different. Although A and B are generated at the same time, the passing time is different, namely: t_{th_a} and t_{th_b}. Then, when the signal amplitude changes $\triangle V_{\text{input}}$, and the signal peak time is constant t_{in}, the resulting delay time change is called the amplitude walk effect. The variance of the leading edge timing is:

$$\sigma_{th} = \frac{V_{th}}{V_m^2} t_m \sigma_{Vi}. \quad (3)$$

In order to reduce the time-wandering error, the peak time t_m of the signal should be short, the discrimination threshold V_{th} should be small, and the signal amplitude difference $\triangle V_{\text{input}}$ should be small.

In Figure 2, input pulses B and C have the same amplitude but different peak times. For example, when the ionization chamber or PIN semiconductor detector absorbs the same particle energy but the particle incident position is different, the trigger delays are *th_b* and *tu_c*, respectively. The change in delay time due to the change in peak time At_m is called the rise time walk effect. The variance of the leading edge timing is:

$$\sigma_{th} = \frac{V_{th}}{V_m}\sigma_{tm}. \tag{4}$$

If both the amplitude change and the peak time change are considered, the maximum time travel of the detection circuit when the leading edge is triggered is:

$$\sigma_{th} = V_{th}\left(\frac{T_{i\max}}{V_{i\min}} - \frac{T_{i\min}}{V_{i\max}}\right). \tag{5}$$

For example, in the commonly used detection system combining scintillator and photomultiplier tube, the signal rising edge range is 3 ns to 7 ns, and the amplitude variation range is 200 mv to 4000 mv, the threshold is set to 50 mv, and there is $\sigma_{th} = 1.7$ ns.

One of the causes of time jitter is noise. The noise mainly comes from the detector and the electronic circuit in front of it, and it may also be generated by the time detection circuit itself. Moreover, noise is superimposed on the input signal, causing statistical changes in its amplitude and rise time, as shown in Figure 3(a). The noise of the time detection circuit appears as a statistical change in the threshold level, as shown in Figure 3(b).

When the time circuit noise is not considered, only the system noise superimposed on the signal is considered, as shown in Figure 3(a). We set the slope of the input pulse at crossing the threshold to be $V_{yh}'(t_{th})$. When the noise voltage probability density is normally distributed, the mean value is 0, and the mean square value is V_{noise}, the standard deviation of the threshold crossing time caused by noise is:

$$\sigma_{T1} = \frac{V_{\text{noise}}}{V_{th}'(t_{th})}. \tag{6}$$

The influence of the noise of the time detection circuit is shown in Figure 3(b). The probability density of the threshold level change caused by the discriminator noise also obeys a normal distribution, and the mean square value is $V_{\text{threslola}}$. Then, the resulting standard deviation of the over threshold time is:

$$\sigma_{T1} = \frac{V_{\text{threshold}}}{V_{th}'(t_{th})}. \tag{7}$$

The total standard deviation of the timing due to the two noises is:

$$\sigma_{T1} = \sqrt{\sigma_{T1}^2 + \sigma_{T2}^2}. \tag{8}$$

In order to reduce the time jitter error caused by noise, $V_{th}'(t_{th})$ needs to be maximized, so the threshold voltage V_{th} should be set at the maximum slope of the leading edge of the signal.

For incident particles of the same type and energy, even if they are incident in the same area of the detector, the generation time, amplitude, and waveform of the detector output signal fluctuate. Statistical fluctuations in the signal will cause a timed:

$$f = \frac{\text{Triggering electric frequency } V_m}{\text{he biggest } V_m \text{ signal}}. \tag{9}$$

The slope-to-noise ratio η is defined as:

$$\eta = \frac{V_{th}'(t_{th})}{V_{\text{noise}}}. \tag{10}$$

To sum up the abovementioned discussion, in order to reduce the time wander of signal amplitude and rise time, *Vt* should be as small as possible, but in order to ensure that the time detection circuit is not triggered by noise V, $V_{\text{threshold}} > (2\sim3)V_{\text{noise}}$ is required. At the same time, in order to reduce the time jitter caused by noise, the trigger ratio f should be selected at the maximum slope. In order to reduce the time jitter caused by fluctuations, there may be an optimal trigger ratio for a certain detector. Therefore, in the actual timing system, when selecting the threshold voltage $V_{\text{threshold}}$, it is often necessary to calculate f and η according to the amplitude and waveform of the signal to obtain the approximate range of $V_{\text{threshold}}$. Moreover, the trigger ratio was further adjusted in the experiment to obtain the best timing accuracy.

2.2. Zero Crossing Timing. Zero-crossing timing is designed to eliminate the time-wandering effect caused by changes in signal amplitude. If the input signal is $V_{\text{input}} = Af(t)$ and A is the signal amplitude, then the timing over threshold time t_{th} is the solution of the following equation:

$$Af(t) - V_{th} = 0. \tag{11}$$

Among them, V_{th} is the threshold of the discriminator.

It can be seen from the abovementioned formula that when V_{th} is a constant value, for different amplitudes A, the over queue time t_{th} cannot be constant. When *ft* is an arbitrary function, only when $V_{th} = 0$, different amplitudes A will not affect t_{th}. Therefore, in order to eliminate the time-wandering effect caused by the change of the amplitude A, the zero-crossing time of the signal must be used as the timing point, which is called the zero-crossing timing. The discriminator used for zero-crossing timing is called a zero-crossing discriminator (ZCD).

When the signal uses zero-crossing timing, it needs to go through the shaping circuit first to make it have a zero-crossing point. As shown in Figure 4. Commonly used shaping circuits are double differential Gaussian shaping $(CR)^2 - (RC)^m$ and dual delay line $(DL)^2$ shaping.

2.3. Constant Ratio Timing. Constant ratio timing is a time detection circuit with a constant trigger ratio. It is a timing method developed to solve the problem that the trigger ratio cannot be adjusted to the optimal value in the zero-crossing timing.

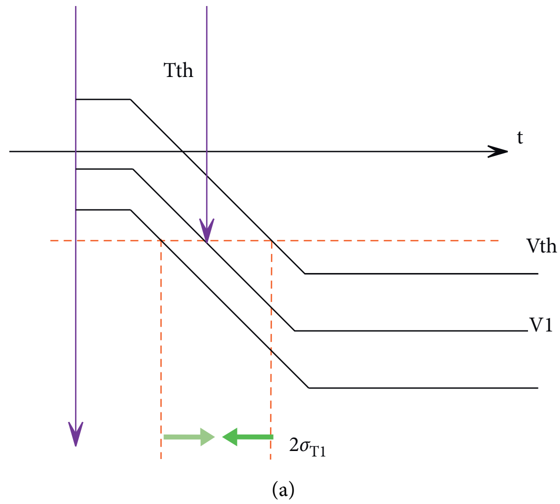

FIGURE 3: Time wobbles caused by noise.

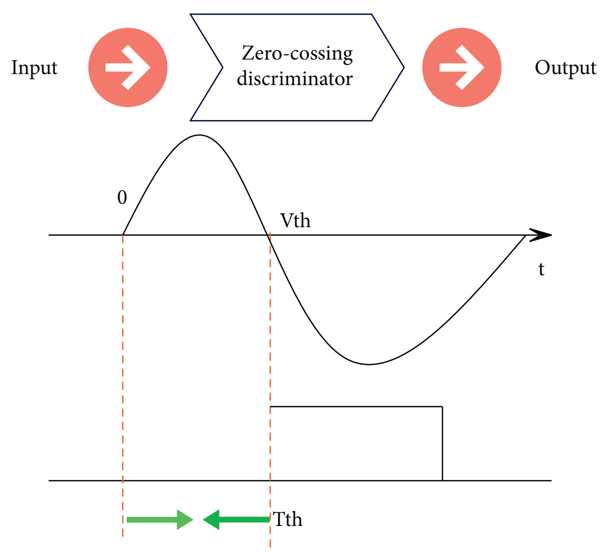

FIGURE 4: Schematic diagram of zero-crossing timing.

If the input signal is $V_{input} = Af(t)$, A is the amplitude, and $V_{th} = p{\cdot}A$ is the trigger threshold, the transition time V_{th} depends on the solution of the following equation:

$$Af(t) - pA = 0. \tag{12}$$

It can be seen from the abovementioned formula that *f*t) is an arbitrary function, and the solution of *t* has nothing to do with *A*.

The realization method of constant ratio timing is shown in Figure 5:

The input signal $V_{input} = Af(t)$ is divided into two paths: one way becomes the signal -*pAf*(*f*) after passing through the attenuator with attenuation coefficient p and inversion, and the other way becomes the signal $Af(t - t_d)$ after delaying t_d. These two signals are synthesized into a bipolar signal through the adder, and enter the + and − input terminals of the zero-crossing discriminator ZCD. When $t_d > t_M$, t_M is the peak time of the signal, the discriminator is triggered when $Af(t - t_d)$ rises to pA.

If the input signal is $V_{input} = Af(t)$, then there is:

$$V'_{input}(t) = -pAf(t),$$
$$V^*_{input}(t) = Af(t - t_d), \tag{13}$$
$$V_1(t) = Af(t - t_d) - pAf(t).$$

At the zero-crossing timing point t_{ZCD}, the trigger time $t_{threshold}$ is the following solution:

$$Af(t - t_d). \tag{14}$$

Then, *f*(*t*) is an arbitrary function, and t_{ZCD} has nothing to do with the amplitude. By adjusting the attenuation coefficient *P*, it is easy to adjust the trigger ratio to the best value to minimize the timing shake.

When the rise time changes in the constant ratio timing, like the zero-crossing timing, the timing jitter caused by the rising edge cannot be eliminated. As for the time jitter caused by noise, the potential difference between the two inputs of the discriminator is:

$$V_{ZCD}(t) = Af(t - t_d) - pAf(t). \tag{15}$$

When the input noise is white noise, under the condition of the same high-frequency passband of the system, the noise of $V_{ZCD}(t)$ is $\sqrt{1 + p^2}$ times of the input noise. In terms of noise, it is slightly larger than the leading edge timing, and when p is small, it is similar to the leading edge timing. Therefore, the slope-to-noise ratio for constant-ratio timing is less than or close to that for leading-edge timing.

Since the constant ratio timing is also a zero-crossing timing, in order to avoid random triggering caused by small noise signals, an additional prediscriminator is also used to preselect the input signal, that is, the input pulse larger than the prediscriminator can be truly output at the final timing.

2.4. Amplitude Rising Edge Compensation Timing. None of the abovementioned timing circuits can eliminate the time error caused by the rising edge wandering effect. Therefore,

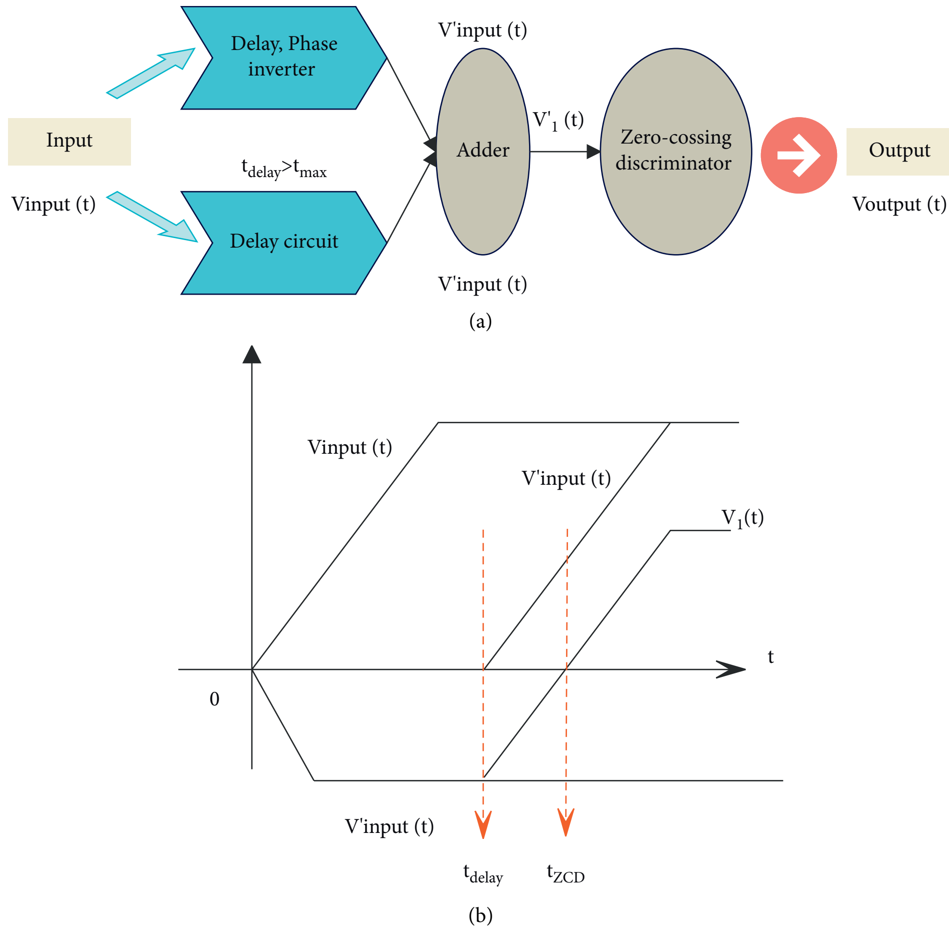

Figure 5: Schematic diagram of constant ratio timing.

on the basis of the constant ratio timing, the amplitude rising edge compensation timing technology, which is referred to as ARC timing for short, is developed. ARC timing enables amplitude and rising edge compensation for certain shapes of signals.

On the basis of constant ratio timing, the user-defined discrimination threshold is $V_{th}(t) = pAf(t)$, and the threshold varies not only with the amplitude A but also with the rise time. Then, there is an over threshold time detection equation:

$$Af\left(t - t_d\right) - pAf(t) = 0. \tag{16}$$

Among them, t_d is the delay time. If it is assumed that the leading edge of the input signal is a linear leading edge, and t_m is its peak time, the relationship between the amplitude of the rising edge and the time function is:

$$Af(t) = A\frac{t}{t_m}. \tag{17}$$

By taking it into formula (16) and expanding it, we get:

$$Af\frac{\left(t - t_d\right)}{t_m} - pAf\frac{t}{t_m} = 0. \tag{18}$$

In the abovementioned formula, (A/t_m) is the slew rate of the signal, which can be canceled. This gives rise to time and amplitude-independent timing:

$$t_{ARC} = \frac{t_d}{1 - p}. \tag{19}$$

As for time jitter caused by noise, ARC timing is also a zero-crossing timing. Therefore, when white noise is input, the slope-to-noise ratio of ARC timing and leading edge timing is related as follows:

$$\left(\eta_T\right)_{ARC} = \frac{\sqrt{1 + p^2}}{1 - p}\left(\eta_T\right)_{\mathrm{Lend}}. \tag{20}$$

ARC timing can eliminate the time wander caused by the change of the rise time, so the time wander caused by the statistical fluctuation of the signal waveform is also smaller. This advantage largely makes up for the lack of a constant trigger ratio.

Like constant ratio timing, ARC timing requires a prediscriminator with a nonzero trigger threshold to start, so as to avoid random triggering caused by small noise signals. Figure 6 is a schematic diagram of the ARC timing. Unlike the constant ratio timing, which is behind tm, the ARC timing is in front of tm, so it cannot be guaranteed that the prediscriminator starts to work before the timing point is generated. Figure 6 employs a dual-preset discriminator technique to eliminate timing errors caused by small signals.

2.5. Digital Constant Ratio Timing. Digital constant ratio timing (dCFD) is a detector digital signal processing technology built on digital systems. The digital constant ratio timing inherits the design idea of the analog constant-ratio timing technology and takes full-waveform digital sampling as the main technology to obtain the amplitude information of the waveform with sufficient precision. Then, the trigger ratio can be constant in the algorithm, the trigger threshold can be adjusted accordingly, and the time information can be calculated by means of digital signal processing.

Figure 7 shows the implementation of digital constant ratio timing and analog constant ratio timing.

Having a constant group delay speed in the passband minimizes the distortion of the rising edge of the pulse in the passband and stretches the front edge of the waveform as linearly as possible. The gain and group delay of an ideal 4th-order Bessel filter is shown in Figure 8. The Bessel filter has the flattest group delay curve in the passband.

The transfer function of the Bessel filter is:

$$H(s) = \frac{\theta_n(0)}{\theta_n(s/\omega_0)}. \tag{21}$$

In the formula, $\theta_n(s_0)$ is the inverse Bessel polynomial:

$$\theta_n(s) = \sum_{k=0}^{n} \frac{(2n-k)!}{(n-k)!k!} \cdot \frac{s^k}{2^{n-k}}. \tag{22}$$

The change in the slope of the rising edge of the waveform will cause the timing point to move, but this movement is a deterministic error. It is related to the shape and size of the input signal. However, for a dual-channel timing system, this part of the delay can be calibrated and processed through calibration, which will not cause the expansion of errors, as shown in Figure 9.

For the signal $x(t)$, if t is a continuous variable defined on the time axis, it is called $x(t)$ as a continuous-time signal, also known as an analog signal, and physical signals such as pressure, humidity, and flow rate are continuous analog signals. If t only takes values at discrete points on the time axis, then $x(t)$ is called a discrete-time signal, denoted as $x(nT_s)$. Among them, T_s represents the time interval between two adjacent points, also known as the sampling period, and n is an integer.

That is:

$$x(nT_s)\, n = -N_1, \ldots, -1, 0, 1, \ldots, N_2. \tag{23}$$

Generally, we normalize T_s to l, and $x(nT)$ can be abbreviated as $x(n)$, which is called the budding time series. Usually, computers or special processing chips represent data with a limited number of bits, so the magnitude of $x(n)$ also needs to be quantized to take discrete values. When $x(n)$ takes discrete values in both time and amplitude, $x(n)$ is called a digital signal.

The discrete-time system can be abstracted as a transformation, or a mapping, that transforms the input sequence $x(n)$ into the output sequence $y(n)$:

$$y(n) = T[x(n)]. \tag{24}$$

A discrete-time system can be either a hardware device or a mathematical expression. For a discrete-time system in the time domain, it can be described by a linear constant-coefficient difference equation:

$$y(n) = \sum_{i=0}^{M} b_i x(n-i) - \sum_{i=1}^{N} a_i y(n-i). \tag{25}$$

Its system response function H(z) is:

$$H(z) = \frac{Y(z)}{X(z)} = \frac{\sum_{i=0}^{M} b_i z^{-i}}{1 + \sum_{i=1}^{N} a_i z^{-i}}. \tag{26}$$

The most commonly used are linear time-invariant systems. That is, the system satisfies the principle of linear superposition, and the system input signal response has nothing to do with the signal input time.

$$\begin{aligned} F(\omega) &= F[x(t)] = \int_{-\infty}^{+\infty} x(t) e^{-j\omega t} \mathrm{d}t, \\ x(t) &= F^{-1}[F(\omega)] = \frac{1}{2\pi} \int_{-\infty}^{+\infty} F(\omega) e^{-j\omega t} \mathrm{d}\omega. \end{aligned} \tag{27}$$

For discrete-time series $x(n)$, the discrete Fourier transform and inverse Fourier transform are:

$$\begin{aligned} F\left(e^{j\omega}\right) &= \int_{n=-\infty}^{+\infty} x(n) e^{-j\omega n}, \\ x(n) &= \frac{1}{2\pi} \int_{-\infty}^{+\infty} F\left(e^{j\omega}\right) e^{j\omega n} \mathrm{d}\omega. \end{aligned} \tag{28}$$

In analog signals and systems, the Fourier transform is used for spectral analysis. The Laplace transform, as a generalization of the Fourier transform, analyzes the signal in the complex frequency domain. In discrete signals and systems in the time domain, the Fourier transform of the sequence is used for frequency domain analysis, and the Z transform is its generalization to perform complex frequency domain analysis on the sequence. The z-transform and inverse Z-transform of the sequence are:

$$\begin{aligned} F(z) &= \int_{n=-\infty}^{+\infty} x(n) z^{-n}, R_{x^-} < |z| < R_{x^+}, \\ x(n) &= \frac{1}{2\pi j} \int_{c} F(z) z^{n-1} \mathrm{d}z, c \in \left(R_{x^-}, R_{x^+}\right). \end{aligned} \tag{29}$$

In digital signal processing, all we are dealing with are sequences of numbers of finite length. For the discrete Fourier transform (Discrete Fourier Transform—DFT) of

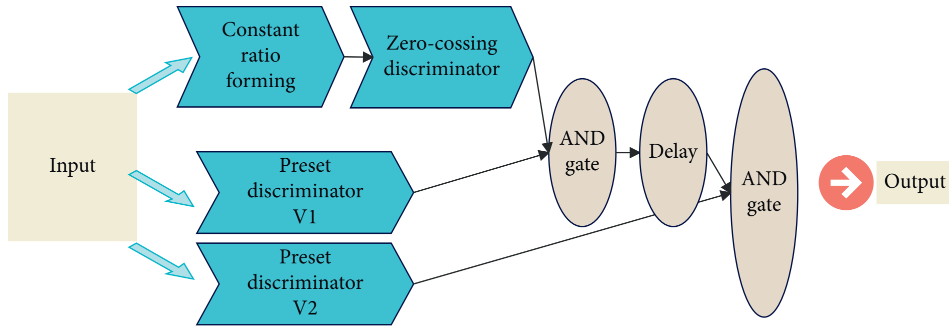

Figure 6: Schematic diagram of ARC timing.

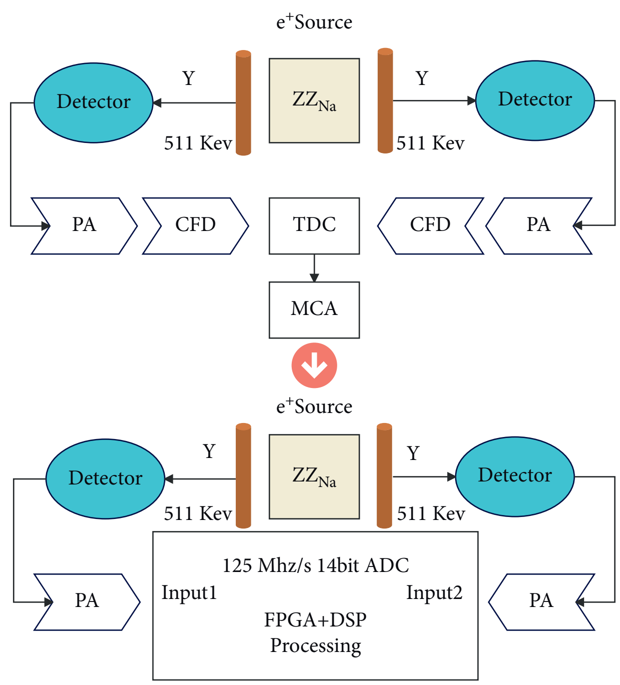

Figure 7: Schematic diagram of digital constant ratio timing.

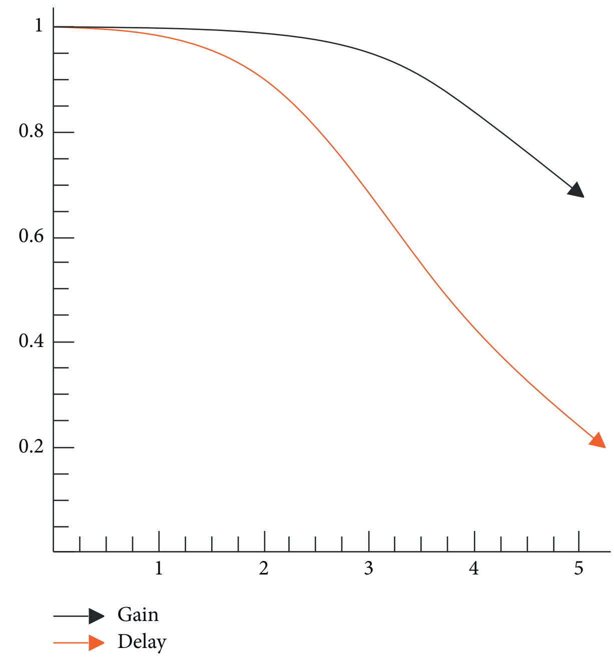

Figure 8: Schematic diagram of gain attenuation and group delay of 4th-order Bessel filter.

finite-length sequences, we have opened up a way to discretize in the frequency domain, so that digital signal processing can be performed in the frequency domain by means of digital operations.

The DFT of a finite-length sequence $x(n)$ of length N is:

$$F(k) = DFT[x(n)] = \sum_{n=0}^{N-1} x(n) W_N^{kn}, k = 0, 1, \ldots, N-1. \quad (30)$$

In the formula, $W_N = e^{-j(2\pi/N)}$.

Digital filters are functionally classified, and like analog filters, they can be divided into low-pass, high-pass, band-pass, and band-stop filters. Digital filters can be classified into infinite impulse response (IIR) filters and finite impulse response (FIR) filters from the implemented network structure or from the unit impulse response classification, and their system functions are:

$$IIR: H(z) = \frac{\sum_{r=0}^{M} b_r z^{-r}}{1 + \sum_{n=0}^{N} a_k z^{-k}},$$
$$FIR: H(z) = \sum_{n=0}^{N-1} h(n) z^{-n}. \quad (31)$$

The digital filter frequency response can be expressed as:

$$H\left(e^{j\omega}\right) = \left|H\left(e^{j\omega}\right)\right| e^{jQ(\omega)}. \quad (32)$$

In the formula, o is the digital angular frequency, $|H(e^{j\omega})|$ is the amplitude-frequency characteristic, which

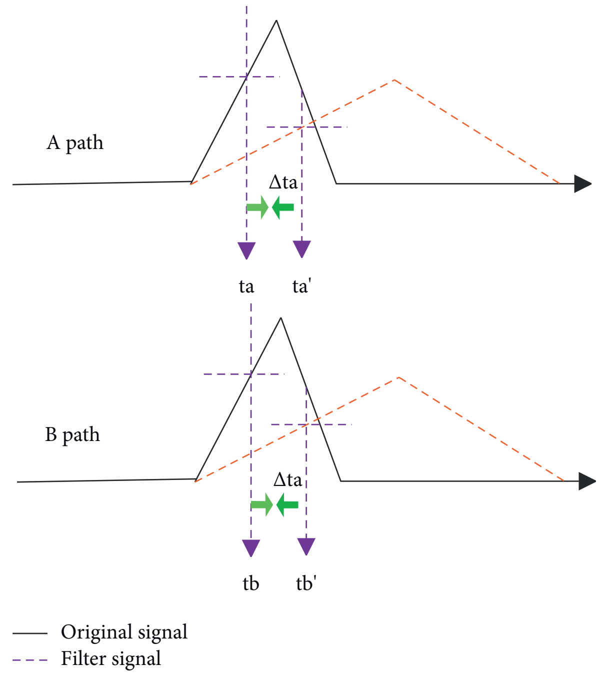

Figure 9: Schematic diagram of waveform broadening.

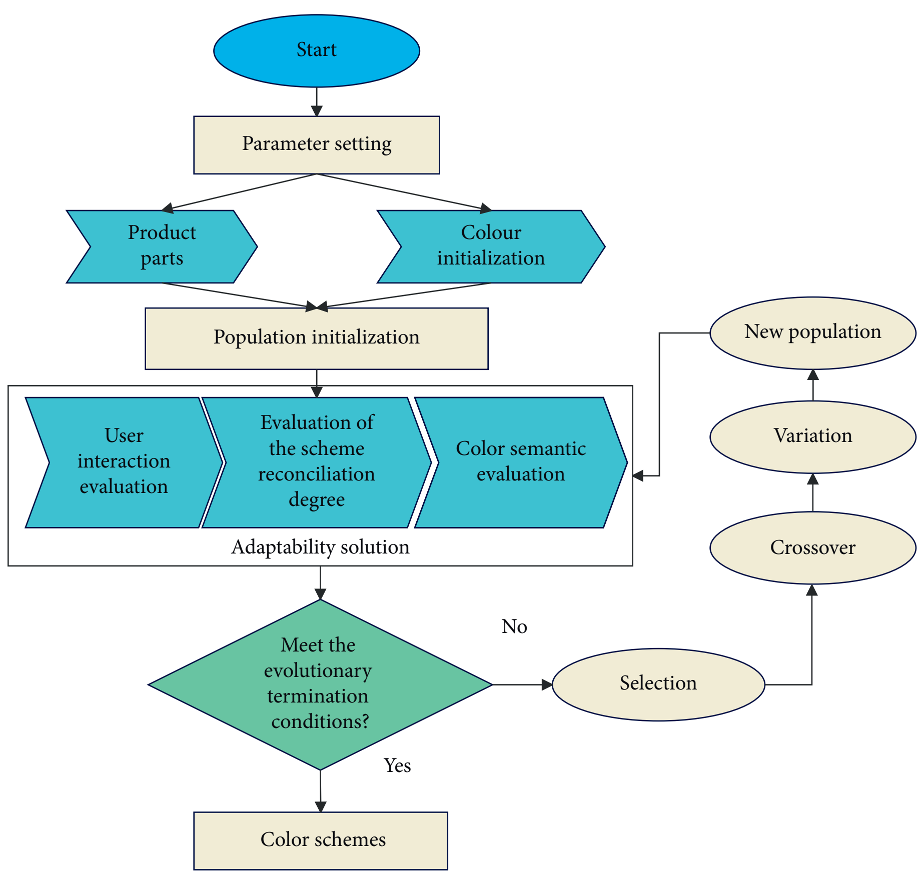

Figure 10: System operation flow.

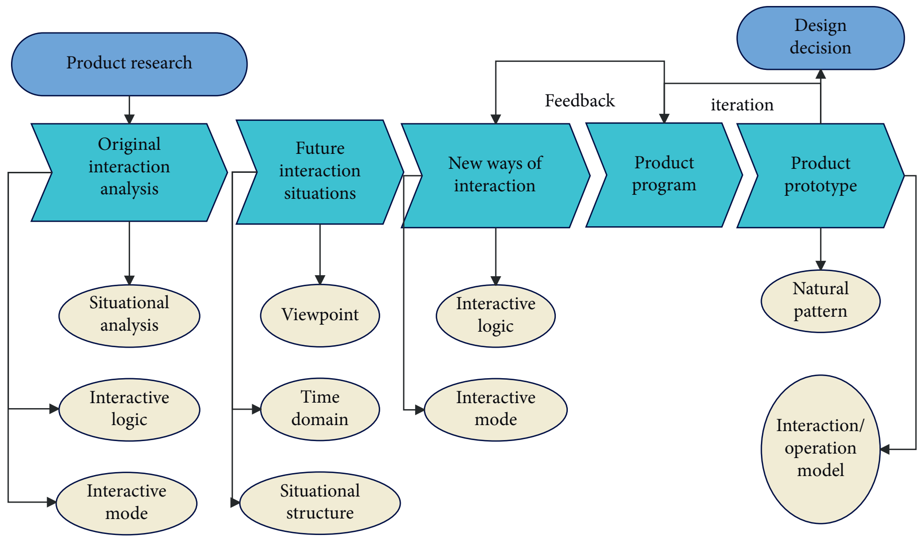

Figure 11: Interactive product design program.

represents the amplitude attenuation of each frequency component after the signal passes through the filter, and $Q(\omega)$ is the phase-frequency characteristic, which represents the time delay of each frequency component after the signal passes through the filter.

3. Interactive Product Design System

This paper searches for individuals with high fitness in the color scheme population to obtain satisfactory results for users. The interactive product design system based on intelligent space decomposition technology and Internet of Things technology is shown in Figure 10.

Figure 11 shows the user interactive product design program, which not only maintains the operability of traditional product system design but also reflects the user idea's emphasis on interaction and situational analysis. Its basic logic is to construct a future interaction situation on the basis of analyzing the original interaction, propose a new interaction method in the new interaction situation, and finally test the interaction effect by making a product prototype, so as to realize the original intention of interaction design for user experience.

The interactive evolutionary design cognitive fuzzy solution model is shown in Figure 12. In Figure 12, this paper establishes a "text-scenario-symbol" product modeling design hierarchy mapping based on the general cognitive laws of people's perception of form to target the vertical dimension. For the horizontal dimension, through the clustering arrangement of the iterative generation scheme, the visual attention jump and disorder in the fitness evaluation are reduced. The spatial decomposition is realized in Figure 12.

On the basis of the abovementioned, the effect of the interactive product design system based on the intelligent space decomposition technology and the Internet of Things technology proposed in this paper is verified, and the experiment is carried out in the way of simulation combined with practice. The statistical interactive design effect is shown in Figure 13.

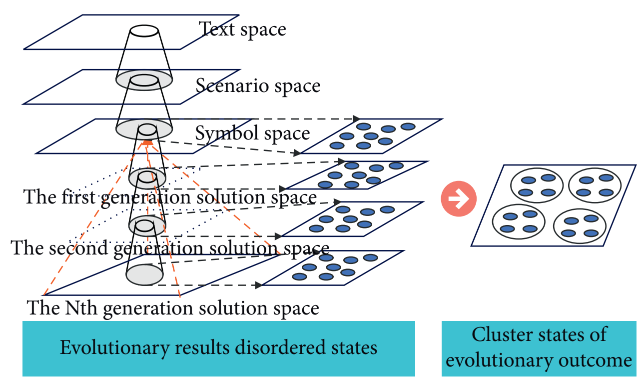

Figure 12: Cognitive fuzzy solution model for interactive evolutionary design.

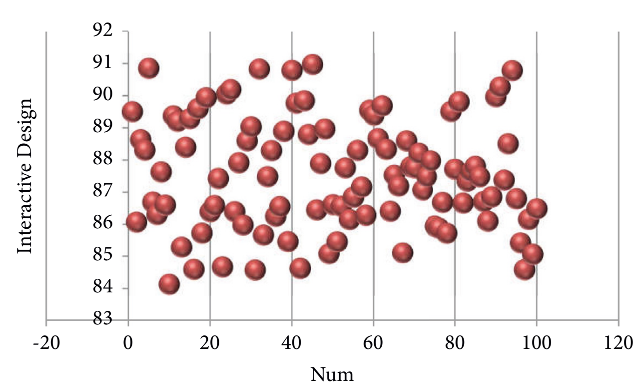

Figure 13: Interaction design effect.

The abovementioned research verifies that the interactive product design system based on intelligent space decomposition technology and the Internet of Things technology can effectively improve the product design effect.

4. Conclusion

With the development of the Internet, the interaction between users and products has gradually become more diversified, and new products with various powerful functions have gradually appeared on the market. However, at present, most of the products are mainly based on the research and development of functions and technologies, while ignoring the care for the user's humanity. As for how to combine advanced technology with products, how to convey semantic symbols, and maximize the needs of users, we can improve the user experience of using products by strengthening the semantic communication between users and products. Moreover, we explore the product design method based on product-level semantic interaction and use the communication concept of semantic interaction to provide users with information so that users can obtain a better experience and meet users' cognitive needs for easy-to-understand and easy-to-operate products. This paper combines intelligent space decomposition technology and Internet of Things technology to construct an interactive product design system to improve the effectiveness of product interaction design in the e-commerce era. The research verifies that the interactive product design system based on intelligent space decomposition technology and Internet of Things technology can effectively improve the product design effect.

Data Availability

The labeled dataset used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no competing interests.

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