Research on Autonomous Robot Display UX/UI Design Using Emotional Design Theory

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Abstract

Background: With the growing adoption of autonomous delivery robots, the importance of display UX/UI design that considers emotional interaction with users is increasingly emphasized. Emotional design theory serves as an effective approach to facilitate such interaction, contributing to the formation of positive experiences between robots and users. **Method:** Based on the three stages of emotional design—visceral, behavioral, and reflective—this study defined user scenarios and derived relevant design keywords for each stage. Subsequently, it conducted a comparative analysis of three robot display cases: Naver Labs' Rookie, Hyundai Robotics' Dal-E Delivery, and Serve Robotics' Serve Robot. The degree of emotional design engagement was analyzed using qualitative comparison criteria, and the strengths and weaknesses of each display were identified using keyword-centered analysis. This process led to the extraction of priority UX/UI elements that should be considered at each emotional design stage. **Results:** The analysis found that Rookie demonstrated a high level of emotional design engagement across all three stages and received positive evaluations in terms of user experience. Moreover, all sample cases, including Rookie, Dal-E, and Serve Robot, showed particularly high engagement in the behavioral stage. Based on these findings and the identified design keywords, this study proposed a concrete direction for UX/UI design and developed a final display prototype. **Conclusion:** This study suggests that UX/UI design based on emotional design theory can enhance the emotional quality of user experience with autonomous robot displays. By incorporating visual, motion-based, and feedback-driven elements, the design aims to foster emotional connections with users and provide experiences that go beyond functional interaction.

Keywords

Autonomous Robot
Display
UX/UI
Emotional Design
HRI (Human-Robot Interaction)

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Importance of Robot Display UX/UI

With the advancement of digital innovation and autonomous driving technology, autonomous robots are playing a crucial role in supporting or replacing daily tasks across various fields (Jie, 2023). In particular, as autonomous delivery robots rapidly establish themselves in logistics and service industries, the importance of displays that efficiently convey information through robot-human interaction is becoming more prominent. Displays serve as an important medium for robots to communicate their intentions and status to users, helping users easily understand the robot's operational status and respond appropriately when necessary (Jang, 2024). Along with the development of robots, the importance of HRI (Human-Robot Interaction) is gradually increasing, with research on robot user experience becoming particularly notable. In HRI, emotional interaction is an important element that strengthens the emotional connection between robots and users, evolving from users merely perceiving robots as objects of control to a comprehensive experience that includes social interactions such as communication and emotional exchange (Kim, 2017). However, while there has been progress in HRI research, it often remains theoretical compared to the advancements in robot technology, and there are still few commercialized examples utilizing human-centered design. Emotional design theory is emphasized as an important approach to effectively introduce emotional interaction, which can lead to positive user experiences through emotional interaction with users (Jung, 2016). By applying this to robot display UX/UI, users can accept robots more familiarly, and the interaction experience can be enhanced through emotional empathy. Therefore, this study aims to propose a direction for enhancing user interaction experiences with robots by applying emotional design theory to autonomous robot displays.

Research Scope and Methods

The research scope focuses primarily on robots capable of performing delivery scenarios, with an emphasis on their displays. For this purpose, Naver Labs' Rookie robot, Hyundai Robotics Lab's Dal-E Delivery robot, and Serve Robotics' Serve robot were selected as research subjects. By analyzing each robot from an emotional design perspective, this study aims to present a foundation for display design direction that can enhance the value of autonomous robot utilization by strengthening emotional interaction between robots and users. The research process proceeded in the following order: preliminary case studies of robot display,

scenario establishment, sample selection, comparative analysis of UX/UI by scenario, and final UX/UI design proposal.

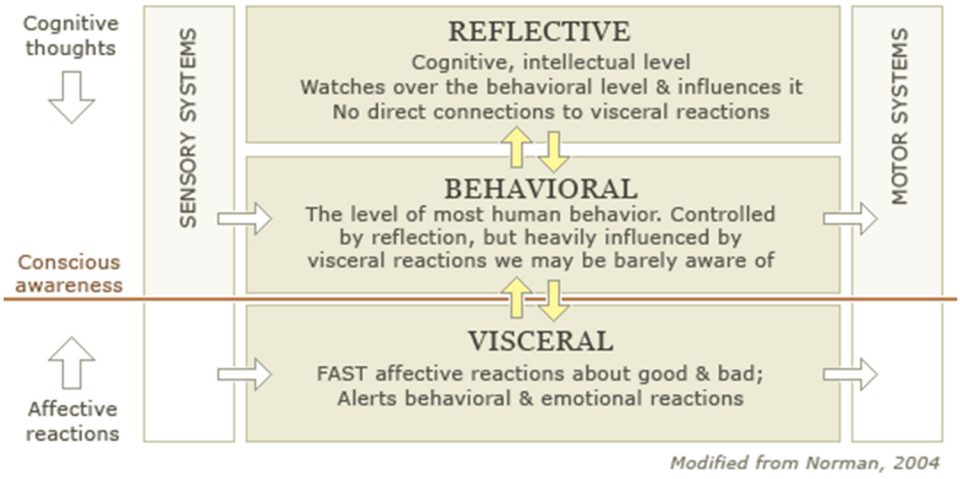
Theoretical Review

Concept of Emotional Design

Emotional design focuses on enhancing user experience through emotional connection beyond simply providing functional value in products. It involves understanding the psychological experiences of humans that appear as responses to external stimuli and utilizing these elements in design (Jung, 2007). Donald A. Norman categorized emotional design into visceral, behavioral, and reflective stages, presenting an important concept that approaches the entire process of user experience with products from an emotional dimension (Norman, 2004). Emotional design theory can be utilized to enhance the usability of robot displays by appropriately employing elements that can evoke emotions at each stage. (Figure 1)

Figure 1

3 layers of Emotional Design



Main Reference: Interaction Design Foundation (2024). Don Norman's Three Levels of Design interaction-design.org/literature/article/donald-norman-s-three-levels-of-design

The visceral stage explains the emotional response a user feels when first encountering a product. For example, visual elements such as colors, graphics, and animations significantly influence the user's first impression and can elicit intuitive responses about the product's reliability. It's important to provide attractiveness, intimacy, and stability through emotional direction, enabling users to experience emotional reactions. This plays a crucial role in making

users feel intimacy and stability through visual appeal, especially in robot displays. The behavioral stage refers to the emotions users feel while using a product, including its functionality and usability. It's important to reduce the cognitive burden that occurs while users operate the product and provide intuitive operability. The experience should offer utility, immediacy, and clarity through clear information provision, concise UI configuration, and intuitive navigation. The reflective stage relates to the emotional evaluation after using the product. This forms satisfaction with brand value or user experience and emphasizes aspects where users can reflect their own values through the product. Therefore, it refers to higher-dimensional emotions felt after use, based on satisfaction, reliability, and attachment, which can be developed through providing personalized experiences, emphasizing feedback, and designing storytelling elements. These factors help build trust in the product and increase brand loyalty (Koh, 2019). The three stages of emotional design play an important role in robot display UX/UI design to induce positive emotional responses and provide intuitive interaction during the process of user interaction with robots (Broadbent, 2013).

Robot Design Case Studies

To compare and analyze robot display UX/UI according to emotional design theory, three representative global cases of delivery robots, which actively use displays to expose information and enable interactions for receiving products, were selected as research subjects. (Figure 2)

Figure 2

Preceding Case Study Target Robots

Naver Labs' Rookie is an autonomous driving robot that delivers items in indoor environments, operating in Naver's second headquarters '1784'. It can deliver items in multi-layered structures through elevator boarding capabilities, maximizing delivery efficiency in various indoor spaces (Hwang, 2022). Rookie's display is characterized by a UX/UI design that

allows users to interact smoothly with the robot through graphics that resemble eyes. Hyundai Robotics' Dal-E Delivery is an autonomous driving robot that delivers items in indoor environments, and like the Rookie robot, it conducts multi-layer deliveries using elevators (Hyundai, 2024). Dal-E is characterized by a display mounted on top of its head for smooth interaction with users, providing high-resolution display and intuitive UI/UX. Serve Robotics' Serve Robot is one of the leading companies in outdoor robot delivery, focusing primarily on automating last-mile delivery of food, beverages, and small items. Serve Robot moves autonomously on sidewalks or walkways and provides technology that can safely deliver items even in complex external urban environments (Keerthi, 2024). The display is located on the rear upper part of the robot's storage compartment and is characterized by displaying large typography and minimal design elements.

Display UX/UI Comparative Analysis

Scenario and Keyword Definition

This study aims to establish comparative analysis criteria for autonomous robot display UX/UI based on the three stages of emotional design: visceral, behavioral, and reflective. Each stage focuses on forming key experiences and emotional bonds that robots provide to users, based on emotional reactions occurring during the interaction process between users and robots. To achieve this, scenarios were defined based on the characteristics of each stage of emotional design, and key design keywords were established as analysis criteria, grounded in the three stages of emotional design theory. (Table 1)

Table 1

Design keywords Definition by Scenario

Scenario 1	Scenario 2	Scenario 3
Visceral	Behavioral	Reflective
When the robot arrives at the destination and the user first sees the display	The process of interacting with the display to receive items	The moment when the item receipt is completed and the robot departs after completing its mission
Attractiveness, Intimacy, Stability	Efficiency, Immediacy, Clarity	Satisfaction, Reliability, Attachment

Scenario 1, corresponding to the visceral stage, deals with the emotional reaction users feel when first encountering a robot. Therefore, it was set as the moment when the robot delivers to the destination and the user first faces the robot's display, with attractiveness, friendliness, and stability defined as keywords. The behavioral stage addresses the emotional reactions users feel while interacting with the robot's display during the process of receiving goods.

Accordingly, a series of processes was set as the scenario: the user touches the display, proceeds with authentication, and then receives the goods, with efficiency, immediacy, and clarity as central keywords. The reflective stage is related to the emotional evaluation after using the robot. Therefore, it was set as the moment when the user finishes receiving the item and the robot is about to leave to complete its mission, with satisfaction, reliability, and attachment defined as analysis keywords.

UX/UI Comparative Analysis

Definition of Comparative Analysis Method

A comparative analysis of three robots—Rookie, Dal-E Delivery, and Serve—was conducted based on the defined scenarios and keywords. Samples corresponding to each scenario were selected for each robot, and based on this, evaluations were conducted with eight experts working in the robotics industry. These experts were able to assess the engagement with the required keywords at each stage using a four-point scale. The results of eight evaluations were compiled, and the final engagement level was derived based on standard deviation by applying weights for each item. (Table 2)

Table 2

Interview Participant Profile (experts working in the robotics industry)

Respondents	Gender	Age	Occupation/Group	Respondents	Gender	Age	Occupation/Group
P1	Male	30s	UX Designer	P5	Female	30s	Site Operator
P2	Female	20s	Product Owner	P6	Female	20s	Developer
P3	Female	20s	Product Designer	P7	Male	30s	Developer
P4	Male	40s	Product Owner	P8	Male	40s	Developer

Visceral Stage Comparative Analysis

According to the comparative analysis results, (A) provides UX/UI that can enhance attractiveness for users by using smooth eye wave motion. After the eye motion, it displays the orderer's name to form a bond with the user, and uses smooth animations in the connections between each screen to provide intimacy and stability. (B) and (C) are characterized by using brand assets to provide stability. However, (B) provides purpose-oriented information rather than emotional interaction with users by displaying order details, resulting in low engagement in terms of attractiveness and intimacy. (C) was analyzed as having no engagement in terms of attractiveness and intimacy as it displays a prompt to click a button for receipt along with the

brand logo. (Table 3)

Table 3

Scenario 1 Visceral Stage Comparative Analysis

Scenario 1 Sample Setting		
Analysis Target Sample (A)	Analysis Target Sample (B)	Analysis Target Sample (C)
		
Rookie	Dal.E	Serve

Scenario 1 Engagement Analysis			
Sample	Keyword	Content	Engagement
(A) Rookie	Attractiveness	Induces interaction through smooth eye wave motion	●
	Intimacy	Forms bonds by displaying names	●
	Stability	Induces stability through smooth motion	◓
(B) Dal.E	Attractiveness	Uses 3D assets	◒
	Intimacy	Lacks elements that provide intimacy	○
	Stability	Provides stability using brand assets	◓
(C) Serve	Attractiveness	Lacks elements that provide attraction	○
	Intimacy	Lacks elements that provide intimacy	○
	Stability	Provides intuitiveness and stability with brand logo and receipt button	◓

● High engagement ◓ Medium engagement ◒ Low engagement ○ No engagement

Behavioral Stage Comparative Analysis

According to the comparative analysis results, (A), (B), and (C) all showed high immediacy as they have simple product receipt processes. In terms of authentication methods, (A) allows receipt solely through facial recognition without touch, (B) provides choices between facial recognition and authentication number input, and (C) enables authentication and receipt through a single process that only allows authentication number input. Thus, in the authentication process where efficiency can be analyzed, all three samples were equally analyzed as having normal engagement, as they were judged to have efficiency through different methods. Regarding clarity, (A) was analyzed as having high engagement as it displays concise icons and text that can convey information about the user's next action, allowing information to be clearly recognized. (C) was also analyzed as having high

engagement as it places text largely to fill the screen, allowing clear recognition of information across all age groups. Despite using concise images and text, (B) exposes robot brand assets unrelated to the scenario, resulting in a lack of clarity compared to (A) and (C), and was thus analyzed as having low engagement. (Table 4)

Table 4

Scenario 2 Behavioral Stage Comparative Analysis

Scenario 2 Sample Setting		
Analysis Target Sample (A)	Analysis Target Sample (B)	Analysis Target Sample (C)
		
Rookie	Dal.E	Serve

Scenario 2 Sample Setting		
Analysis Target Sample (A)	Analysis Target Sample (B)	Analysis Target Sample (C)
		
Rookie	Dal.E	Serve

Scenario 2 Engagement Analysis			
Sample	Keyword	Content	Engagement
(A) Rookie	Efficiency	Minimizing user touch actions for efficient product retrieval	◓
	Immediacy	Providing a simple product retrieval flow with concise motion	●
	Clarity	Using concise icons and text for clear information recognition	●
(B) Dal.E	Efficiency	Providing efficient product retrieval through authentication options	◓
	Immediacy	Simple product retrieval flow and immediate product retrieval possible	●
	Clarity	Lacks clarity due to using robot images unrelated to actions	◒
(C) Serve	Efficiency	Providing a single option that only allows authentication number input	◓
	Immediacy	Configured to move immediately to the next action without motion	●
	Clarity	Clearly conveying information by placing text largely on the screen	●

● High engagement ◓ Medium engagement ◒ Low engagement ○ No engagement

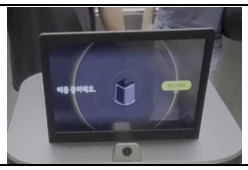
Reflective Stage Comparative Analysis

According to the comparative analysis results, samples other than (A) show a lack of

reflective elements. (B) is analyzed as having no engagement in satisfaction and attachment as it displays the same UX/UI as the visceral stage with text indicating it is moving, without any display exposure after product receipt. However, in terms of reliability, it was analyzed as having low engagement as it consistently exposes brand assets that represent the robot image. (C) has elements that can provide reliability and satisfaction by displaying phrases like "enjoy" and emojis along with a message to step back for safety after receipt, but can be analyzed as having low engagement due to a lack of personalized experience and storytelling elements. (A) provides a high emotional experience even in the reflective stage. It forms attachment by providing a personalized experience that allows the orderer to see a customized message upon receipt by displaying a phrase set by the sender along with emojis. When returning, it expresses a greeting motion through eye motion, designing the entire process from meeting to parting as a special storytelling element with the user, resulting in high engagement in satisfaction. (Table 5)

Table 5

Scenario 3 Reflective Stage Comparative Analysis

Scenario 3 Sample Setting		
Analysis Target Sample (A)	Analysis Target Sample (B)	Analysis Target Sample (C)
		
Rookie	Dal.E	Serve

Scenario 3 Engagement Analysis			
Sample	Keyword	Content	Engagement
(A) Rookie	Satisfaction	Inducing satisfaction by providing eye motion that greets with eyes	◓
	Reliability	Lack of elements that can provide reliability	◒
	Attachment	Enhancing attachment by providing user-customized messages	◓
(B) Dal.E	Satisfaction	Absence of elements that can provide satisfaction	○
	Reliability	Lack of reliability due to repetitive use of robot images	◒
	Attachment	Absence of elements that can provide attachment	○
(C) Serve	Satisfaction	Enhancing satisfaction by displaying positive emojis and messages	◒
	Reliability	Lack of elements that can provide reliability	◒
	Attachment	Absence of elements that can provide attachment	○

● High engagement ◓ Medium engagement ◒ Low engagement ○ No engagement

Comparative Analysis Results

This study conducted a contrastive comparative analysis on the display UX/UI configurations and experiences of three pioneering robot cases currently in service. Based on the three-stage theory of emotional design, scenarios were defined, and keywords were derived for each scenario and redefined as comparative analysis elements to analyze the resulting emotional effects. Through this research, it was confirmed that the Rookie robot includes high elements of emotional design in the visceral, behavioral, and reflective stages. Additionally, it was observed that all robots—Rookie, Dal-E Delivery, and Serve Robot—possess efficiency, immediacy, and clarity in the behavioral stage. This indicates that when configuring initial robot display UX/UI, it would be effective to benchmark Rookie's robot display overall and refer to the display UI/UX corresponding to the behavioral stage of Dal-E Delivery and Serve Robot.

Prototype Development and Validation

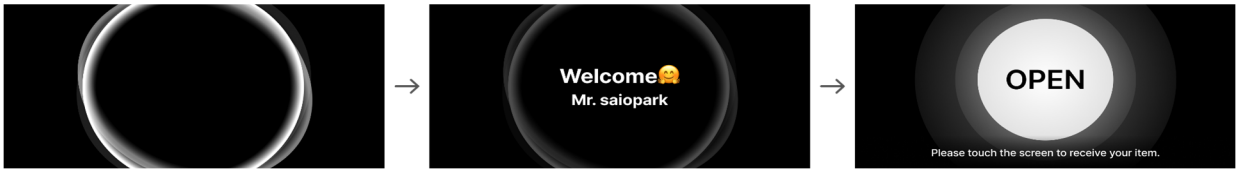
Prototype Development

Visceral Stage

The visceral stage is the moment when the robot arrives at the delivery location and the user first encounters the display, focusing on inducing the user's intuitive emotional response. The main design keywords considered at this stage are attractiveness, intimacy, and stability. First, to enhance visual attractiveness, smooth color tones and entrance animations were applied to the display, and the Eye LED, which is recognized as the robot's eyes at the top of the screen, was linked to enable organic movement, allowing the robot to be perceived as a living entity. Intimacy was designed to be formed through real-time display of the user's name at the top of the display or personalized greeting messages such as "Welcome, Mr. ○○". This contributes to the user recognizing the robot not as a simple machine but as an interaction partner. Finally, to ensure stability, the interface was designed to provide a clearly distinguished flow by stages, allowing users to interact in a predictable manner. The structure, where the robot’s name is displayed first upon encountering the user, followed by sequentially appearing guidance messages and the receipt button, effectively reduces cognitive confusion. This approach fosters a sense of stability by establishing a clear and systematic flow of information. (Figure 3)

Figure 3

Visceral Layer Display Design



Behavioral Stage

The behavioral stage is the phase where users interact with the robot through the display to receive products, a critical section where usability determines experience satisfaction. The design keywords considered at this stage are efficiency, immediacy, and clarity. First, to enhance efficiency, the system was configured to allow users to choose between QR code recognition or facial recognition as their preferred authentication method through the display. This maximizes authentication accessibility according to the user's situation and minimizes interaction time by eliminating unnecessary procedures. To ensure immediacy, after authentication, the system was designed to display storage compartment opening and product receipt information without separate success information. This not only simplifies unnecessary confirmation procedures but also indirectly allows users to recognize that physical operations have been accurately recognized, quickly providing a sense of control over the robot. Additionally, for clarity, the interface visually separates information delivery areas from user action areas, and minimizes user confusion through visual hierarchy such as text contrast, size, and color. (Figure 4)

Figure 4

Behavorial Layer Display Design

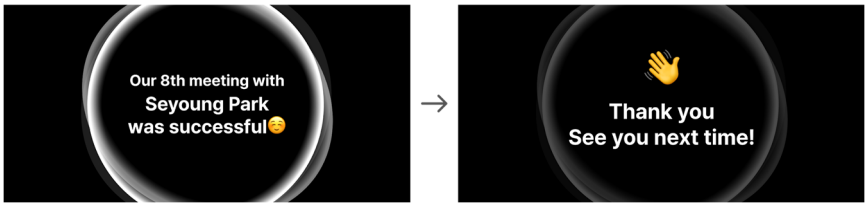
Reflective Stage

The reflective stage corresponds to the point when the robot leaves after the user has completed product receipt. At this stage, reflective emotions about the interaction are formed, and long-term impressions of the service experience are determined. The key design keywords

here are satisfaction, reliability, and attachment. To enhance user satisfaction, immediately after product receipt, the display outputs positive feedback messages such as "Thank you for using our service today!", while simultaneously expressing emotions through Eye LED-linked animations. This gives users the emotional satisfaction that the robot is expressing 'gratitude' like a human. Additionally, for repeat users, the display exposes cumulative interaction phrases such as "This is our ○th meeting," providing a continuous user experience based on reliability and attachment. This helps the robot to be perceived as an entity that maintains a consistent relationship with the user, rather than just a simple machine. (Figure 5)

Figure 5

Reflective Layer Display Design



Prototype Validation

To validate the developed display UX/UI, an A/B test was conducted. For comparison and evaluation, the Rookie robot sample (A), which showed high engagement in the engagement comparative analysis, was resized according to the guidelines for screens needed for testing. The evaluation was conducted through heuristic analysis by recruiting eight experts, and the evaluation items used were attractiveness, intimacy, stability, efficiency, immediacy, clarity, satisfaction, reliability, and attachment, corresponding to the design keywords derived for each stage. Prior to the evaluation, a brief education on the test purpose and touch methods was provided to help evaluators understand, and the test was set up to operate in an external public parking lot to simulate the actual environment. After task performance, evaluators were asked to evaluate the previous sample and the improved prototype on the nine evaluation items using a 7-point Likert scale.

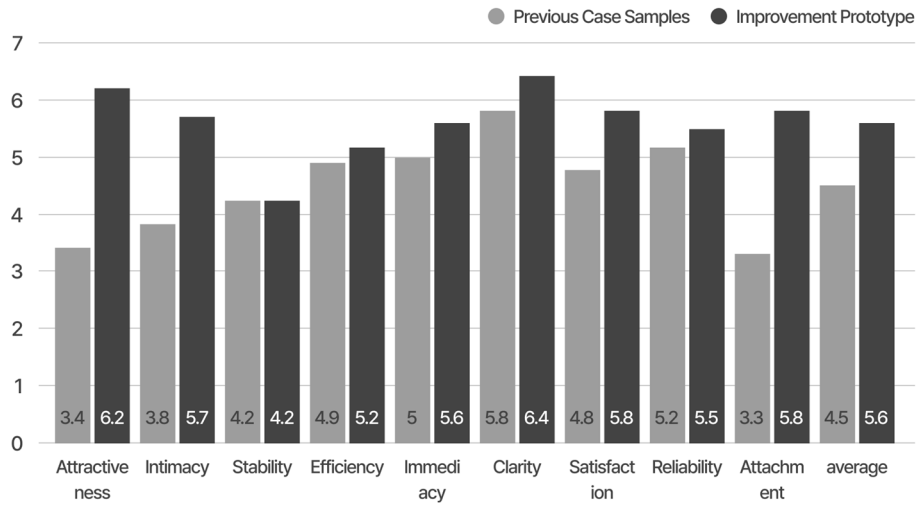
Validation Results

The results of the 7-point Likert scale responded to by the validation evaluators are as follows. The newly created prototype received higher scores in most items than the previous case sample with high engagement, with an average score 1.1 points higher. The efficiency, which showed the greatest increase, is considered to be the result of improving understanding

of basic functions through comprehension of the overall structure. The attractiveness, intimacy, and attachment, which showed high increases, are considered to be the result of enhanced bonding through the use of emojis expressing emotions. Stability and reliability did not show significant differences, which seems to be due to the evaluation being conducted through the testbed environment and low-specification displays, causing evaluators not to feel significant differences in usability between the two samples. (Figure 6)

Figure 6

Verification Results



Conclusion

This study has academic significance in that it derived case analysis and prototype development based on the three stages of emotional design theory for autonomous robot display UX/UI. By establishing keyword-centered comparative criteria through analysis of existing previous cases and reflecting them in actual robot displays, it aimed to narrow the gap between theory and practice. This UX/UI configuration is designed to satisfy functional convenience while considering emotional satisfaction, with the purpose of providing a memorable experience beyond simple interaction. In particular, to evoke emotional bonds and satisfaction in user interactions, the design reflects not only visual expressions but also the emotional flow throughout the interaction. Although research and development in HRI are progressing, the focus is still on technology-driven advancements in robotics. I hope that through the integration of technology and design, it will serve as a foundation for presenting

robot services that can be used in daily life. In the future, there is a need for integrated interface design including various HRI elements such as Eye LED, Belt LED, and Sound, in addition to displays. By extending the application of emotional design theory to such multi-sensory interfaces, richer user experiences and emotional immersion can be induced. It is hoped that this study will be used as basic data for future autonomous robot display UX/UI design and emotional design convergence, and is expected to lead to follow-up research on the applicability of emotional design according to various robot types and usage scenarios.

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