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# Towards Happy Housework: Scenario-Based Experience Design for a Household Cleaning Robotic System

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## Abstract

INTRODUCTION: In the interwoven trend of the experience economy and advanced information technology, user experience becomes the substantial value of an interactive system. As one of the early innovations of a smart home, the current design of household cleaning robots is still driven by technology with a focus on pragmatic quality rather than the experiential value of a robotic system.
OBJECTIVES: This paper aims to uplift the design vision of a cleaning robot from an automatic household appliance towards a meaningful robotic system engaging users in happy housework.
METHODS: Theoretically, experience design and scenario-based design methods were combined into a specific design framework for domestic cleaning robotic systems. Based on the user study and technology trend analysis, we first set three experience goals (immersion, trust, and inspiration) to drive the design process, then chose 3D point cloud and AI recognition as backup technologies and afterwards extracted three main design scenarios (scanning and mapping, intelligent cleaning, and live control).
RESULTS: The design features multi-view switching, a combination of animation rendering and real scene, fixed-point cleaning, map management, lens control and flexible remote, and shooting modes are proposed. Seventy-one participants evaluated the concept with online AttrakDiff questionnaires. The results indicate the targeted experience is fulfilled in the design concept.
CONCLUSION: By integrating experience design and scenario-based design methods with technology trend analysis, designers can envision experiential scenarios of meaningful life and potentially expand the design opportunity space of interactive systems.

Keywords: cleaning robotic system, user experience design, scenario-based design, pragmatic quality, hedonic quality

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## 1. Introduction

In urban households, cleaning accounts for a large proportion of household chores and thus is an indispensable part of family life. Commonly, most people regard household cleaning as tedious and time-consuming work. Therefore, most intelligent home cleaning innovations assume that users would prefer to be free from the fragmented cleaning chores and become more willing to allocate their time to socialising, entertainment and creative work. Using artificial intelligence (AI) and the internet of things (IoT), domestic cleaning robots are becoming more prevalent in modern families' daily lives. According to the Brand Essence Market Research report, the automation system of household cleaning is the primary factor in uplifting the global cleaning robot market to $34.94 billion by 2028[1].

However, human-computer interaction (HCI) scholars have noticed the danger of delegating housework to automation systems that may deprive enjoyable and

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meaningful daily experiences from performing housework [2] [3]. Meanwhile, recent social science studies indicate that household chores may bring some positive outcomes, such as an increment of self-confidence for married women [4], enhancement of independence and social participation for older adults [5], and alleviation of work pressure for males [6].

Particularly, household cleaning can benefit personal mental health. For example, washing dishes can be performed as an informal mindfulness practice. Sensory experiences of water temperature, soap smell and dish appearance may increase inspiration and decrease nervousness [7]. Also, engaging in the repetitive processes of household cleaning can be a source of a sense of control over personal environments [8]. Further, based on positive psychology, household cleaning can be transformed from monotonous chores into fun family activities if the activity fulfils the cleaning task's goal and provides enjoyment in the process [9].

The ultimate purpose of design is to create a better life for people, not necessarily faster or easier[2]. We need to take a more humanist perspective and concentrate on enjoyable and meaningful everyday experiences [10]. Automatic cleaning systems do impact the household cleaning experience. Designers need to reconcile experience with the advantages of automatic systems.

Scenarios can facilitate designers to discern the pain and the pleasant points of activities and create situated design knowledge [11]. With scenario thinking, designers can carry out user analysis, identify future user needs, and build new human-robot interaction modes where the pain points of housework are removed by automation. However, new design features are designed to prolong the pleasant parts. Integrating intelligent technology and scenario thinking is the key to evoking enjoyable experiences. For example, taking advantage of core flow technology and new filter innovation, the Dyson Pure Cool Me fan air purifier provides a personalised scenario that an individual would fully control the airflow direction in a range of 70° and enjoy a purified and fresh breeze. By integrating intelligent technology into scenarios of desirable human experience we can add excellent product value for users and guide personal well-being development.

In this work, we aim to design interactive system for meaningful life and present a scenario-based experience design case of a household cleaning robotic interactive system. In the following sections, we firstly introduce the related work on design of domestic robots, secondly reveal the critical results of design research that backup for key scenarios and experience design goals, thirdly present the specific design framework for a household cleaning robotic system and lastly report the evaluation of the designed system.

## 2. Related work

### 2.1. Household cleaning robot development

A household cleaning robot is an autonomous mobile system that cleans floors, windows, lawns, beds, and others. It has been utilised in mopping, UV sterilisation and other purposes at home. The history of domestic cleaning robot development can be divided into three stages by three types of robotic navigation technology accordingly: 1) using infrared to detect and avoid obstacles without maps during the 1990s; 2) using gyroscope and ground photoelectric sensors with maps produced by collision during 2000-2018; 3) using LiDAR-based simultaneous localisation and mapping (SLAM) and visual SLAM to have enriched maps and real-time positioning [12]. The next stage may focus on the movement control of cleaning robots with the combination of multiple sensors.

Technology is one of the dominant factors in cleaning robot design, especially in pragmatic aspects. Technical challenges in the design of cleaning robots were summarised by Prassler and Kosuge’s work, such as absolute positioning, sensor coverage for robust obstacle avoidance, area coverage in unknown dynamic environments, multi-robot coordination, and power supply [13]. Joon and Kowalczyk utilise adaptive manufacturing technology and a well-proved control algorithm to build an autonomous mobile cleaning robotic system in an environment with obstacles [14]. Bisht et al. present a unique design concept of a glass façade cleaning robot for dynamic modelling and efficient path-plan simulation [15]. Muthugala et al. propose a wall-cleaning robot capable of adapting vacuum power based on the adhesion-awareness to improve safety and reliability [16]. Palleja et al. analysed the performances of three commercial floor-cleaning mobile robots and one research prototype and contributed an algorithm of domestic random path planning for cleaning [17].

Besides technology development, how users adopt domestic cleaning robots have been studied in parallel by HCI scholars. For example, Sung et al. conducted a six-month long-term field study on how 30 households accepted a new vacuuming robot and established a domestic robot ecology framework including four temporal stages: re-adoption, adoption, adaptation and use/retention [19]. Vaussard et al. identified the influence of key technologies by comparing seven robots and conducted an ethnographic study within nine households to uncover users’ needs [18]. Their studies suggest two aspects of cleaning robot design, how well a robot accomplishes its task and how well it integrates inside the user’s space and perception [18]. Also, a lack of trust in the robot and the unwillingness to make a physical change at home hinder the acceptance of a cleaning robot [18].

Empirical studies highlight domestic cleaning robots as socially interactive agents [19]. Fink’s work points out that playing with a moving robot, giving one’s robot a name, collaborating on cleaning tasks with a robot, etc., are all social activities with a robot [20]. Similarly, Forlizzi's work uncovers that cleaning robots may affect family relationships by changing who cleans and how he/she cleans [21]. Families would be proud to own and show off an intelligent cleaning robot to friends; they may explore how to use it together, watch it work together and even do other housework together [21]. A cleaning robot can transform the cleaning task into a social activity, including the entire household [22]. In this sense, a domestic cleaning robot can be treated as a social service robotic system that can potentially provide more experiential value.

## 2.2. Experience design for household robots

The ISO9241-210 standard defines User experience (UX) as the user's entire feeling before, during and after using a product or system, including emotions, preferences, cognitive intentions, physiological and psychological responses, and other aspects. UX integrates feelings from pragmatic and hedonic aspects of design, compassing all aspects of a product, service, or business connection [23].

Desmet, Hassenzahl and Pohlmeyer argue that most of the existing interaction design and industrial design have been trapped in traditional design thinking oriented to solve human factors and usability problems [24]. However, "zero-problem" products do not necessarily inspire deep happiness. A design process should start with an in-depth reason for UX [25]. In other words, the profound meaning of UX should be first considered before those pragmatic goals [26]. Following Hassenzahl's idea of “think experience before product”, Lu and Roto propose to set explicit experience goals at the starting point of a design process, and then define and conceive product features that may evoke targeted experience [26].

Designing imbuing home robots with personality promotes user trust and acceptance. Whittaker et al. developed three distinct robot personas based on personality theories and suggested that users want robots that mimicked but accentuated their own personality [27]. Hendriks et al. conducted a semi-structured interview to find out that when users know their robot's personality, they can interact appropriately with robots [28].

In the healthcare domain, Papadopoulos et al. suggest that enjoyment and experience of personalisation is the primary enabler of the socially assistive humanoid robotic implementation [29]. Fitter et al. show that a human-sized humanoid robot has the potential to encourage the elders to exercise social-physical and cognitive games by evoking pleasant, enjoyable, engaging, challenging and energetic experience [30]. An essential contribution of their work is understanding how robots with designed social interaction skills and dynamic physical interaction abilities can encourage exercise.

In the education domain, Kim and Tscholl studied young children's embodied interactions with a social robot [31]. They found the potential of humanoid robots as an enabler to embodied learning experiences and social and emotional experiences [31]. Jong et al. suggest that entertainment-related experiences may drive children's intention to adopt a domestic social robot [32].

Experience design of social robots implies potential ethical questions such as whether to keep emotional relationships with robots. To deal with ethical challenges, involving users in the design research process can give a chance to researchers to take users' actual concerns into account, thus reducing the potential limitations of technology [33][34]. Fronemann et al. provide recommendations to reconcile experience and ethical design: transparency, predictability, psychomotivational effects, step-by-step information and explainability [35].

## 2.3. Scenario-based design for household robots

Generally, a scenario means a series of actions and events. As a design tool, scenarios refer to stories about people and their activities in particular contexts, which make ideas more concrete and address complex situations in a meaningful way [36]. Scenarios help design teams focus on what matters most and serve as primary representations of past situations and future design proposals [37]. Scenario-based approaches deal with several issues of design work, such as evoking a design team's reflection on the design content, providing multiple views of intangible interaction, and pushing rational design moves [38].

Scenario-based approaches support the experience design of complex tangible products from the following perspective [39]. First, in the early stage of product development, scenarios flexibly capture the implicit knowledge of user experience and integrate it with technical requirements and product specifications. Second, scenarios promote communication among all stakeholders and provide a shared vision of the intended overall experience. Third, experiences and scenarios have a similar underlying narrative structure of the sense-making process; thus, scenarios are utilised to define the meaningful user experience.

Scenarios have been widely applied to household robot innovation, emphasising the human experience. Scenarios play an essential role in understanding, ideating, and evaluating the experiential quality of interaction between humans and robots at home. McGinn et al. developed a domestic robot control scenario based on 3D virtual reality to investigate novice robot operators' performance, control behaviour and subject experience [40]. Alternatively, Kim et al. utilised scenarios as outputs of ideating robotic solutions for innovative home services from the user experience perspective [11]. Neuhaus et al. propose specifying scenarios of robotic superpowers as an essential step for meaningful domestic robot ideation [41]. Furthermore, Syrdal et al. created open-ended scenarios to evaluate long-term human-robot interaction in a naturalistic environment [44]. In contrast, Cortellessa et al.

conducted a cross-cultural evaluation of domestic assistive robots with video-based scenarios [45].

In this work, we aim to create experiential value of a household robotic cleaning system by integrating experience design, scenario-based design, and technology trends.

## 3. Designing a cleaning robotic system

The two-year design project presented below is part of “Product-Service System Design for Future Smart Home”, a collaborative program between Jiangnan University and one leading company (the following referred to as Company E) in the domain of in-home robotic appliances in the world. Beyond incremental technology improvement, this design project targeted new scenarios of the novel interaction between a human and a robotic cleaning system. Meanwhile, Company E wished to launch the new interactive cleaning system within 2-3 years, indicating that the technology to be adopted should be available soon. Therefore, we interwove experience design, scenario-based design, and technology-driven design thinking throughout the project.

### 3.1. Design research

The design research of this project consists of desk research and intensive user studies, including field study, focus group sessions and expert interviews. In-depth user insights and technology trends were derived from design research results, then constructed into new scenarios and further transformed into experience design strategies.

#### Technology trends

We studied cleaning robotic system technology trends from scientific papers, industry consulting reports and online user reviews. Four appropriate technology trends for cleaning robot development were identified: 3D point cloud, AI scene recognition, modularisation of software and hardware, and somatosensory interaction.

The 3D point cloud is obtained by scanning the 3D laser detector. When a laser beam hits the object's surface, the reflected laser beam can carry information such as azimuth and distance. Because the scanning is extremely fine, many laser points can be obtained, so a laser point cloud can be formed to represent the 3D object.

AI scene recognition is usually achieved through semantic segmentation, which is linked with constructing point cloud maps. Semantic segmentation refers to classifying objects at the pixel level by combining machine learning algorithms and summarising the pixels belonging to the same class in order to complete the understanding of images.

Modularisation of software and hardware means users can program to configure or transfer hardware such as motors, sensors, cameras, and lights. Users can learn and cooperate with modular components through programming to achieve gains in robot performance and practice circuit control, mechanics, and other knowledge. Users can write autonomous action algorithm programs using different artificial intelligence modules.

Somatosensory interaction is an interaction paradigm derived from the integration of real-time image recognition, augmented reality, face and gesture recognition, dynamic capture, and so on. The accuracy of the somatosensory interaction intention, the rationality of the interaction form, the immediacy of the interaction feedback and the simplicity of the interaction behaviour are the four critical factors in the development of somatosensory interaction scene applications. Robots can become an essential carrier of interactive somatosensory systems with the development of sensors and the maturity of intelligent identification technology.

#### User studies

Following the desk research, the user studies were carried out in three stages with the guidance of scenario-based design thinking: ethnographic studies on users, focus group sessions and expert interviews.

In the first stage, we conducted four in-house interviews with the users of the household robotic systems. With ethnographic research methods such as observation and video recording of the actual situation of using a cleaning robot, we collected the information such as purchase motivation and user behaviour. We concentrated on the user scenarios of quick guidance, scanning and mapping, AI recognition, whole house cleaning and live image. We condense preliminary home-based insights into pain points and user demands of robots.

We ran a two-hour focus group session in the second stage to dig out in-depth user insights and design opportunities. After an introduction to technology background, nine participants attended a group brainstorming, including personal story sharing, future smart home envisioning and human-robot relationship discussion. The session reveals user expectations for cleaning robot functions in different home situations.

In the third stage, we interviewed five expert users, among whom two persons with expertise in digital interaction, one in industrial design, one in environmental art and the last in engineering. The experts validated the insights from our previous research and identified five pain points with existing household cleaning robots:1) lack of detailed object information; 2) a tedious mapping process for users; 3) lack of direct and effective human-machine control; 4) the cognitive gap between humans and robotic system; 5) abstract and boring presentation.

### 3.2. Key scenarios

The insights from the desk research and user studies were synthesised from the three aspects function, interaction, and visualisation shown in Figure 1. Three critical scenarios with corresponding design strategies emerged from the research insights introduced above, as shown in

Figure 1: scanning and mapping, intelligent cleaning, and live shooting.

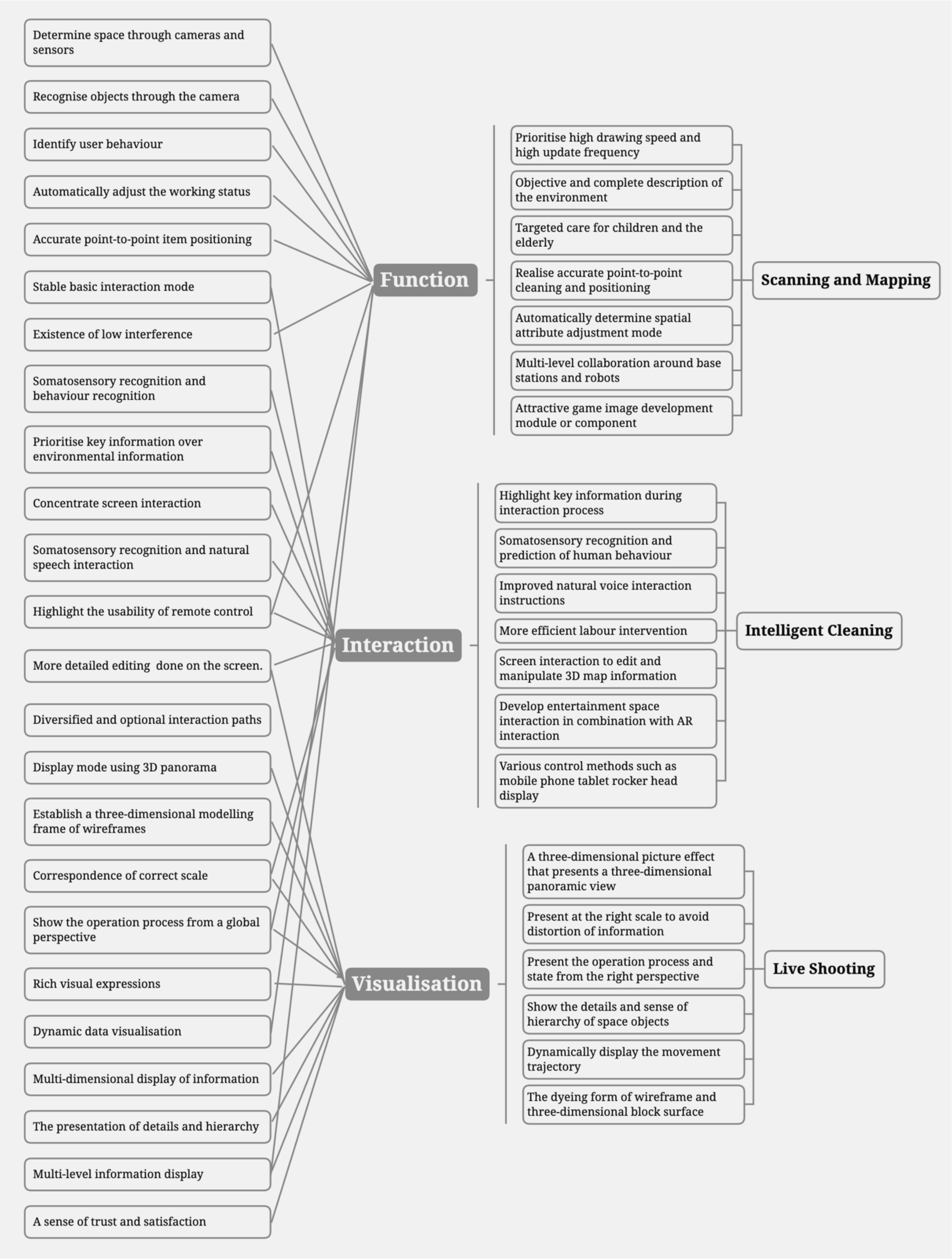

**Figure 1.** Research insight mapping

### Scanning and mapping

The scenarios of scanning and mapping address one of the biggest challenges of plane mapping: a considerable need for information of height and object details in the presentation process, which may significantly degrade the user experience. Users have to interact with a robotic system by reading low-resolution and barely usable maps. Taking the advantage of 3D map construction, the map-building process can be visualised for a transformation from wireframe to 3D map. Therefore, the amount of presented information can be increased; for example, the robot's performance can be prioritised to output. The new design should let users perceive the direct and complete scanning process.

The traditional cleaning robotic mapping is a tedious waiting process for users. Design with a focus on UX can increase user’s feeling of excitement and immersion in which robotic actions match one’s expectations for work progress and efficiency. This requires adjusting the relationship between the drawing speed and the visualisation effect. The system needs to actively restore the characteristics of the actual environment through 3D models, low-level meshes, wireframe planes, etc. Therefore, the new design shall emphasise the directness and immediacy of the mapping process, quickly display the scanning progress with a low-profile wireframe, and quickly output the map model.

### Intelligent cleaning

The scenarios of intelligent cleaning highlight accurate scene recognition and specific spot cleaning. Semantic information covers location and object attributes. Information at different levels of concreteness is given different weights to adapt to the operational characteristics of a robotic system. Semantic segmentation is performed according to features such as shape, material, furniture types, functions, and usage frequencies. Further annotation and content classification provide semantic information about specific objects and help users issue more "point-to-point" instructions.

On the user interface of intelligent cleaning, the content classification is presented in the form of layer overlays arranged reasonably. The information amount displayed at a time is controlled to simplify the user interface effectively. For example, separating furniture from apartment types and daily necessities from furniture, which is more in line with the user's understanding of home space. Reasonable mapping operation logic for platforms with different screen sizes is required.

### Live shooting

The scenarios of live shooting rationally arrange the interaction logic of shooting and motion, laying the foundation for functions such as home display, home monitoring, and pet photography. The provided live-action images of the robotic cleaning system can directly affect user experience. The images can convey the sense of quality and technology of products. To provide desirable user experience, the images should be clear and stable, the user interface should be straightforward, and the control method should be agile and responsive.

Optical and point cloud cameras can provide technical support for the AR experience with actual scenes and annotations. There are broad applications of AR technology regarding the extensibility of a robotic cleaning system. 3D maps, real-life images and AR annotations can build a home game space, enhancing the user experience of playfulness as the added value of a robotic cleaning system.

## 3.3. Experience design framework for a household cleaning robotic system

The overall architecture of an intelligent cleaning system comprises interaction design and product design. The interaction design covers service processes, media elements, interactive frameworks, function levels, etc. The product design includes modelling the machine and the control module (Figure 2). The interaction design and the product design of the intelligent cleaning system (**Figure 3**) are inherently connected from the user experience perspective. This project considered user experience as a prioritised design goal to drive the design progress.

**Figure 2.** The machine and the control module

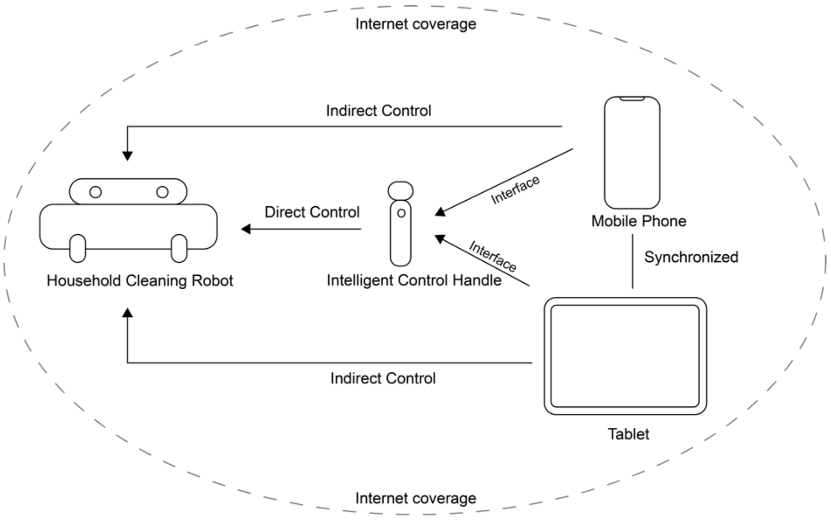

**Figure 3.** The intelligent cleaning system

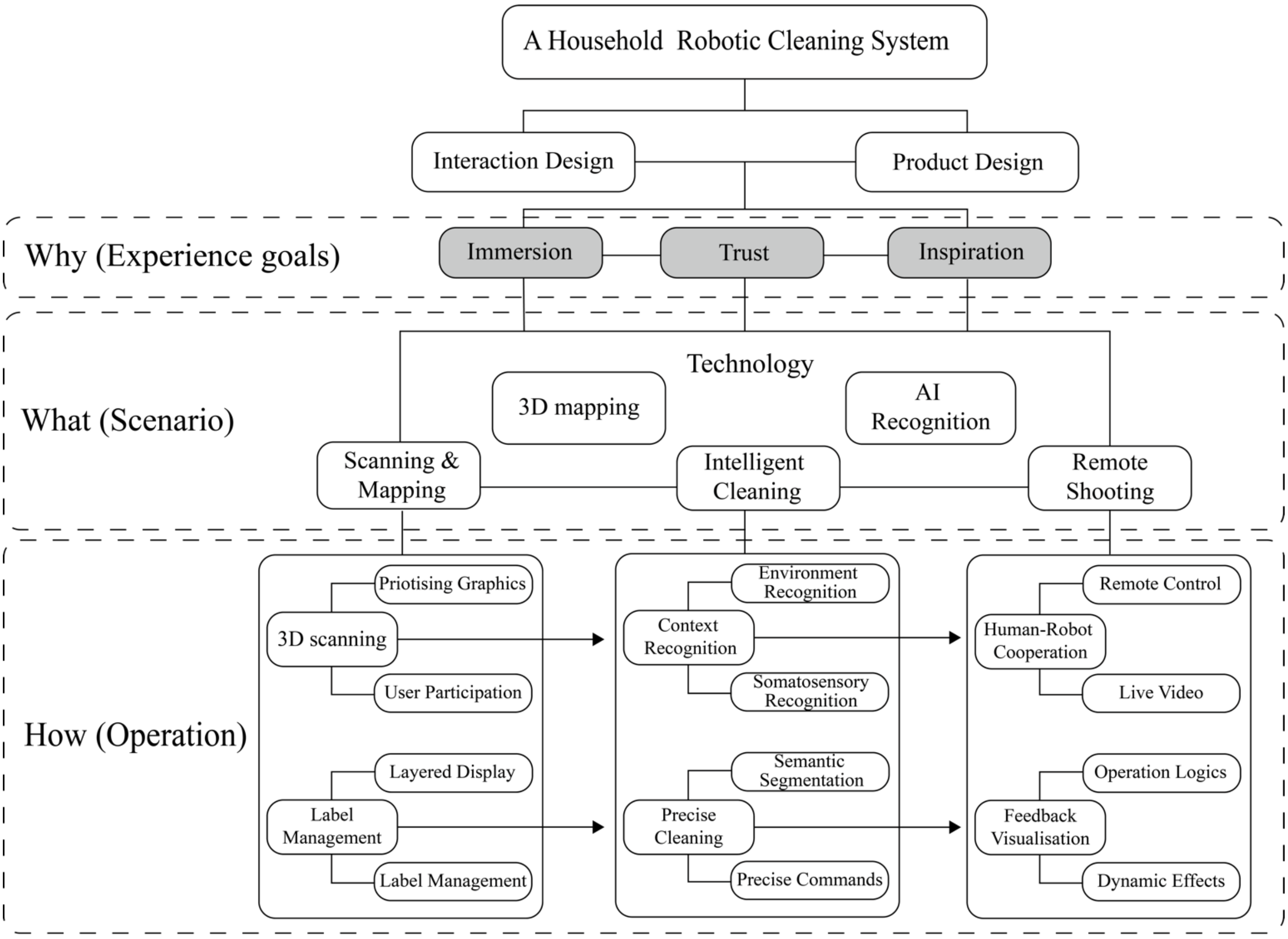

**Figure 4.** Experience design framework for a household cleaning robotic system

Combining the in-depth insights from the previous studies with Hassenzahl's experience design framework, we established a specific experience design framework for creating a household cleaning robotic system (

Figure **4**). Beyond a helpful device, we envisioned a new cleaning robot as a family member providing both instrumental and experiential value. Taking technology and key scenarios into account, we targeted three experience goals as the in-depth reason to use a cleaning robotic system: **immersion**, **trust**, and **inspiration**. 4. Experience design concept for a household cleaning robotic system

## 4.1. Immersion in scanning and mapping

Immersive experience is a technology-mediated illusion through a mimetic system that engulfs one's senses and leads to the alignment of one's attentional focus to a synthetic yet per perceptually authentic reality [44]. When scanning the home environment and mapping the target cleaning area, the robotic cleaning system can visualise working context. By switching multi views and previewing rendering effect of a cleaning area, users can be immersed in the visualisation of the targeted cleaning context.

### Multi-view switching

(i) Robotic perspective. Drawing on the ideas of the FPS (first-person shooting) game, a "first-person" robotic perspective of scanning is added. To visualise the process, we aim to enhance the stability of the picture and reduce the sense of dizziness. The lens is designed to adopt a virtual overhead fixed camera position, and the field of view of the wide-angle lens is slightly higher than that of the robot's near-ground perspective. The first-person perspective follows the pointing movement, so the "immersive viewing angle" option is provided. By selecting the reference point of the point cloud and locking the spatial position of the field of view, it can seamlessly connect with AR technology. Thus, a 360-degree panoramic view can be achieved by turning the device.

(ii) Global perspective. For the presentation of the 3D map, the top view angle higher than the viewing plane can contain more information and show the spatial relationship on a more accurate scale. The presentation of the home space and household items is also more complete. The global perspective has better operability. The multi-finger moving, zooming, and rotating operations have a smooth interactive experience and compatibility. Users can also click and long press to complete the selection of objects in the map and then realise 3D annotation and cleaning settings.

(iii) Plane perspective. Under this perspective, the map can be converted from a three-dimensional to a two-dimensional top view and return to a simple and flat display effect. The "slapping" angle of view limits the use of two-axis rotation. The advantage is that it cannot only retain some details of the scanned environment but also better support the adjustment and editing of the space.

### Rendering effect preview

(i) The combination of animation and actual scenes allows users to easily understand the scanning process when rendering. From the insights of the user research, visual rendering styles were filtered out according to utility and user acceptance. Four categories of point- line, low poly, wireframe, and actual texture map were finally selected. In the scanning process, the two modes of the point line and low poly have good vertical compatibility.

(ii) Point-line mode. The point-line mode comprises one-dimensional points and lines scattered in the three-dimensional space. The brief presentation method can better balance the speed and imaging integrity, emphasising the fast speed and dynamic. Particularly, it can follow the scanning progress and output quickly with low latency, creating a preview experience that is easy to operate. The low-fidelity effect does not affect the user's perception of its stereoscopic scanning characteristics and can respond to the preview effect of zooming and rotating on the screen as quickly as possible.

(iii) Wire frame mode. This mode strengthens the contour features of objects and the environment through lines and always ensures the strongest contrasting wireframe effect for the outer contour when rotating the 3D map, emphasising the clarity of presentation. On the one hand, it separates holistic objects from each other, which conforms to people's basic cognition of the shape of objects, and shows concise, orderly, and clear distinctive features in visual perception; on the other hand, objects with clear boundaries can have better recognition, more convenient for fixed-point cleaning and multi-step editing operations.

(iv) Net mode. The grid mode is composed of monochrome polygonal grids generated based on point clouds, which can maintain a high degree of aesthetics while retaining the spatial depth characteristics. It can outline the depth and height of the space at a faster speed and highlight the low-poly effect that blends with the scene. By fitting with the real scene image, this mode can describe the scanned area and the general environment shape. The low-surface style can create a sufficient sense of dynamism for the mapping process. As the scanning progresses and the grid gradually extends, it can convey positive "information" feedback to the user.

(v) Scene Texture. This mode can restore the actual environment to the greatest extent, including the original texture and details in the scene to the greatest extent. It can output the 3D map closest to the visual perception of the naked eye, emphasising the real and restoration. This mode creates a map by cutting and better supports high-level editing operations such as cleaning, point selection, and annotation. However, the high-reduction effect requires a longer calculation time, determining that the displayed content can only be intercepted from a static scene at a particular time. It can shape the map with a sense of order through cropping and support high-level editing operations such as cleaning, point selection, and labelling. However, the effect of a high degree of restoration requires a longer calculation time, which determines that its display content can only be intercepted from a static scene at a certain point in time.

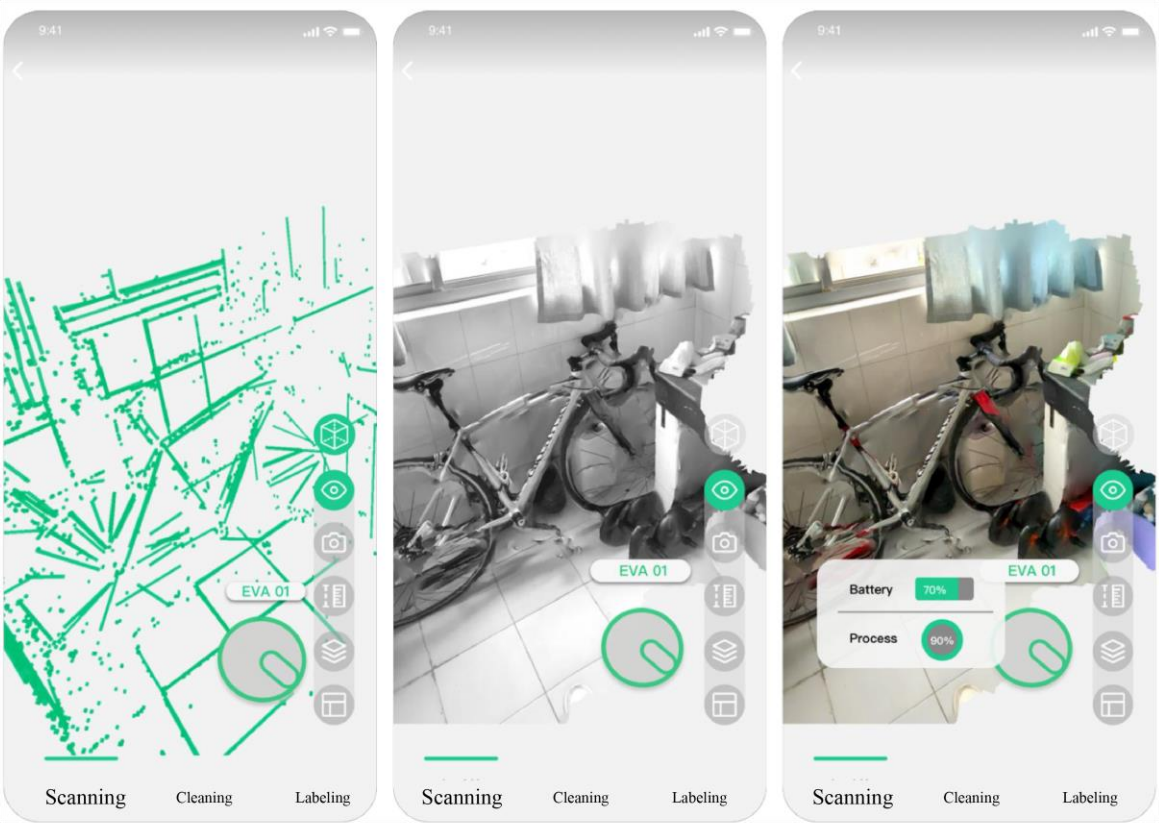

**Figure 5.** User interface for the scenarios of scanning and mapping

## 4.2. Trust in intelligent cleaning

Trust means users feel confident that the robotic cleaning system is capable of achieving users' goals. The cleaning function is centred on a trustful cleaning experience and arranged around the presentation of and interaction with 3D maps. The functions of "fixed-point cleaning" and "map management" support collaborative calls and provide a sense of accuracy. The options of visualisation maximise the truthfulness of cleaning functions.

### Fixed-point cleaning

A fixed point emphasises accurately hitting a certain point while minimising the impact on the surrounding area. It is applicable to a robotic cleaning system. When people find the location that needs to be cleaned, they often have the habit of "just scan this area". This usage scenario does not require the robot to start cleaning from the beginning but starts in a quiet state and walks in a straight line to reach the calibration area and then start cleaning. The calibration of spot cleaning requires the support of intelligent hardware.

(i) Automatic spot cleaning. The voice module or remote-control handle calls the robot, and the laser can provide accurate guidance for delineating the cleaning area. The robot arrives at the fastest speed, recognises the guidance, and cleans the marked area.

(ii) Manual fixed-point cleaning. To maximise efficiency, cleaning specific parts can be completed as quickly as possible. The handle remotely controls the robot to move forward at the position to be cleaned, and the cleaning is achieved through the repeated operation of forwarding and rotating.

**Map management**

(i) Area setting. Different home areas are automatically divided into multiple three-dimensional maps. It is convenient for independent viewing and have a better interactive experience in a relatively common three-dimensional space. At the first level, you can complete renaming, updating, and deleting operations; after clicking, you can enter to view map details and complete secondary functions such as object update, label management, and report management.

(ii) Area report. The 3D map of the area is expanded with the priority logic of the global perspective, and the quadrilateral cutting is carried out to consider the integrity and detailed performance of the environmental information. The area cleaning report uses the form of a card with a pop-up window. The report includes information such as cleaning time, dust volume, terrain complexity, etc., presented in the form of a bar chart or a pie chart. Click on the corresponding data, and the effect of a heat map or a colour mask visually identifies the map. Add a function bar to customise the cleaning mode of the current area and make detailed adjustments on a deeper level on whether to clean, change the suction size, and adjust the cleaning time.

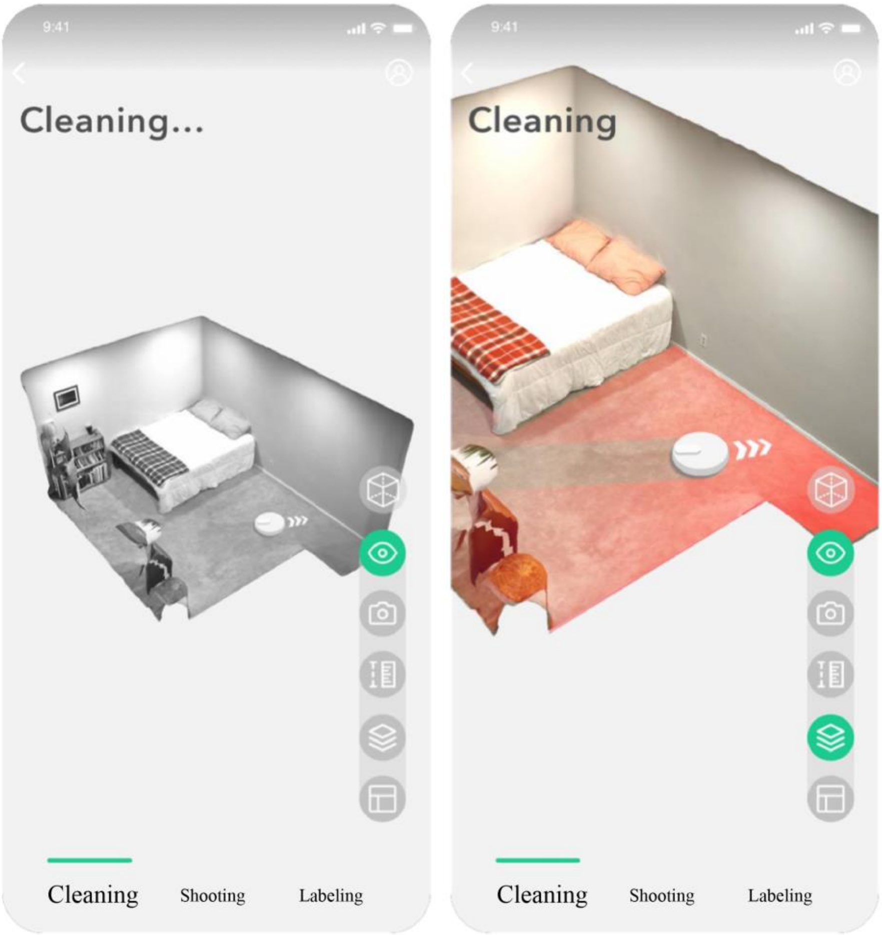

**Figure 6.** User interface for the scenarios of intelligent cleaning

## 4.3. Inspiration in the remote shooting

Inspiration is feeling a sudden and overwhelming urge to express creatively, or to engage in new thoughts or actions to actualize new insights [45]. The shooting function provides multiple access ports, enabling seamless switching from live images to other functions. In shooting mode, the camera can be called to complete complex scenes and angles for a creative shooting experience. The robotic system can invoke the lift camera, activate the live image function, support better shooting quality, and thereby evoke inspiration experience of control.

### Lens control

(i) Lifting. Using electric lifting hardware, the camera module is in the storage state when it is in cleaning mode, reducing the height to ensure the robot's accessibility. When entering the shooting mode, the robot turns on the camera assembly after confirming that there is no obstacle above, and the camera rises to the working height. It automatically retracts after scanning and returns to the charging base; it turns off after exiting shooting mode.

(ii) Rotating. The lens can do tilt， left and right rotation.

(iii) Following. The robotic cleaning system can frame selection to follow the object, make the lens follow the rotation, perform full tracking, time-lapse photography and perform other functions.

### Remote control mode

Connect the remote-control handle to the mobile phone, enter the shooting mode interface, start the remote-control mode, and the interface cuts into the central perspective of the robot. The function keys of the remote control include the robot start/return key, the direction control key, the camera start/close key, and the direction control key.

### Shooting mode

The robotic system adopts control logic like drones. Through the screening of the standard functions of the camera, combined with the product positioning of the cleaning robot, three options of photography, video, and time-lapse photography, are set. The interactive experience from the monitoring perspective is defined in detail from the following aspects.

(i) Full-screen monitoring. The global field of view and angle can be used to monitor the robot's operation by simulating 3D animation. The larger display area and the top-down viewing angle of the high-level camera create an immersive monitoring experience. In terms of interactive actions, it supports zooming and rotating the map, and users can cut into different perspectives through the side toolbar to preview different rendering effects.

(ii) View the Data board. The data card is called up by clicking on the cleaning function bar, and the displayed content includes the system running data, including power, running time, remaining time, etc. Displays cleaning mileage, cleaning area, remaining progress, and more.

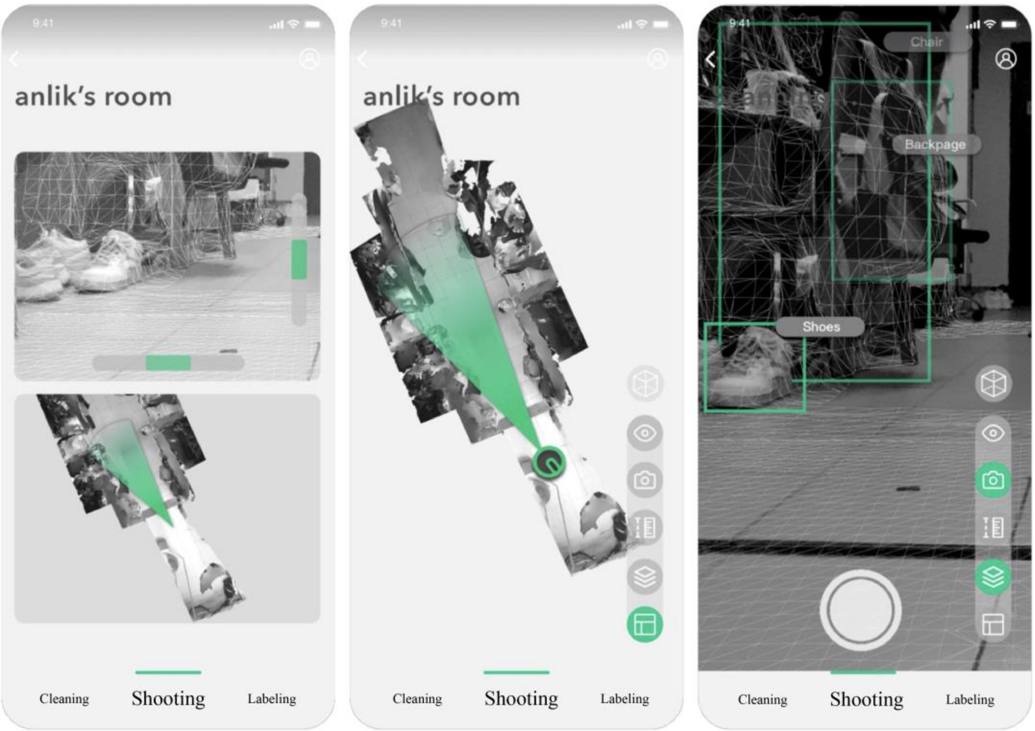

**Figure 7.** User interface for the scenarios of remote control

# 5. Concept evaluation

In this project, we evaluated the user experience design of the robotic cleaning system in two steps: first, presenting the storyboard, video, and product concept description to the online participants; second, inviting the online participants to complete a questionnaire based on the AttrakDiff questionnaire.

AttrakDiff is a standardised seven-point Likert scale test to judge an interactive system's hedonic and pragmatic qualities. This questionnaire is made up of 28 items, distributed in 4 dimensions: pragmatic quality (PQ), hedonic-stimulation quality (HQ-S), hedonic-identification quality (HQ-I) and overall attractiveness (ATT) [46].

## 5.1. Questionnaire structure

The questionnaire consists of three parts. The first part is about basic information about participants and house cleaning, such as how often to clean a house. The second part introduces the concept of a newly designed cleaning robotic system. It highlights three scenarios in the format of storyboard and video: scanning and mapping, intelligent cleaning, and live shooting. To test both pragmatic and hedonic aspects of the experience design of the robotic cleaning system, the third part is the AttrakDiff question list.

## 5.2. Participants

71 participants were enrolled on the internet. The age range is from 20 to 60 years old, and approximately 90% of the participants are between 20 and 30. Among the participants, there are 32 males and 39 females. The frequency of house cleaning varies from none (cleaned by other families, 19.7%), once a week (28.2%), two or three times per week (38%), to once per day (14.1%). 81.7% of the participants chose traditional brooms and mops as the cleaning tools, 39.4% chose vacuum cleaners, 25.4% chose sweep robots, and 4.2% chose other tools.

## 5.3. Results

For the overall concept, the means of PQ, HQ-I, HQ-S and ATT are 0.68, 1.96, 2.04 and 1.50 out of the range of -3 to +3 (Figure 8). It indicates that the four aspects of the experience design are all positive, among which the hedonic quality is perceived much better than the pragmatic quality and attractiveness. The confidence of PQ and HQ are 0.91 and 0.93, which means the investigation results are reliable.

The lowest pair is “complicated-simple” (-0.5), whereas the highest is “tacky-stylish” (2.75) and followed by “unimaginative-creative” (2.5) and “conscious-bold” (2.5) (Figure 9). It indicates that the weakest point of the experience design concept is to be perceived as complicated, and the strongest is to be felt as creative and bold.

Aligning the experience design goals immersion, trust and inspiration with the items “dull-captivating” (2.25), “unpredictable-predictable” (0.75) and “unimaginative-creative” (2.5), respectively, it turns out that the design fulfils these goals.

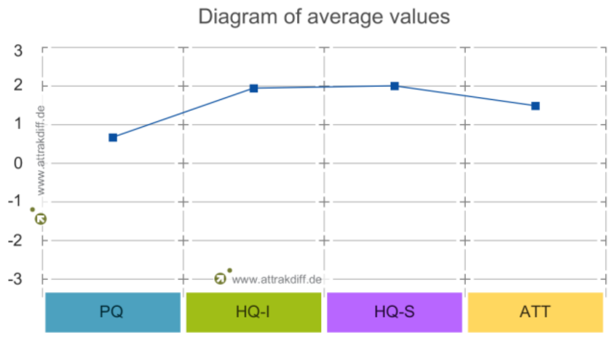

**Figure 8.** The means of PQ, HQ-I, HQ-S and ATT

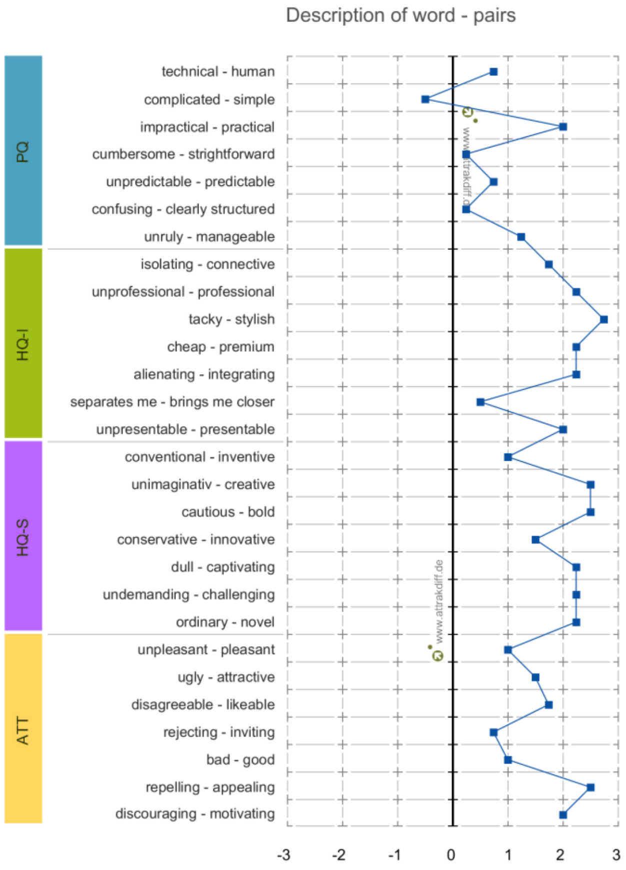

**Figure 9.** The mean of each word pair

## 6. Conclusion

The novelty of this work lies in introducing the scenario-based design method into the technology-mediated experience design of a household cleaning robotic system. The new integrated design changes the traditional role of a household cleaning robot from an automatic appliance towards a playful companion engaging families in happy housework. To cope with the complexity and particularity of home environment, this research did not only focus on the new functional opportunities driven by technology. Rather, we adopted human-oriented design mindset and interwove technology trend analysis with in-depth user experience insights. It turns out that starting with experience thinking expands the design opportunity space because of meaning change of design target leads to new scenarios. Imagining a cleaning robot to be designed as a steward, we can bring new design opportunities, for example, a cleaning robot taking care of air quality in each corner of home.

Theoretically, we proposed a scenario-based experience design framework for a household cleaning system. It consists of experience goals, scenarios, and technology. The framework guided the systematic design of equipment control, interaction style, mode expansion, and visual presentation.

Taking advantage of 3D point cloud mapping and AI recognition technology, the resulted experience design revolves around the three interactive scenarios of "scanning and mapping", "intelligent cleaning" and "live shooting". For experience goal setting, we prioritised the hedonic aspects over the pragmatic aspects. The experience goal of immersion is beyond the usability goal of efficiency, trust beyond precision, and inspiration beyond satisfaction. Specifically, the feature of 3D scanning and label management is designed for immersive experience in the scenario of scanning and mapping. The feature of context recognition and precise cleaning is designed for trust in the scenario of intelligent cleaning. The feature of human-robot cooperation and feedback visualization is designed for the inspiration in the scenario of remote shooting.

From a design research methodological perspective, we conducted progressive research from technology, users, scenarios, information architecture to visualization in a step-by-step and cyclic process from rationality to sensibility. We presented a “research for design” paradigm and outlined the development of a new smart home cleaning system. The limitation of this research lies in the online user experience evaluation of design prototyping that can hardly provide real-in-life experience of using a product. Although at the early stage of new product service system development, using design prototype to elicit the user's imagination of experience is rather economic and effective, whereas product evaluation in the field can bring more in-depth insights into observation on how users interact with a robot.

In the near future, more household cleaning scenarios can be built based on more accurate 3D maps and wider scene recognition. By integrating an interactive system and a robot work linkage mechanism, the coordinated scheduling of multiple types of services for home robots can be completed with strong analysis capabilities, fast mapping capabilities, and refined cleaning capabilities. Relying on multi-dimensional media and data, intelligent robots can achieve indoor precise movement, intelligent cleaning, collaborative work, object tracking, safe cruise and other functions. Combined with the three-dimensional game engine, it can also create more education and entertainment applications in the field of augmented reality. Scenario-based robotic interactive system research can bring more positive emotional experiences into smart home design, and ultimately create rich life experiences for users.

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