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DeclutterAR: Mobile Diminished Reality and Augmented Reality to Address Hoarding by Motivating Decluttering and Selling on Online Marketplace

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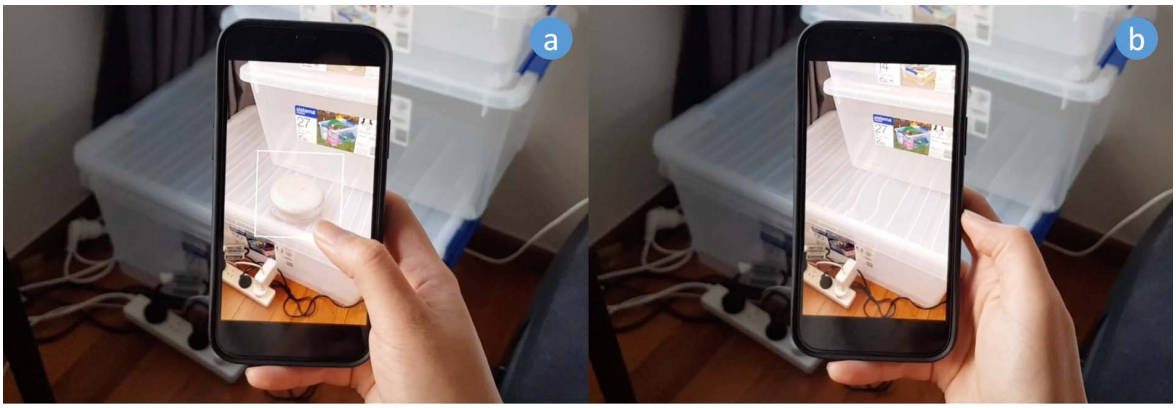

Figure 1: Key functions in the DeclutterAR: a. select the object for removal; and b. visualise the removal of clutter.

Abstract

Hoarding behaviour is a widespread issue in which people have difficulty discarding or parting with their possessions. We present our work to address hoarding behaviours in people and promote the selling or donating of items that they no longer use or value through an online marketplace application (app). We introduce DeclutterAR, a feature linked to the marketplace app that uses Diminished Reality to remove real-world objects in the Augmented Reality (AR) scene, allowing you to visualise your "cluttered spaces" as "decluttered spaces". DeclutterAR also allows users to sort removed objects to sell or give away. This work describes the system implementation and preliminary user study and discusses concepts of using Diminished Reality to motivate and support users in visualising target behaviours.

Index Terms: Human-centered computing—Human-Computer Interaction (HCI)—Interaction paradigms—Mixed / augmented reality; Computing methodologies—Computer graphics—Image manipulation—Image processing

1 Introduction

Hoarding behaviour is a widespread issue referred to as the "persistent difficulty discarding or parting with possessions" [6]. More persistent and severe hoarding behaviours are often categorized as a hoarding disorder and may affect 2–5% of the population [24]. Severe hoarding can have negative physical, mental, and lifestyle effects [24]. Hoarding symptoms are also associated with various mental illnesses and mental health issues such as anxiety and depression [39].

Existing popular methods for tidying or "decluttering" include the KonMari Method[1] that encourages people to only keep items that spark joy in their lives [20] and the DanShaRi[2] method to "deny, dispose and detach" from unnecessary items. These methods require motivation for people to begin and keep applying to their lives and have yet to be empirically proven methods for addressing hoarding. Previous systems designed to address hoarding involved the automated listing of items to online marketplaces [1] or game-based behaviour change apps [29]. The opportunity remains to combine assisted listing of items with behaviour change techniques to motivate people to declutter their spaces.

Our work aims to address hoarding behaviours in people and, concurrently, encourage them to sell or give items they no longer use or value through a system connected to an online customer-to-customer (C2C) marketplace app. We developed the system, DeclutterAR, that removes real-world clutter in the AR scene in real-time through Diminished Reality (DR) [23, 25]; allowing you to visualise your "cluttered space" as a "decluttered space." Then, the real-world items are added virtually into a listing in the user's marketplace store. While existing DR systems to remove real-world objects are often used as a supplementary feature together with adding virtual AR objects into the scene (e.g., in AR interior design apps [33]), we expand the design space for using DR as a primary interaction function. We discuss the limitations, future works and planned studies from this concept.

2 Related Work

This work was inspired by and built upon previous systems for addressing hoarding behaviours and Diminished Reality.

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[1] https://konmari.com/what-is-konmari-method/
[2] http://yamashitahideko.com/profile/

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2.1 Systems to Address Hoarding

An example system that helps users to address hoarding is Rapoptosis. It consists of smart hangars that list your clothes for sale online if you have not worn them for a long time [1]. Another system is Zephyr which uses cognitive behaviour change interventions to treat hoarding [29]. In Zephyr, the user undergoes image attentional training by locating the image of a tidy space out of 9 images, 8 of which showed cluttered spaces. The user was also prompted to take pictures of their spaces and rate how cluttered they were. It provides congratulatory feedback if clutter has reduced or motivational feedback if it has increased. These systems have yet to be evaluated for addressing hoarding.

Mental imagery or visualisation of one's goals, target behaviour and activities can also motivate changes in behaviour [5], increase motivation [30], and promote activity completion [2]. Mental visualisation exercises to imagine one's cluttered room without the clutter could treat hoarding [26, 35]. AR, Mixed Reality (MR) and Virtual Reality (VR) systems have been used to help users *virtually* visualise target outcomes and influence behaviours (e.g., eating behaviours [37]). Users of VR exposure therapy systems, which enable the sorting and throwing away of hoarded items in virtual environments, diminished the level of clutter in their real-world spaces after the therapy [27, 34]. Immersion and exploration of VR renderings of users' decluttered rooms for 10 minutes enhanced motivation for change in hoarding behaviours [3]. Our work was inspired by these visualisation techniques for influencing hoarding behaviour change.

Unlike these VR systems for treating hoarding through simulated environments, we present an AR/MR/DR system for virtually visualising decluttered spaces in real-world environments. While the concept of allowing users to interactively remove clutter in the real world was explored through the Augmented Reality World Editor [9], the World Editor was not specifically designed to address hoarding behaviours. Our system introduces an additional yet potentially crucial step in hoarding intervention: allowing users to sort their hoarded items and assisting them in listing the items on online marketplaces to facilitate decluttering actions (selling or donating items).

2.2 Diminished Reality

Diminished Reality is a set of techniques for concealing, eliminating, and seeing through real-world objects in a perceived environment to "diminish" the reality in real-time [25]. DR differs from AR/MR techniques that overlay virtual objects on the real-world [25]. It is often used together with AR/MR to improve the illusion of realism by first removing objects in real-world scenes and then adding a virtual object over the same area. For example, in AR marker hiding [18], the markers are removed before overlaying it with the virtual object. In interior design, any existing furniture is removed through DR and replaced by virtual furniture [33]. TransforMR system enables object substitution for composing alternate mixed realities by using DR to remove existing moving objects like cars and replace them with virtual objects [15].

In applications where DR is a primary feature of the interaction, DR can support users in visualising hidden backgrounds. This could be through work area visualisation where the DR system allows users to see through the worker's hand and tool (e.g., drill or pen) to view the hidden work area (e.g., [22]). A similar concept was used for blind spot visualisation for cars and pedestrians [28]. DR can also enable the removal of unwanted or unsightly items in AR views [9] and distracting items in workspaces [4], support the filmmaking pre-visualisation process [21], change the weight perception of an object [10], and improve learning effect in anatomy education [13]. Our work expands the applications of DR to visualise and motivate clutter removal as a primary interaction feature.

Many DR techniques use pre-observation of hidden backgrounds or multi-view cameras to provide the illusion of object removal [25]. However, for hoarding scenarios, we have to assume that the hidden backgrounds cannot be observed (i.e. the system will not have previous images of decluttered environments). Inpainting methods should be used to generate plausible background images based on the surroundings and overlay them over the unwanted object [25]. DR also needs real-time video inpainting, whereas image inpainting refers only to removing objects in static images [16]. Deep learning inpainting methods are usually computationally intensive (e.g., [36]) and require cloud server-run models to work in real-time on mobile devices [15]. More computationally efficient approaches that are accessible to mobile devices include applying the Pix2pix generation model to remove visual clutter in real-time, as shown in World Editor [9]. However, it only supported wooden textures and the removal of small items (whereas our method aims to work with the inpainting of arbitrary backgrounds). Real-time video inpainting algorithms can be even more efficient and dynamic. Previous work by Siltanen [32] presented an approach to generating inpainted textures based on neighbourhood pixels of the unwanted object. The PixMix approach [11, 12] applied a patch-based search algorithm that fills in the region of interest on a plane with image patches of the surroundings. A modified PixMix approach can be implemented on mobile devices [31]. For more realistic renderings but at the cost of more computation, scenes can be segmented into multiple planes using a point cloud reconstructed with visual-SLAM and image inpainting is executed on each plane [17]. In our work, we built upon the PixMix approach due to its balance in delivering relatively high-quality and computational efficient DR in real-time on mobile devices.

3 System Implementation

DeclutterAR was implemented on a mobile device as a smartphone app. It supports cross-platform deployment. In this section, we describe the interaction flow, software, and hardware implementation.

3.1 Interaction Flow

There are four main aspects of the user interaction flow as described below. The app screens related to these aspects are illustrated in Figure 2.

3.1.1 Prompting

DeclutterAR can be set to issue periodic (e.g., daily or weekly) notification prompts to the user that it is time to declutter their cluttered spaces ("Declutter Time!" in Figure 2a). The user can decide to approach the cluttered space and start decluttering. The AR view opens when the user opens the app or responds to the prompt. Users can then point their device camera at the space.

3.1.2 Item Selection

Users can adjust the selection box to select the item(s) to remove by dragging the box corner to resize it and dragging the box to move it (Figure 1a). Once the items are correctly selected, the user confirms this by tapping on the "Declutter" button (Figure 2b).

3.1.3 Visualisation

The DR and inpainting algorithms will run in the background to remove the item within the selection box. Users will see that the item is removed on the app's AR view and the space appears decluttered (Figure 1b). The user can tap on the online marketplace icon at the bottom of the screen to start sorting and listing the item (Figure 2c).

3.1.4 Sorting and Listing

Lastly, the user can sort the item to sell or give through a two-option slider and indicate the listing price in a text input field (Figure 2d). DeclutterAR creates a listing on the linked online marketplace for either case (Figure 2e).

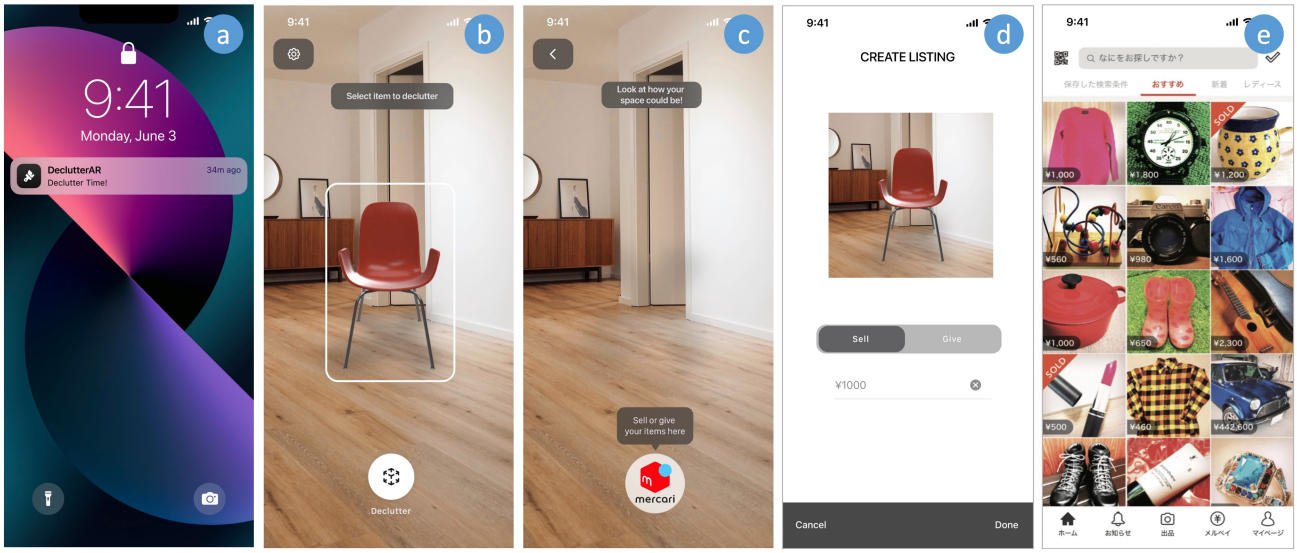

Figure 2: DeclutterAR screens (left to right): a. Notification Prompt, b. Item Selection, c. Visualisation, d. Sorting and Listing, e. Mercari online marketplace.

3.2 Software and Hardware

We used Unity[3] and AR Foundation to build DeclutterAR. When the app starts, it shows the AR camera view and scans the real-world environment with plane and feature point detection. When the user confirms the item selection in the selection box, a contour detection and tracking algorithm is called for the selected area to isolate the main item to be inpainted. An inpainting algorithm begins on the contour area and constantly updates the inpainting result to the AR view. The PixMix inpainting approach [11, 12] and contour detection/tracking were implemented in C++ and OpenCV[4] as a Unity plugin. We modified previous open-access variants of the PixMix implementation[5] [14, 31]. The system takes the initial image from the selection box as the image for listing the item. Once the item is sorted to either sell or give away, the app links to the Mercari online marketplace app[6] and creates a listing. The system can be potentially linked with other online marketplaces.

Our app was implemented on an iPhone 12 (software version 15) with RGB camera. It was developed and tested on a Macbook Pro 2016 (macOS version 12.4). Since it was built through Unity (version 2019.2), it can be cross-deployed to other operating systems (e.g., Android and Windows).

4 Evaluation Protocol

We conducted a preliminary user study to understand users' initial reactions and feedback on DeclutterAR.

4.1 Performance

We measured the system's performance for inpainting and tracking, running on an iPhone 12. It used a video resolution of 720 x 960 pixels (portrait mode). The average time of inpainting was 146ms, with the average ratio of inpainted pixels to entire frame pixels of 15.8%. It reaches about 18 to 26 frames-per-second (fps) for the inpainting and tracking results.

[3] https://unity.com/
[4] https://opencv.org/
[5] https://github.com/Mugichoko445/DRMarkerHiding and https://github.com/tydahlwave/Thesis
[6] https://jp.mercari.com/

4.2 Qualitative Feedback

Three users (avg. age = 43, two female and one male) tested DeclutterAR and the four main aspects (described above) with guidance from a researcher. The researcher conducted semi-structured interviews with each user individually with the questions: "How do you feel after using our application?", "Do you face the problem of hoarding? If so, give an example and details of your cluttered space.", "Do you see yourself using an online marketplace? Selling or donating?" and "What do you think visualising aspect?".

Our qualitative analysis showed users were new to the concept of using visualising to promote decluttering (P1, P2, P3) and thought that it was 'innovative' (P2). Users also felt that the system could be useful to them in motivating themselves to declutter (P1, P2, P3). P2 was intrigued by the sorting and listing function, commenting that it is "...like you are caching the item [...] putting it into virtual space and then adding it to your selling lists [...] I don't think I have seen this before." P1 mentioned that she would usually try to sell unwanted hoarded items on the Facebook marketplace and would consider selling on the marketplace linked to DeclutterAR. P2 and P3 remarked that usually, these hoarded items are hard to sell, and they would often try to give them away to friends or family first. If not, donate the items to charity. All users showed hoarding behaviour to some degree, with cluttered spaces in corridors (P1, P2), bedrooms (P1, P3) and the living room (P3).

Overall, this user feedback provided a brief insight into the positive potential of DeclutterAR, the users' experiences and current needs.

4.3 Planned User Studies

We intend to evaluate the usability of DeclutterAR and how it could help address hoarding behaviours. From the findings of the preliminary study and previous literature on hoarding behaviours and behaviour change, we designed a two-phase experimental approach that answers a research question in each phase:

Phase 1 – *"What are the cluttered spaces like and who might be the main users of this intervention?"* In the first phase, we aim to better understand the potential users that might benefit from our application. We plan to recruit at least 30 participants and have an online survey in which we ask them to take and upload pictures of their space. In particular, we want to know more about the most

commonly hoarded objects and places in users' dwellings. Furthermore, we would like users to self-report their space on the Clutter Image Rating scale [7] (9-point scale, with each point is represented by an image, 1: very tidy and 9: very cluttered). At the same time, we want to ask users' opinions on whether a third-party intervention to promote decluttering would be useful and whether they would like to participate in a longer-term decluttering intervention study with our application.

Phase 2 – *"In-the-wild" study*. *"How does DeclutterAR affect motivation to declutter and hoarding behaviour?"* In the second phase, we plan to track users' weekly behavioural changes and user experience. We follow guidelines and study methods from previous behaviour change technologies studies in human-computer interactions [19, 29]. We will establish two groups: 1) an active control group that would attempt to declutter their space and sell or give away items online without our application, and 2) a DeclutterAR group that would complete a similar decluttering process using our system. We expect to have at least 20 participants in each group, with the length of the initial study being 4 weeks and a post-study evaluation at 1 week and 8 weeks periods after the initial study. We aim to recruit and screen participants for light cases of hoarding (clutter image rating between 1 to 3) with no prior history of neurological conditions. Clutter image ratings of 4 or more are recommended as clinically significant cases of hoarding [38].

During this phase, we will log the DeclutterAR application usage, including such metrics as interaction time and the added items and places. Users will also be offered a weekly behaviour change questionnaire (during first 4 weeks, and then 1 week and 10 weeks after the study). The questionnaire includes Clutter Image Rating [7], Self-Report Behavioural Automaticity Index (SRBAI) questionnaire [8], and several 5-point Likert scale items as "This system has made me more aware of my cluttered space." and "I feel more motivated to declutter my space."

In parallel with the weekly behaviour change questionnaire, we also plan to ask users a weekly experience questionnaire with such open comment questions as: "How was your behaviour change experience?", "Did the system help or hinder you? How/why?", and "Is there anything else you would like to add?"

Semi-structured interviews. At the conclusion of Phase 2 (4-week period), we plan to collect users' opinions on our system and self-reported opinions and changes in their behaviours. We will have a series of interviews with participants. We plan to ask them the following open comment questions: "How do you feel after using our application?", "Did your behaviour change? What has changed?", "Did you sell items that you usually would not?", "How did our project affect your motivation to declutter?" and "How much clutter did you manage to clear in real life?" (similar to the VR exposure therapy study in [34]. As a result of the evaluation, we expect to have an understanding of the potential impact of our method on users' behavioural changes towards decluttering.

5 Limitations

As of now, our proposed solution only supports mildly cluttered spaces (Clutter Image Rating between 1 to 3), and we plan to target only users with light cases of hoarding in our user study. Although we believe that our approach can potentially be applied in more serious cases of hoarding, the complexity and contextual appropriateness of a DR inpainting approach present certain challenges. For instance, in severe cases of hoarding, a participant's living space may be completely obscured by hoarded items (e.g., complex background with multiple different items), making the generation of replacement texture complicated or the method itself inappropriate (e.g., removing one object might not alleviate the hoarding problem). Furthermore, it is unclear whether severe hoarding might appear due to another mental health condition, addressing which could provide better results for users. Perhaps the best application of our approach in such a case would be using our system in conjunction with conventional medical practices or whenever a participant's hoarding condition is reduced to a lower scale.

6 Conclusion and Future Work

Hoarding is a common issue that affects individuals with different physical, mental, and lifestyle conditions. We present a system that applies Diminished Reality and behavioural training to help users declutter their spaces with potential subsequent sales or giveaways of unneeded items. We believe that our system has the potential to resolve light to moderate cases of hoarding and more severe cases if applied in combination with other medical practices. We hope that our work will bring attention to the applications of Augmented and Diminished Reality interactions for mental health, as well as highlight the potential connections between immersive media, behavioural training, and internet-of-things for quality of life improvements. We aim to explore how our application could be further improved through collaborative and social interactions by helping users collectively clean and declutter their spaces through real-time co-present and telepresence experiences.

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