Robot Vacuum Redesign

Broad Accessibility Through Lifecycle Analysis and Improvement

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Author Note:

Scott Church is a human factors designer and analyst. This report constitutes a capstone project for human-computer interaction and represents a portion of his portfolio.

Abstract

The intent of this report is to build on current designs to create a robot vacuum that impresses users from the start and accommodates the widest range of users possible throughout its life cycle. It examines user reactions and beliefs about current technology to highlight design issues. New requirements are defined, redesign elements are tested, and a final design is described. The testing process for the final design is explained. Throughout, good design elements and future possibilities are noted. The information contained in this report could benefit both existing robot vacuum companies and those trying to break into the robotic home assistance market.

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Introduction

There are a plethora of robot helpers on the market today as part of the rise of the smart home. While some companies like Roomba were created especially to design and build robot vacuums, established electronics companies such as Samsung are now entering the multi-billion dollar market and competing with less known home-tech brands such as XiaoMi. At least 20 different companies are fielding their versions of the technologies that will likely perform many domestic functions in our domiciles in the coming years (Sung, Grinter, Christensen, & Guo, 2008). While future robots will perform the full range of human domestic activity such as dusting fans, folding laundry, and possibly even performing repairs, the current generation of robot helpers are mostly ground-based vacuums, with a few floor mops coming to market in the past year.

For proper functioning, people have to interact with these helpers in various ways. The initial setup, the "training" of both the human and the robot, the scheduling or manual activation, the use of a smartphone app, the foot sucking avoidance, and the maintenance are just a few examples. There are as many approaches to designing these functions as there are companies creating the devices, and not all are created equal. The field is ripe for the creation of best-practices principles and gleaning of lessons from current systems.

No matter the design, all robot vacuums have a life cycle. Defining the stages is useful for finding areas to improve. First, a user might research vacuums, weighing cost and features. Once acquired, by purchase or gift, a user will unbox the vacuum. The initial setup follows unboxing. Each user will then have their first use experience during which they will start to learn

about the robot, how to use it, and how well it will work. The user might configure advanced functions during their first use and download an app. Continued operation for all users will entail maintaining the robot. Eventually, the user will discard the vacuum at the end of its useful life, and possibly upgrade to another version. A robot vacuum that is difficult to use from the start and inconvenient to maintain will earn poor reviews and likely be returned.

Research

After familiarizing myself with general robot vacuum designs and testing several myself, I conducted informal interviews with friends and family who had used the devices. My convenience sample was limited to the eight robot vacuum owners I could meet in person and observe interactions in their homes. I asked questions about various stages in the robot vacuum lifecycle:

1. Why did you buy this one?
2. What was it like when you set it up?
3. How do you control it?
4. Does it have an app to help control it? If yes, how does it work?
5. How often do you have to perform maintenance?
6. What do you like most about it?
7. What problems do you have with it?

After the conversations, I wrote notes about anything that stood out. I summed up general answers and themes:

1. People were happy with overall cleaning performance, but they did not know how the robot navigated. Some versions often got lost or stuck.
2. The setup process was not memorable.

3. Most used a version of power/start/stop to operate the vacuum, but only a few knew about the functions of other buttons.
4. Users had mixed feelings about using associated apps. Some had integrated their devices with smart home controls, whereas others knew there was an app but never set it up on their device. Some people were unaware that they could use apps at all.
5. Users had to empty dustbins and clean brush rolls often to maintain operation, but two had devices with brush rolls that were advertised as self-cleaning and one self-deposited its debris in a special trash can.
6. Users praised their vacuums for saving them time and reducing their housework load.
7. The biggest complaints were about losing the vacuum when it got stuck somewhere, having to frequently empty the dustbin, and cleaning the brush roll, including those that were advertised as self-cleaning.

In addition to these formal interviews, I read through 100 reviews of robot vacuums on Amazon by viewing the first page of comments for ten vacuums. I selected the five highest rated and the five lowest rated by stars. I tallied positive and negative remarks for the seven themes to visualize positive and negative aspects for each in Table 1.

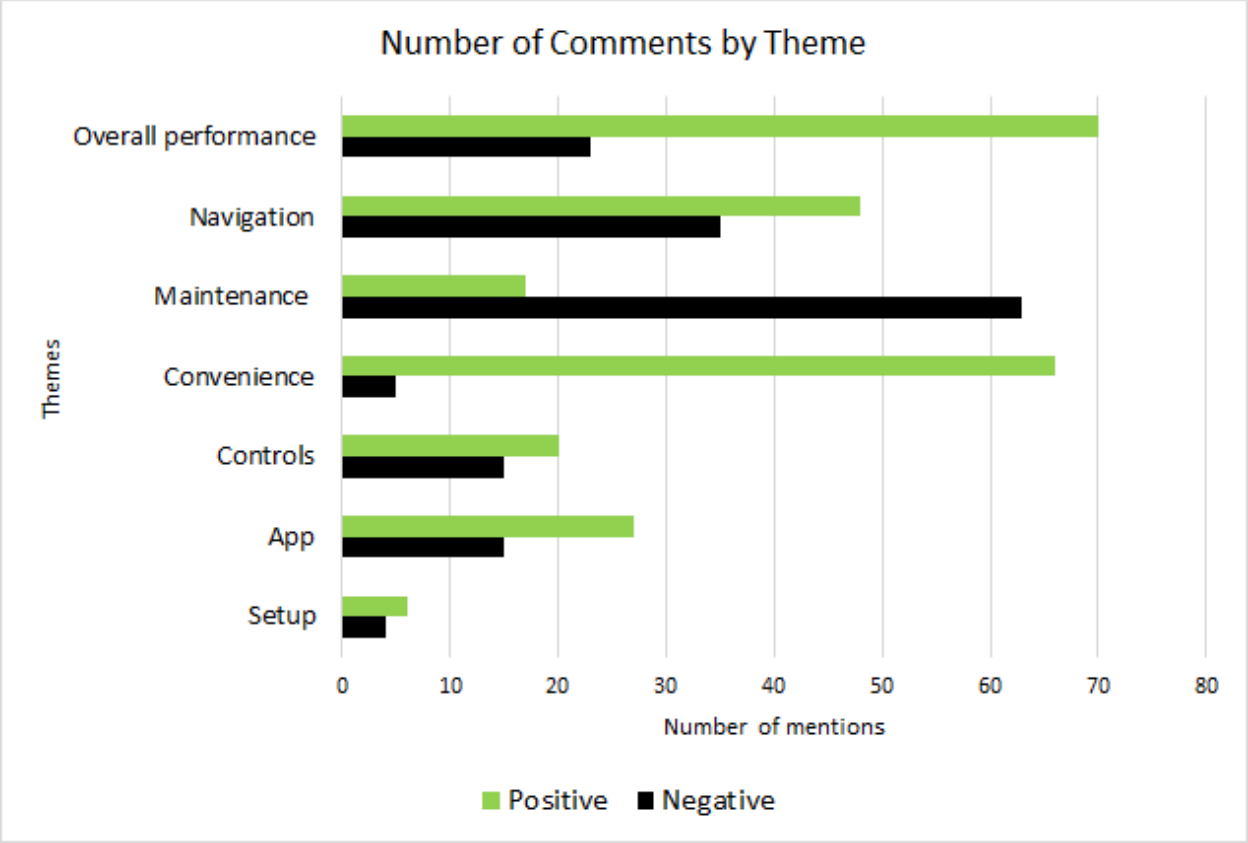

Table 1. Number of reviews mentioning recurrent themes for robot vacuums.

Requirements

I began writing requirements to address the biggest issues users reported with their devices that could be solved by a redesign of the vacuum itself. Analyzing the ratio of good-bad reviews helped guide the process. Maintenance was the biggest problem, and the controls had the second highest bad-good ratio. Redesigning the app would also be useful, but as the project evolved, it took on an entirely new character. I decided not to focus on the app because I wanted the vacuum to be accessible to all users, although I note some great app features along the way. As I asked about maintenance and controls, I showed controls to users that did things they did not realize were possible. Many owners did not know what they were missing, and so the initial setup and introduction became a big focus. Designers must not only listen to what users are

saying about a product, they must also listen for what the customers are not saying. If first impressions last forever, a successful design must create a positive first interaction.

To develop the requirements that would fix the problems I identified, I considered stakeholders. The primary robot vacuum stakeholders are users, marketing professionals, user experience/user interface (UX/UI) designers, and the robotic engineers. Users have the biggest stake in the requirements because, without user/customer satisfaction, the devices will not sell. The marketing professionals need to make sure that the specifications and functions being used used to advertise the product actually match its abilities. The UI/UX designers are responsible for much of the early interaction and must ensure easy access to the features users are buying so that enjoy their purchases. Engineers have to create functional products that perform as advertised and accommodate maintenance considerations. Here are the requirements, listed in order of user complaint magnitude.

1. Maintenance on the robot vacuum must be easily performed by any user and without a need for tools. [critical to users, engineers]
    a. Emptying the dustbin must require minimal effort. [critical to users, engineers]
    b. Cleaning the rollers must be efficient. [critical to users, engineers]
    c. The device must inform users what errors it has encountered and what maintenance it needs to continue operation. [critical to users, UI/UX designers, engineers].
2. Controls need to be comprehensible to inexperienced users. [critical to users, UI/UX designers]

   a. The vacuum needs to have physical controls that are clearly mapped to functions. [critical to user, UI/UX designers, engineers].
      i. Remotes for vacuums must enhance the user's ability to control the vacuum. [critical to user, UI/UX designers, engineers]
   b. Advanced function controls must be instructive. [critical to users, UI/UX designers]
      i. The robot vacuum must have a dedicated app. [critical to users, UI/UX designers]
      ii. The robot vacuum must seamlessly integrate with common smart home controllers, including Alexa, Siri, and Google Home. [critical to users]
3. The setup process needs to be simple enough for any user to get started without reading. [critical to user]
   a. The robot must be able to communicate how to place, configure, and use it. [user and UI/UX designers]
      i. The vacuum must communicate through a variety of mediums using voice, text, and apps. [critical to users, UI/UX designers]
   b. Scheduling regular cleaning must be efficient and flexible. [critical to users, UI/UX designers, engineers]
   c. Setting no-go zones must be intuitive for the user and prompted by the vacuum itself. [critical to users, UI/UX designers, engineers]
   d. The setup process needs to provide the user with clear expectations. [user, marketing personnel, engineers]

Redesign

Throughout the redesign, I asked for user input and created many iterations of designs for the maintenance, control, and setup interaction phases.

Maintenance: Redesign

Interestingly, vacuums with negative comments about maintenance were still highly rated overall. Yet, maintenance is clearly the area that needs the most improvement. An improved dustbin system to meet Requirement 1.a is a top priority for the new design. Maximizing dustbin size is more of an engineering issue, but human factors issues must be integrated with these larger dustbins. A brief task analysis of a user emptying a dustbin is straight forward. 1. Realize it needs to be done. 2. Open vacuum. 3. Release dustbin from vacuum port. 4. Carry to trash can. 5. Open cleanout. 6. Ensure all debris is out of the bin. 7. Reinstall the dustbin. Interacting with different models revealed that the orientation and certain aspects of the dustbin affect the ease of the overall process. Some vacuums have bins that slide into the back of the vacuum, and others have bins that sit on the top (Figure 1, 2)

Figure 1. Rear mounted bin in Shark Ion

Figure 2. Top mounted bin in Samsung R7065

Preparing for my redesign, I showed users both versions, and they preferred the top mounted bins because they did not have to reach underneath the vacuum to pick up the bin, enhancing accessibility. Top-mounted bins are also better for visibility from a design perspective. One of the specific complaints about emptying dustbins was how dirty of a job it was. Users routinely had to wash their hands after performing the overall maintenance task, something that can usually be avoided when using conventional vacuums. To open the vacuum and release the bin, current designs require users to squeeze a release, pull a lever, or push a button. Only a top-mounted button keeps the user's hands away from the dirty bottom of the bin and the sides. Opening the bins is also a consistent problem.

Cleanouts are sometimes mounted on the sides or back of bins, and manipulating the opening controls requires tilting the bin at an angle. The worst dustbins are ones that require

force to open. A violent opening can send dirt everywhere. Design cues from the dropout bottoms of bagless vacuums helped me come up with some ideas for a cleaner process. Users were receptive to the ideas and would accept any option that would improve the experience. Some dustbins are covered by a flap and some are clear on the top so a user can evaluate how full the bin is at any time. There was no strong consensus among users about which design was better.

Users, especially those with dogs and long-haired people in their households, complained of brush roll issues across all models. Though cleaning the brush roll is less common than emptying the dustbin, it is a task that deserves redesign. Existing vacuums incorporate grooves on the brush roll shaft for cutting entangled hair free, but the user must go find a knife or scissors to slide along the groove. When asked if they would prefer a vacuum that came with a dedicated tool, users said yes but didn't want to pay significantly more for it. Self-cleaning brush rolls are nice in theory, but when they jam because the blades on the brush roll have dulled, the entire brush roll must be replaced (Figure 3). Users expressed interest in a design that streamlined the experience and they were open to replacing certain parts if the parts were cheaper than the whole brush roll.

Figure 3. "Self-cleaning brush roll with tangled hair and damage.

Preventative maintenance can prolong the life of most machines. Still, most people perform maintenance on their vacuums other than emptying the bin only when the vacuum has stopped working. Proposing to owners that their vacuums might be able to inform them how to help it do its job was of little interest to most, but a few technophiles liked the idea. Reframing the question as "Do you want to know when it is going to stop working?" made the idea more appealing. Some robot vacuums communicate with ambiguous error codes, which leaves the humans troubleshooting and wasting time that they bought the devices to save. I suggested some more effective ways that the vacuums could communicate their issues. Voice notifications like "The brush roll is stuck, please remove the debris," were preferable to blinking lights in all cases. Smartphone app notifications were of interest, but only to those who already had the apps and connected homes.

Controls: Redesign

Owners who had not configured their devices to interface with smartphones claimed to have no interest. When asked “why?” they primarily said it was too complicated or inconvenient. When I suggested some low-effort, seamless connectivity, options, most of the previously uninterested owners were more open to using a smart device to control and communicate with their vacuums. Still, to accommodate the widest range of users, the need for good basic controls was clear.

Controls for vacuums vary extensively. Existing designs use between one and eight buttons (Figure 4). Other than maintenance, controls had the highest ratios of negative comments to positive comments.

Figure 4. Eufy RoboVac 11S 1-button and iRobot 650 8-button designs.

Showing controls on current vacuums to potential users and asking them what they thought the controls would do helped pare down several button configurations to just one option. I had the prospective users guess the functions of existing buttons and then replicated the more

universally understandable ones for further designs. During interviews, the buttons (other than POWER/GO and home buttons) that were not labeled in writing caused problems for most people, even if they had some familiarity with robot vacuums (Figure 5). When prospective users guess the function of an unfamiliar button correctly, they were still not certain of how the robot would perform the action.

Figure 5. Proscenic, Roborock, Samsung, and iClebo displays ranked by clarity to users.

With so many functions and features packed into these robots, physical controls become overly complex. Users are opposed to trying to program or manipulate the ergonomically inconsiderate buttons on a vacuum like the iRobot 650 in Figure 5, so I designed and presented different remote configurations. Owners are not making use of a large range of great functions offered by current devices because these modes are hidden behind menus, accessible only through apps, and require unmemorable button combinations and sequences. Those interacting with these devices do not know the useful modes exist. People complain of inadequate suction

power without realizing the vacuum is operating in eco-mode. Their cords and shoes get mangled not knowing the vacuum can be ordered to stay away from certain areas. They rush home to turn on the vacuum before company arrives when they could have scheduled the cleaning or activated it remotely. While using smart devices would let users explore these options, apps are not always accessible and user-friendly. Some robot vacuum features are embedded in other smart home apps making it hard for a user to find them for download. Also, most smart home apps require a signup process after downloading. Even logged in, users must take several additional steps to connect the vacuum to their WiFi. Home assistants intended to control the vacuums require further configuration within their own apps. Almost every owner I talked to wanted to be able to use some of the advanced features I told them they already had but they needed help to get started.

Setup: Redesign

Discussing possible solutions to accessing their device's full capabilities with owners, I realized that redesigning the earliest phases of the interaction were key to helping new buyers get the most from their machines and thus maximizing their satisfaction. Owners want not only to be able to take care of their machines and control them easily, but they also want to take advantage of all they have to offer, including being delighted with the overall experience. Emotional design plays a role in satisfaction. People name their robot vacuums. They praise them in online reviews. The good impressions should start right from the beginning, with a sleek unboxing to demonstrate value, as opposed to the typical mess of packaging so common in "average" products (Figure 6).

Figure 6. Roborock unboxing and associated packaging

That the setup was mentioned so infrequently by reviewers indicates that this opportunity for the vacuum to influence user perceptions is underutilized in current designs. A good setup design could lessen frustration by modifying user expectations to mirror actual performance, which is often limited by expensive technology. Stakeholders other than the users must take note of the maintenance and control requirements, and a company could exceed user expectations if they gave their robots a proper introduction. To explain how my new design improves the setup, controls, and maintenance phases and meets all the defined requirements, I will describe it from the beginning of its lifecycle with the user.

Final Design

Unboxing: Final Design

The packaging is well-planned and easy to remove. The vacuum, charging cable, remote control, and dock are nestled in cardboard cutouts. The vacuum itself features a modern look, hinting at technologically advanced capabilities and mirrors other smart home devices, while maintaining some distinctive features, like large green sensor “eyes,” that evoke a friendly robot feel that has been by normalized by popular media, such as Wall-E and Short Circuit (Manoj

2016). The dustbin opening outline faintly resembles a smile. Because of the cardboard cutouts, there is no need to rummage through additional plastic bags for parts. A pamphlet greets the user from the top flap of the box (Figure 7). This sets the stage for meeting Requirement 3, easy setup.

Figure. 7. User's view when unboxing.

Controls: Final Design

Before the setup, however, the user might observe the physical vacuum controls (Figure 8). Meeting requirement 2.a, basic needs of users are addressed by the green POWER/GO button. It turns the robot on and starts the cleaning process. To the right is the red HOME/STOP with a charging symbol - it sends the robot back to its dock to charge. To the left of the

POWER/GO BUTTON is a VOICE CONTROL button that initiates a spoken interface that can be used to control the rest of the functions directly from the vacuum.

Figure 8. Physical vacuum controls.

To meet requirements 2.a.i and 2.b, the remote control is labeled in writing and common symbols with instructions for how to use the two more complex functions, spot clean and no-go zone. It addresses the needs of users who are interested in using more advanced options via a physical device. The remote control allows access to spot cleaning modes, no-go zones, and manual controls. The VOICE CONTROL button activates the vacuum's natural language interface. After many iterations of button designs, all potential users correctly identified the functions of these buttons, including which way the vacuum would move with the manual controls using the pictorially realistic vacuum represented on the control pad. In addition to functional, understandable controls, I designed the remote to fit comfortably in a normal size hand with commonly used controls within a thumb's reach.

Even though my users had understood the remote, I realized after I had shown it that the controls would probably not work with vacuum wheel configurations. The vacuums I had seen and tested move only forward and backward with no lateral options - they must rotate to change directions. I also realized that the color scheme was inconsistent and that black-on-white text would be more legible, so I have included my revised final remote in this report next to the one shown to users (Figure 9).

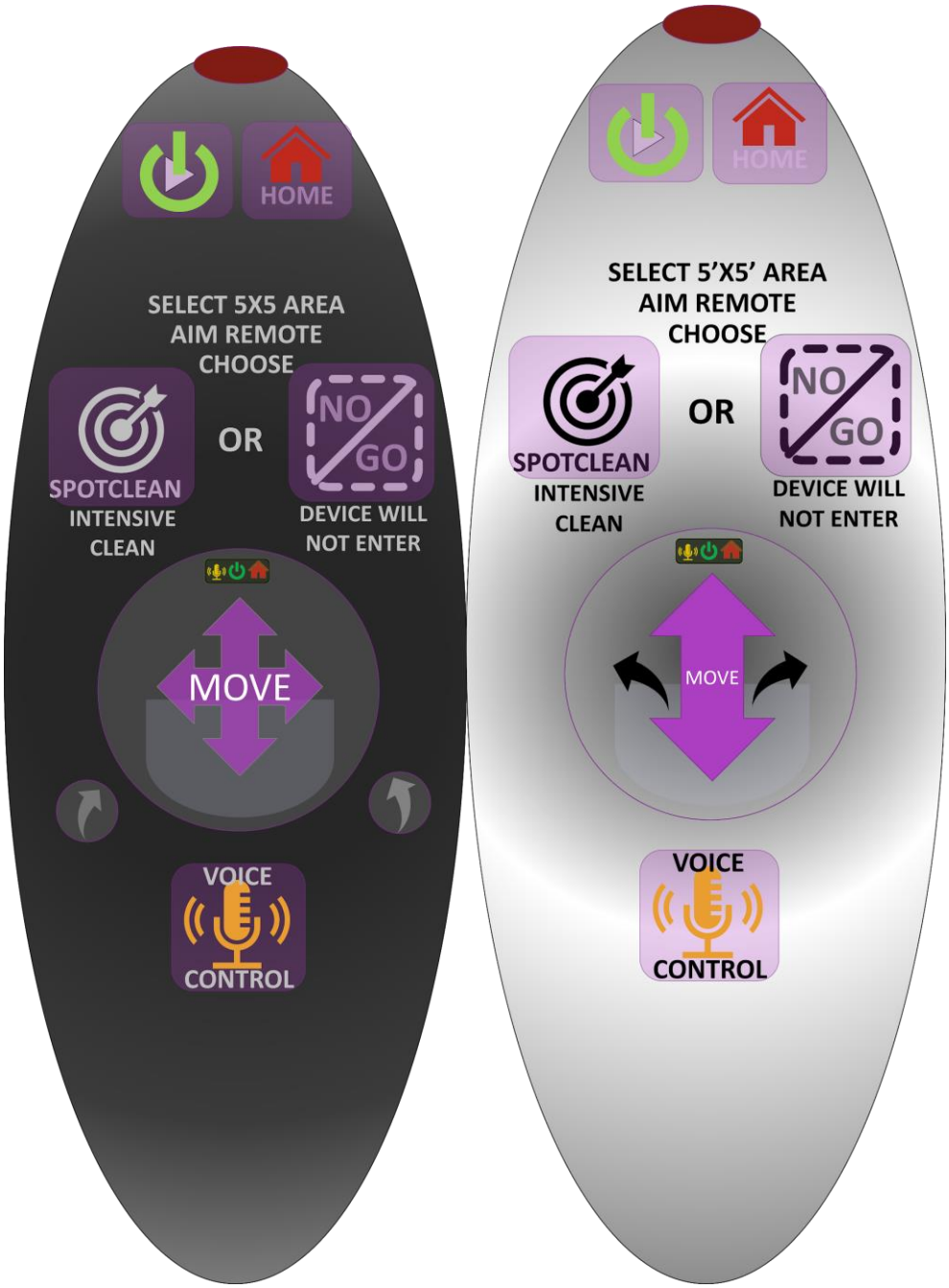

Figure 9. Remote Design and Revised Remote Design

Setup: Final Design

The quick-start pamphlet has a diagram of the dock being plugged in with the vacuum being placed nearby and turned on with a QR code with the message "Connect your smart device

now.” Inside, the guide has pictures of and recommends a few places to place the dock, such as under a couch or a corner table, where the infrared beam from the dock that helps the vacuum find it will still be able to be found. The visual guide and the option to use the app satisfies requirement 3. Recommendations for placement help establish a user’s mental model of how the vacuum will guide itself back to charge, decreasing frustration and easing troubleshooting if the vacuum happens to get lost because something is blocking it, helping meet requirement 3.d.

If the user scans the QR code to download the app, a vacuum setup screen appears upon opening. The app seeks to connect immediately to the vacuum, and after agreeing to some options (“Would you like to allow the app to access your Bluetooth and WiFi settings to pair your vacuum now?”) the app setup process is complete. The user is not forced to create a new, proprietary account, and no personal data is required unless the user wants to register the vacuum with the company. Not all users will want to use an app, and the design respects that, while still continuing the smooth setup and enjoyable, educational user experience in its next phase.

Upon touching the POWER button, a green GO icon begins to glow behind the power symbol. This is good feedback that the device is on and that it has some battery remaining. If the light does not illuminate, a user can check the quickstart guide to see how to place the vacuum on its dock to charge. Then, the vacuum speaks to meet requirement 3.a, and 3.a.i.

Vacuum: Welcome to ‘Robo-best 1’ (or whatever name marketing stakeholders can use and not infringe on copyrights), your floor cleaning friend. If you want me to walk you through setup, say ‘Setup.’ You can say ‘stop’ at any time to end our conversation. If I hear you say ‘Repeat’ I will repeat my last voice communication. I might not be able to understand everything you say, so you can use the app to continue. Just say ‘synch to my device.’ If you want me to vacuum your floor now, say ‘Start the clean’ or press my green GO button. [GO light pulses]. I’ll

find my way back to the dock when I need to recharge." All of this helps to build the user's mental model, satisfying 3.d.

If the robot cannot sense the dock nearby, it will add

"Please install my dock somewhere I'll be able to see it's infrared beam. You can also put it under a couch as long as I'm in front of it when you plug it in, so I can remember where it is."

User selects setup.

If the robot cannot understand the voice, "Sorry, I can't understand you, please help me get set up with the app."

Vacuum: You have selected 'Setup.' You can now schedule cleaning and learn more about my other functions. Some of the things I can do are spot clean, scrub the carpet, and learn to avoid certain parts of your home with no-go zones where you have things I shouldn't pick up, like charging cables or pets.

With this interaction, the vacuum has satisfied 3.b and 3.c.

You can view a full list of my functions if you download the app or look in my manual. What would you like to do?" [vacuum pauses for a command - if there is none it continues] "Say 'schedule cleaning to set up a routine.' Say 'no-go zone' to teach me to avoid areas in your home. Say 'spot clean' to learn about how I can do that.

User: "Spot clean."

Vacuum: You have selected 'Spot clean' [Vacuum will repeat all commands] You can place me in an area or use the controls on the remote to guide me. I will begin a spot clean when you set me down and press GO, or aim the remote at the place you'd like me to clean and press the SPOT CLEAN button.

By the end of the conversation, the user will have a better mental model, clearer expectations, and the beginnings of an emotional relationship with the vacuum.

Maintenance: Final Design

The voice interface is also useful to help users, especially tech-novices, take care of their vacuums. The first time a user hears "My dustbin is full, please empty it," the vacuum will also ask, "Do you have a moment to learn about how to maintain me so I can always help you?"

User: Yes

Vacuum: I will let you know when my bin is full through the app if you have it, with my voice if you are nearby, and by pulsing my red home button and my yellow voice command button. You can also remove my dustbin cover if you want to see what I've been picking up and how full I am. To empty the bin, lift my dustbin cover if it is installed, pull up on the release handle on the top of the bin and lift it out. when you are ready to empty the bin, hold the bin over your trash can and push the open bin button. The bottom of the dustbin will swing open. You can close it by using the rim of the trash can to push the cleanout door back up until you hear a click.

The same alert system is used for all malfunctions, such as a jammed brush roll or clogged filter. If the user starts a clean when a sensor or side brush is degraded and needs to be replaced, the vacuum will still clean but it will also issue the alert.

Some examples of other maintenance related issues.

"Large object detected in brush roll. Please remove it to continue cleaning."

"Please clean the brush roll by sliding the cleaning lever from one side to the other."

"Brush roll cleaning blade has been used 50 times and may be degrading. You can replace with a (standard) safety knife blade."

In my design, a release button affords a quick, clean release of the bin (Figure 10). Adding a handle to carry the bin to the trash decreases overall effort in picking the bin out of the vacuum. The handle negates the need to carry the bin by its sides and reduces human contact with dusty areas. A handle-mounted trigger opens a hinge on the bottom to drop out debris and ensure one-handed operation while holding a trash can lid open.

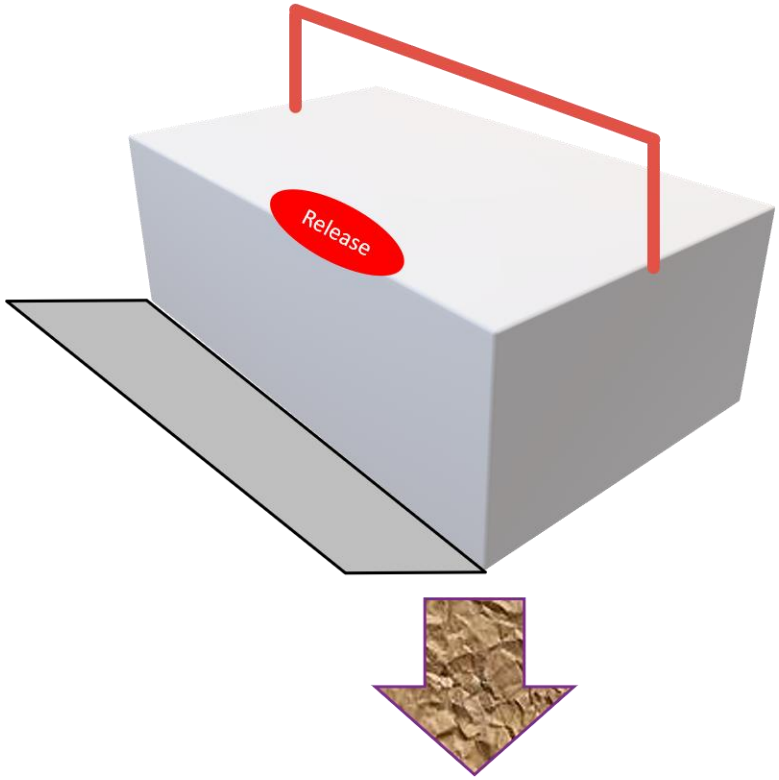

Figure 10. Improved top-mounted dustbin with handle and bottom cleanout..

I added additional elements to indicate when it is time to empty the bin to satisfy Requirement 1.b. When the bin is full, the vacuum stops cleaning and issues auditory and visual cues. A glowing red alert on the ON/START button illuminates, indicating that something has happened. If configured, app notifications are sent to the user's phone to prevent confusion or

frustration upon seeing an unclean floor when encountering the stopped vacuum. The vacuum repeats the auditory alert if the user presses the now red ON/START button so he can know what action to take if he did not hear the alert the first time.

Vacuum: Any time I encounter a problem or need your help, I will try to let you know what it is and what you need to do. If you have my app, I will send you a message through it. If not, I will announce it and blink my yellow voice control button. You can push the button to hear me repeat the issue if you did not hear it the first time.

After a user is notified of the need, cleaning the brushroll on this design is fast and easy to satisfy 1.c. This design incorporates a (replaceable) safety blade next to the roller itself. Rather than remove the brushroll completely for this routine maintenance, the user slides the blade over the length of the roller to cut fibrous debris clear. Easy brush roll maintenance satisfies requirement 1.b. The vacuum/app can also guide a user directly to a retailer to buy replacement parts. While designing an entire app is outside of this project, Figure 11 is a good example of how this screen should look.

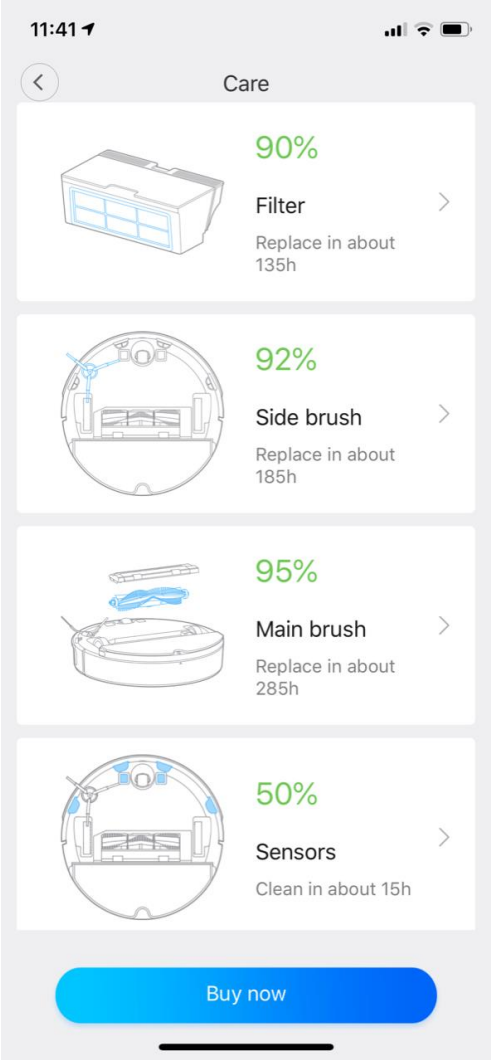

Figure 11. Maintenance screen from Roborock.

Evaluation

I assessed my design by administering a questionnaire to ten people. They listened as I described the unboxing and looked at the graphics I had prepared. I walked them through the design narrative. I used a wizard-of-oz technique to test the voice command scripts. When they asked about downloading the app to continue setup, I also described some of the functions that an app for this design would have. If they wanted to cut the script short because they'd rather

have the vacuum clean by itself immediately, or tired of the process and said “Stop,” I administered the following survey after they had looked at all the graphics.

1. How well did you understand the product? (Understanding)
2. How hard or easy do you think emptying the bin would be? (Bin maintenance)
3. How easy or hard do you think it would be to get the vacuum to do what you wanted? (Easy interaction)
4. How likely would you be to use the app? (Download app)
5. How easy would it be to use the voice control features? (Voice control)
6. How easy would it be to use the controls on the vacuum? (Physical controls)
7. How easy would it be to use the remote control? (Remote Use)
8. How often do you think you would use the advanced features? (Advanced feature use)
9. How would you rate the attractiveness of this vacuum? (Attractiveness)
10. How much would you pay for a vacuum like this? (Acceptable cost)

I tallied scores from 1-10. For question 10, I equated each $100 a user would spend as a point on the scale. I compiled the scores into an overall rating of each design characteristic or area of questioning. This gave each aspect of my design/narrative an overall score out of 100.

Here are the visualized results:

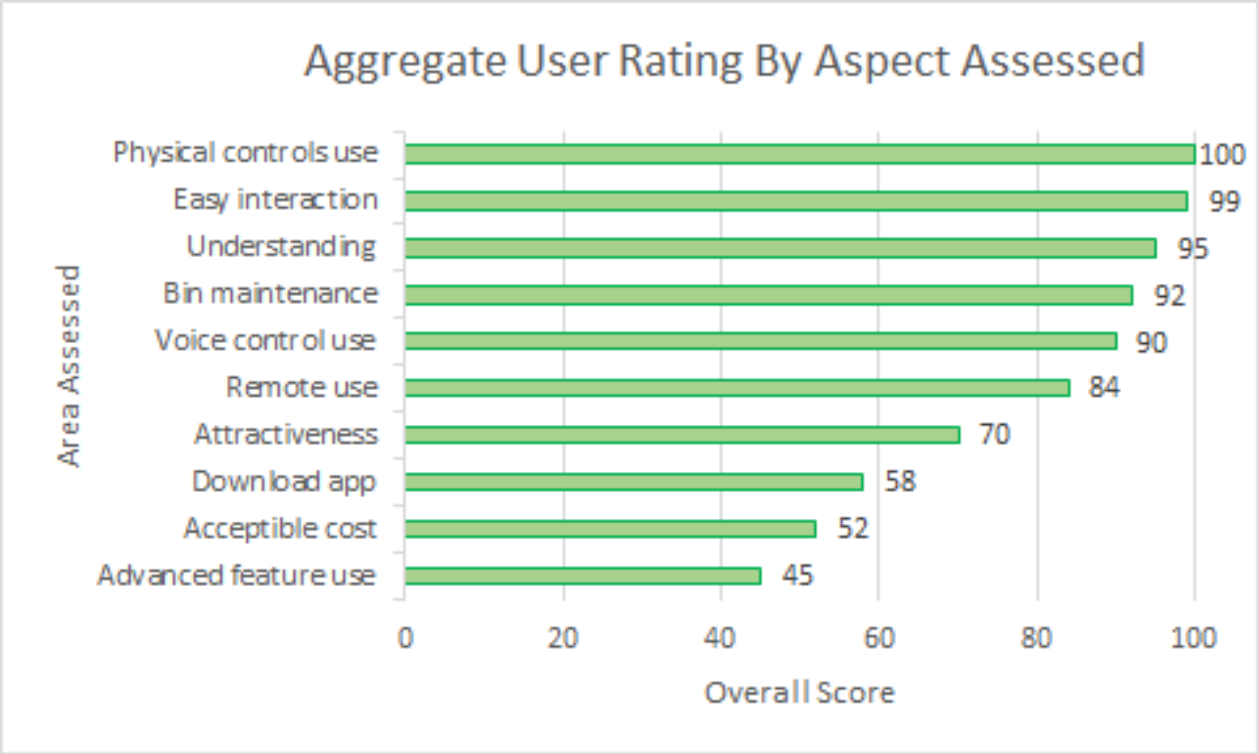

Table 2. User Evaluation Scores by Question

The physical control redesign was a complete success. Every user felt completely confident that they could, at least, turn the vacuum on and send it home. It follows that almost everybody believed their overall interaction with the vacuum would be easy. Most likely, after their interaction with me (and my ability to answer questions as a smart vacuum should), they believed they had better understandings than they actually did. A good way to test this would be to build a prototype and ask them to accomplish certain tasks. The methodical description that I gave them of the bin and its workings likely skewed the maintenance scores, as well. I should have separated the brush roller and bin scores. Most potential users believed they would have an easy time using the voice controls, although this may have been a function of their being able to speak with a human with more improvisational skills than a machine. The remote did not score as highly as I thought it would, possibly owing to slightly confusing wording on the remote. People generally thought the vacuum attractive, but there is a good chance that they did not want

to hurt my feelings after I took the time to show them the design. It would have been better to have a stranger show it to other strangers in a different frame of mind and keep the interactions less personal. If I had designed a full app and made that fun and attractive rather than just describing it, I think it is likely that more people would have chosen to download it, but their relative reticence could also be attributed to the disinterest of people in using their smartphones when physical controls will accomplish the task just as well. It seems that $500 is about the upper limit of what people want to spend, which is accurate and inline with current prices. A self-emptying vacuum runs about $1000, and requires the user to purchase special bags to fit the custom trash can. My design did not include those features. Finally, many users, even after understanding the advanced features, thought they would not use them. I did not, however, define the "advanced features" very well, and users may have thought that my descriptions of spot cleaning and no-go zones were not advanced, but actually standard features. I did not clarify when I asked the question.

In terms of my stated requirements, I did not collect good enough data to be sure that I have met them with my overall design. What data I did collect suggests that users think that my redesign meets my requirements insofar as the overall interaction will be good. Maintenance was perceived to be easy (although I should have asked more questions about this). Requirement 1.a, dustbin maintenance, would be met. Requirement 1.b was not evaluated. Requirement 1.c is probably met, evidenced by the overall understanding of user responsibilities. Users scored the controls as comprehensible (and present) meeting requirement 2, 2.a, 2.a.i, 2.b, and the app I briefly described meets 2.b.i. The voice controls seemed to accomplish each section of requirement 3.

More user testing is necessary. Dustbin and brush roll prototypes must be built and proven to be physically robust and cost-feasible. Multiple realistically rendered designs for overall vacuum look must be shown and judged by users. Voice communication capability must be, at very least, capable of being upgraded and modified as the technology is fielded and users discover inevitable bugs in the system. Fortunately, over-air updates can aggressively address major errors, but the voice commands require more testing and may need to rely on groundwork already laid by current voice assistants.

Conclusion

This report described my robot vacuum redesign process. I described the background research to explain the requirements I created and why I chose maintenance, controls, and setup aspects of vacuum for redesign. I explained my decisions as I went through the redesign process for each aspect of the vacuum I wanted to address. I then put forth a vision for the redesigned vacuum, and explained the process I used to evaluate it.

Redesigning control app would be the next logical step to continue to improve the user's robot vacuum experience and enhance overall flexibility. The appearance of the vacuum should be redesigned or at least refined in extensive user preference analysis. Adding additional features that would appeal to some tech-savvy users, such as custom cleaning patterns, gesture interfaces (pointing at a dirty spot to clean) or even a first-person "spy" mode with the camera, would also give the design a special edge over competing vacuums.

The robot vacuum market is filling up quickly, and the race to the robot home assistant market is just heating up. Well understood, familiar, and integrated home tech-ecosystems will likely come to dominate the competition through good design. The refined setup process and voice integration illustrated in this paper would translate well to other robot assistants and the

future of home technology, laying the groundwork for a robot assistant empire. If a company could implement this ideal design, it would gain an edge over competing products. Technology developed for this robot vacuum could win a company accolades for design, ensure a high rate of user satisfaction, and capture a large market share. It is possible that a successful robot vacuum producer with iconic interaction design and functionality could become a breakout leader at the forefront of the robot assistant market in the way that Apple shattered norms to set new standards for smartphones.

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