HERB (Home Exploring Robotic Butler)
User Interface: Design and Research Process

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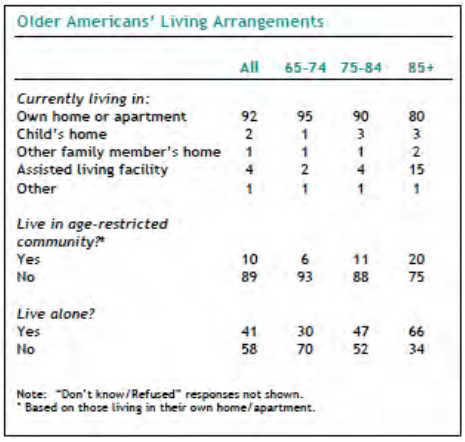
Abstract

As the population of Americans over age 65 increases and increasingly wish to prolong living independently, there is a growing interest and need for technology to provide some level of assistance in care for the elderly at home. Great progress has been made in the capabilities of robotic devices to identify and manipulate objects in home environments. However, the fields of human-computer and human-robot interaction are still relatively young for consumer robotic products. In this paper, we discuss our research in the needs of the potential audience for HERB, a Home Exploring Robotic Butler; initial design requirements and concepts; findings from the testing of our user interface concepts and recommendations for future work.

Introduction

According to a report published by Pew Research Center in June 2009, there are 39 million Americans that are 65 and older, about 13% of the US population. By 2011, the number is expected to rise to significantly as the first of the 76 million baby boomers turn 65. Figure 1[1] shows findings from the Pew Research survey conducted in February to March 2009, which reveals that more than nine out of ten respondents over 65 lived alone and that they were either very satisfied (67%) or somewhat satisfied (21%) with their living arrangements.



Older Americans' Living Arrangements

	All	65-74	75-84	85+
Currently living in:				
Own home or apartment	92	95	90	80
Child's home	2	1	3	3
Other family member's home	1	1	1	2
Assisted living facility	4	2	4	15
Other	1	1	1	1
*Live in age-restricted community?**				
Yes	10	6	11	20
No	89	93	88	75
Live alone?				
Yes	41	30	47	66
No	58	70	52	34

Note: "Don't know/Refused" responses not shown.
* Based on those living in their own home/apartment.

Figure 1. Living Arrangements of Older Americans based on survey of 2,969 respondents 65 or older

These patterns change as the population gets older but the need for robotic research to assist with the needs of eldercare and mobility impaired become increasingly important as the elder population grows beyond what current caregivers can support.

This paper presents work on designing a user interface the elderly or mobility-impaired to control HERB, a Home Exploring Robotic Butler. First, we present related work on interfaces used to control home robots, what aspects were or were not taken into consideration for our designs and rationale. Next we discuss our research on potential users: how they overcome challenges with their daily tasks, what needs are met by caregivers and how they interact with caregivers. We then present our design process to generate paper prototypes to test form factors and navigational hierarchy for communicating with HERB. Last, we present findings from user testing of both the form and the hierarchy, along with recommendations for design and future work.

Literature Research

Our literature research on prior work focused on understanding the strengths, weaknesses of interfaces designed for the elderly or mobility impaired to control assistive robots at home. Additionally, research findings related to technology acceptance, human-robot, or human-computer interaction were of interest as we explored design of an interface for an elderly or mobility impaired person to interact with HERB in their home environment.

In an initial briefing about the HERB project, we learned that a scenario had been proposed to use a laser pointer to indicate an object or objects that HERB's user should pick up. Initial findings were generally positive when potential users of an autonomous assistive robot named EL-E, designed for object-oriented tasks such as identifying, grasping, moving and releasing items, tested several interfaces: an ear mounted laser pointer, a touchscreen and a hand-held laser pointer.[i,ii,iii]

Quantitative and qualitative data were gathered from the trials, which yielded almost a 95% overall

success rate with all three interface types. Learning took less than 10 minutes and object selection was better using a laser pointer than a touch screen.

From this, we infer that part of the satisfaction of using a laser pointer is that it is a more natural way for someone to indicate which item, within their field of vision, they would like to be picked up, rather than look away at a different interface. Additionally, someone with greater motility impairment would also have greater difficulty with fine gestures required by a touch screen. We also aimed to provide a handheld device with haptic feedback as a first generation interface with the intention of using voice and natural gestures as the primary method of interaction with HERB in the future. We chose not to pursue use of a laser pointer for HERB whose primary purpose as a home exploring robot butler will significantly exceed the retrieving tasks of EL-E. Other limitations of using a laser pointer include being in direct line of sight of any object HERB's user would want, technical interference from shiny or patterned floors, and cluttered environments which were common for our population.

Also of interest are HERB potential users' interactions with assistive care. In further work with El-E, service dog commands and modifications to one's home environment (facilitating open/close tasks by tying red towels to door ad drawer handles) were studied[iv]. As with training service dogs, owners learn to use specific words and phrases to communicate commands to their dogs. While modifying a users' behavior and adapting the home environment for assistive care may be cost effective, we didn't feel that our elderly population would feel comfortable with learning and recalling specific verbal commands to control HERB. We used contextual inquiries in field to learn more about elderly and their interaction with caregivers.

A related concern is the acceptability of home robotics. Research by Meng and Lee[v] surface design issues engineers face when developing new technologies for the elderly or infirm. Specifically, a top priority is to enhance perceived quality and accuracy in understanding needs by incorporating user preferences, levels of task requirements and user abilities.[vi,vii] Our experience testing user interfaces (UI) with participants support that a highly customized experience is much more efficient than broad and generic navigation UI.

Informally, our team also collected anecdotal evidence about use of newer technology by older audiences: how parents/grandparents use remote controls, digital cameras, mobile phones and what problems they encounter with each device.

We aspired to design a portable or wearable device with familiar form factors and functionality, requiring minimal recall of instructions to operate, and leveraging emerging technology for maximum performance.

Contextual Inquiries

In designing a device that would be used in a home environment, it was important for us to understand first-hand how our intended audience currently live and manage their tasks in their natural context. To do this, we planned to conduct several Contextual Inquiries (CIs) with elderly participants in their home, interacting with a caregiver. Due to time constraints and difficulty recruiting participants, we present our ideal and actual CIs below.

In our ideal CI, we would have visited the home of an elderly person who was a few months away from being transferred to an assisted living facility and who had a caregiver. We would have observed the elderly person going about their everyday activities, paying special attention to the interaction between the elderly person and their caregiver. Since HERB is designed to replace some of the tasks of the caregiver, we felt that this would be the most important interaction. We would then try to mimic this interaction as closely as possible in our interface. For example, we would observe what the elderly person did or said if they wanted a glass of water from the kitchen and note the language used to communicate this desire to the caregiver, as well as the caregiver's response.

The CIs we performed were not as ideal, but we did gather some important insights from them. First, we conducted two CIs with mobility-impaired people—an administrative assistant and a student. We observed how they compensated for their impairment and what social interactions took place when they were requesting assistance. From this group of CIs, we learned some of the interactions to include in the interface, such as the ability to have HERB open and close doors and cabinets, using props to get items from high places or using feet to move items at floor level. Balance was also an issue when getting up or sitting down, as well as doing tasks that required two hands.

Our second set of user studies took place at an assisted living facility. Our approach here is a modification on the CI technique since, as a condition of our visit, we were not permitted to record or ask many questions. We consider this to be a Contextual Observation as we were able to observe activities in a natural context and speak with the caregivers at high level about some of their interactions with the elderly in their care.

Here we able to watch the elderly interact with their caregivers. Nonetheless, we still garnered a great deal of information. Firstly, we were made distinctly aware of the impairments and disabilities with which some of the elderly were afflicted, and considered this for our design. For instance, we made large, tactile buttons and made sure all the text was large and easy to read to accommodate for the limited vision that many of the elderly had.

Another interesting insight we made from the CIs at the assisted living facility was that much of the interaction between the elderly and the caregivers was non-verbal or preemptive. For example, one caregiver would know that a certain elderly person wanted some water and would just retrieve it, while other caregivers would go around asking if they wanted anything now, without being prompted. The idea of anticipating needs and complementary items along with requests was interesting to us and taken for granted in human caregivers or butlers. Unfortunately, we couldn't implement something this complex into our design, but hopefully, future versions of HERB will include some high-level artificial intelligence capable of this sort of interaction.

A full set of findings from our CIs and COs can be found in Appendix A.

Contextual Design

Following our CIs and COs, our next step was to model the communication flow between an elderly person and their caregiver for a common task. We determined early on that modeling methods used in human computer interaction practices were most appropriate for specific work tasks or service. In our case, since being elderly was a state rather than a work-related role, we selected a situation where an elderly person was assisted by the caregiver to get an item from somewhere near or in their environment.

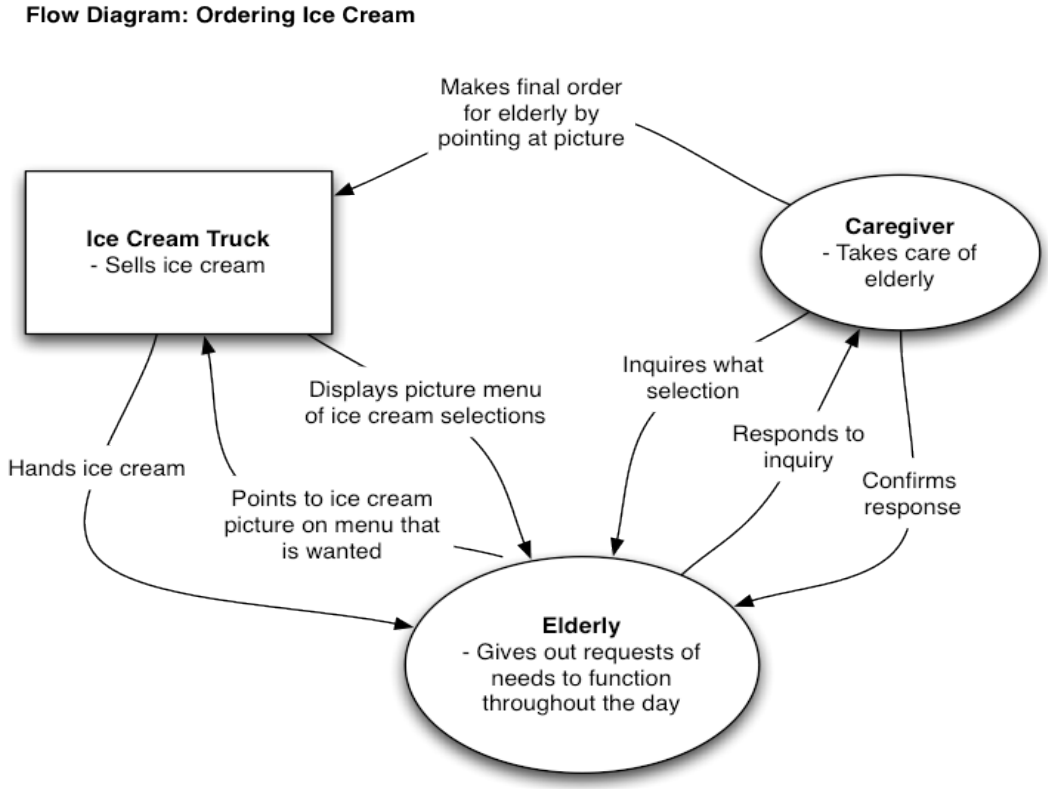


Figure 2. Flow diagram of interaction between the elderly and caregiver for ordering ice cream from a truck.

During one of our contextual observations from the Residences at 5th Avenue, we were able to observe an elderly give instructions to the caregiver when ordering an ice cream during the day when the ice cream truck was on location, see Figure 2.

This helped us visualize the coordination and communication between the potential HERB users and their caregivers. We found that there were a lot of mediations between the caregiver and the elderly when requests were placed, in particular, the caregiver would always confirm a response from the elderly.

Another insight we gained through observation is that the ice cream truck uses pictures as a main mode of communication to the elderly when presenting a selection of ice cream, as seen in Figure 3. This pictorial method of communication seems to be clear as well as efficient, since the elderly would simply point to picture of their ice cream choice and confirm verbally with the caregiver the name of their selection. Use of redundant sensory modes: visual and verbal/auditory seemed to facilitate and enhance communication.

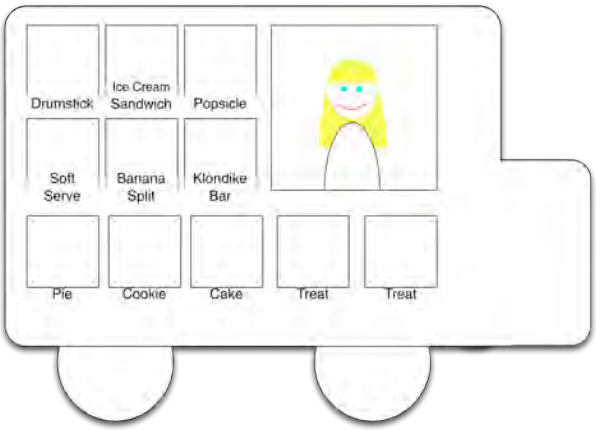


Figure 3. Artifact model of an ice cream truck display from Residences on Fifth

To further understand the limitations of a person with limited mobility, we conducted a CI decided to observe a handicapped worker to coordinate around the office to truly understand the problems that occur in their daily tasks. More importantly, the CI informed us about what types of chores HERB would be ideally suited for, what steps are required to complete a chore and how our interface for HERB would need to support these tasks including status and feedback. Our participant was recovering from an accident that shattered her left femur and has been rehabilitating for years now requiring crutches to walk long distances. Her responsibilities as an administrative assistant required physical activities such as retrieving mail, making coffee in the kitchen, maintaining the condition and paper supply in the copy room, and organizing items around the office.

One of the many tasks that were physically problematic for the participant was retrieving items from high shelves. We created a sequence model for how she managed the task in Figure 4. Breakdowns occurred when the participant needed to use a broom to dangerously wiggle the box off the shelf while carefully coordinating to catch it with both hands. After observing this action, we realized the values that HERB can provide in relieving the daily, physical activities for the elderly and mobility impaired.

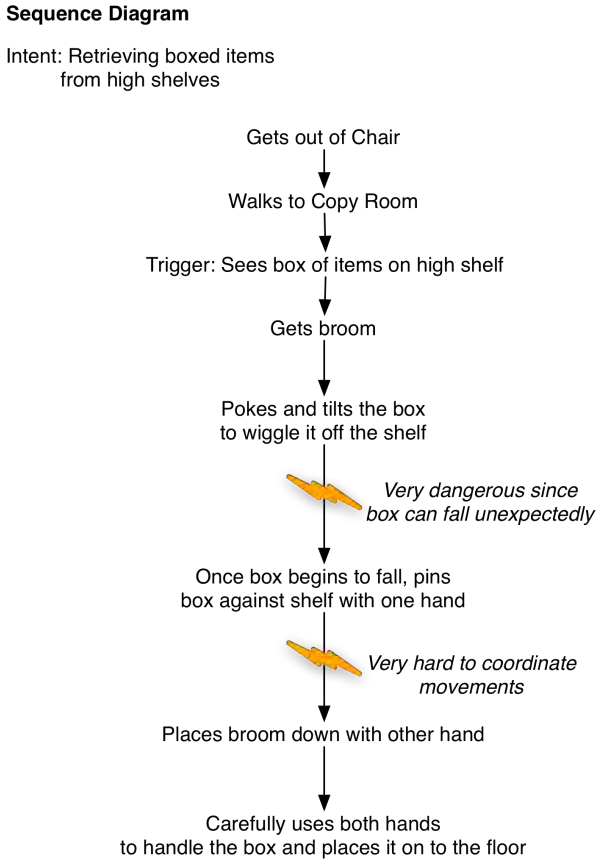


Figure 4. Sequence model for retrieving items from high places

Another task that was difficult for the participant was moving a heavy box of copy paper that is already placed on the floor. A sequence model for

this task is shown in Figure 5. The participant had to constantly bend down while shifting her weight away from the injured leg and maintaining her balance to slide the box of papers, cut the box tie, and take the paper out. She removed reams of paper from the box on the floor and stacked them on overhead shelves above large copy machines. Here, the participant is at risk of aggravating her injuries or falling over from loss of balance.

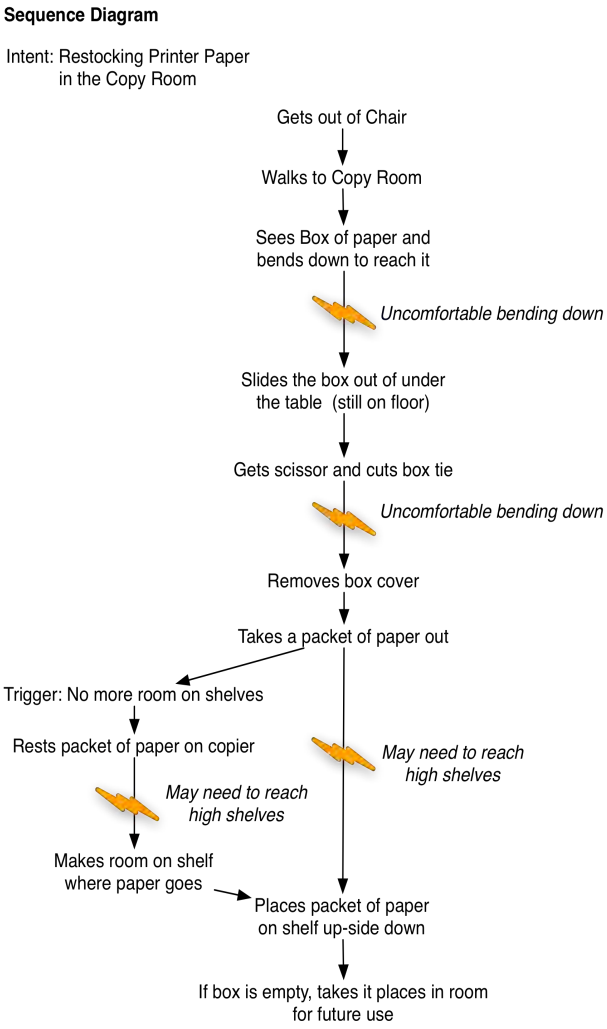


Figure 5. Sequence model for restocking printer paper in copy room

With some empirical knowledge about HERB's potential users and how HERB might be able to assist them as a robotic butler, we move to designing prototypes to support various tasks or requests that a potential user might make.

Prototyping

Paper prototyping is a design method where the design team comes together and creates various different paper mockups of what the final user interface may be like. The focus of paper prototyping is to simply create. The materials used are low-cost and favor iterative design. Paper prototyping is best done after research insights have been collected, as the team shifts to the design phase.

For the purposes of this project, we were mostly interested in what form the controller for HERB would take. The HERB controller is the device that will relay commands from the user to HERB. This component seemed to be the one of most important pieces to the HERB system, since it is the device the user would use to interact with HERB on most occasions.

Through our contextual inquiry and contextual design processes we learned extensively about the limited capabilities of the elderly. Therefore, our prototypes were designed with the target audience's limited facilities in mind. The most impactful of which were poor hearing, poor vision and poor manual dexterity.

After our first round of prototypes were created, we assessed each on the basis of accessibility. We also evaluated the pros and cons of each prototype, as well as what the technological requirements were and if it was feasible overall. We then took that feedback and re-imagined our prototypes once again.

After our informal review process, we selected our top three designs to flesh out further. Each of these top three had something unique about it that we thought would be interesting and useful as a device to control HERB.

Prototype 1: HERB Handy

Our first prototype, the *HERB Handy* is a controller that took on the form of a flat rectangle about 11″ wide by 5″ tall. This device was envisioned to have a very large scroll wheel on one side and large OLED tactile buttons across the front. The other parts of the front surface would also be driven by a display so that text or directions could appear anywhere. The device would have a handle on one side that facilitates holding during movement. The device could be ruggedized by using an exterior material like rubber.

Figure 6. HERB Handy paper prototype

The driving ideas behind HERB Handy were portability, and ease of use from large, tactile buttons and display.

Prototype 2: Tag Bracelet

Our second controller, the *Tag Bracelet*, took a more wearable approach to the problem. The user would wear this bracelet, which had several "tags" on it. Each tag had a small screen and buttons on it to allow the user to manipulate it. The user could add specific tags to it to allow for different use cases. The driving ideas were to easily fit into the user's lifestyle and allow user to always be able to control HERB without locating a separate device.

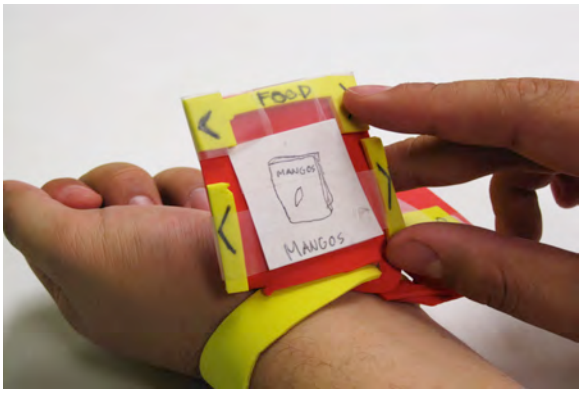


Figure 7. Tag Bracelet paper prototype

Prototype 3: Scroll Screen

Our third and last controller, the *Scroll Screen*, would also be worn by the user, but was much larger. The prototype featured a roll-out flexible display that would be touch sensitive. The user would wear this device on their forearm and pull the screen out from the sleeve worm on their forearm. The advantage of this interface was the large amount of screen real estate.

Figure 8. Scroll Screen paper prototype

The driving ideas behind the Scroll Screen is also wearability but with more real estate for display and controls that would reduce input time for making requests to HERB.

After running through two scenarios of requesting a cup of hot earl grey tea and fetching a blue sweater, only the HERB Handy could realistically support the levels of navigation and information needed for a task. The tag bracelet, as envisioned here would require too much time navigating through each choice to make a selection. The scroll screen was difficult to use as a flexible screen and using only one hand. Both were predicted to be a hassle to use with long sleeves and just one hand. We proceeded to refine the HERB Handy form factor and navigation hierarchy through Think-aloud user testing.

Evaluation

Think-aloud is a usability testing method that asks participants to "think aloud" while they perform specific tasks on a design prototype. The tasks consist of common user scenarios and noteworthy use cases. As the participants complete each task, the experimenters observe the participants' behaviors and record their thoughts. The team performed think-alouds on two different prototypes: a paper prototype and a functional prototype. See Appendix B for scenario and tasks introduced to the participant.

Think aloud: Paper Prototype

We recruited three participants to perform think-alouds on our paper prototype. Our main goal was to explore the form factor of the design and gain an initial understanding of the user interaction. Through the think-alouds, we discovered several insights.

The participants found the form factor to be awkward to handle. In general, the buttons were large enough to provide a strong tactile experience. However, the participants had a hard time holding the device with one hand while pressing the buttons with the other hand. When the participants pressed a button, the entire device was pushed back due to the lack of support from holding the handle on the short end of the device. Though the handle on the short end was designed for portability, our participants held onto the device by the handle, making the weight of the rectangular form awkward to support.

Simple requests were manageable without too much thinking time. However, participants did have difficulties with task management. The participants found the re-ordering of queued tasks to be non-intuitive given the main options to "get", "do chores", "open/close" or "assist." The participants had to navigate to the queue management menu, select the task to be moved, and place it in the correct spot within the queue. The participants had to try several approaches before completing the re-ordering of tasks.

Figure 9. "Screen changes" during think aloud

Moreover, the participants were confused as to whether to look at the device or the robot for feedback and potential interaction. While much of the status information was provided on the device, the participants anticipated the robot to provide feedback as well.

Think aloud: Virtual Prototype

After learning from the think-alouds with the paper prototypes, the team further refined the design and developed a virtual prototype, Figure 10.

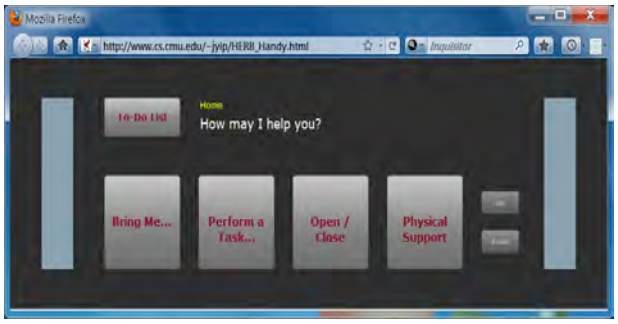


Figure 10. Virtual prototype for refining just the navigation hierarchy

The task re-ordering capability was simplified to an option to move a queued task to the front of the queue. Also, when a new task is entered, the current task is interrupted and the newly entered task replaces the current task. With the virtual prototype, our goal was to test the navigation hierarchy of the design.

We discovered that the vocabularies used to describe the navigation hierarchy are very important. During the think-alouds, the participants expressed confusions as to whether a task falls under one category or another. However, it was rare that they would select an incorrect category. Nonetheless, providing a consistent, intuitive and unambiguous language is essential to the navigation hierarchy.

Design Recommendations

1: Large Displays and Affordances

Based on our artifact model (Figure 5) of an ice cream truck's menu that was used by participants during our observations at the Residences on Fifth, we determined that large text, graphics and interactive components are important in our design. The elderly participants seemed comfortable ordering from the menu and no order confusion was observed.

This was supported by the fact that many of the elderly residents that we observed wore glasses as well. Large buttons accommodate for degradation in fine motor skills. This decay became apparent while observing elderly participants creating bonnets during a crafts session. This factor led us away from design ideas involving pointing devices.

2: Most Advanced, Yet Acceptable

Borrowing from Raymond Loewy's philosophy, we took the approach of creating a device that has more capabilities than the user may have had

experience with, but with the aim of making it familiar. We felt that this was the appropriate approach based on the limited amount of devices we observed being used by our target audience.

The analog scroll wheel on the HERB Handy aims to provide a more common experience to the user than swiping on a touch screen, for example. LEDs line the device next to the scroll wheel to provide navigation feedback.

The main OLED buttons on the HERB Handy also provide tactile feedback and operate similar to the buttons on a television remote control. This design decision also stems from the fact that we did not observe participants using touch screen devices, so tactile devices would be more comfortable for them.

The hierarchical menu system consists of three levels at most. By developing basic hierarchy rules, the menu can expand easily. Due to our potential users' lack of expertise navigating hierarchical menus, we felt that three levels was the optimal amount allowing for good organization, but simple navigability.

3: Portability

Because of the potential for users to move to other locations within the environment and still need to control HERB, we placed a major focus on portability. In order to accommodate our target audience, the device needed to be lightweight and easy to carry. Two of our prototypes centered on the concept of wearable computing. Unfortunately, our wearable prototypes had other drawbacks such as being difficult to use and not allowing for large buttons and screens. The HERB Handy device was designed with a comfortable handle on one side to afford users the ability to carry the device.

During our observations, we noticed that many of our observation participants utilized walkers. The walkers were usually filled with newspapers and other items that the users wanted to keep with them. We felt that the HERB Handy could be either attached to the walker in some fashion or placed in the walker's basket, thus while it is not wearable, it is still a portable device.

Future Research

With HCI methods, our team was able to conduct field research with Contextual Inquiries, create prototypes based on the research findings, and test them with the Think-Aloud method. Due to time constraints, we were unable to create a full high-fidelity working prototype to test. In terms of the HERB Handy, the form and functionality could be upgraded to a fully working prototype as mentioned previously. With a working prototype, its usability can be evaluated in many different domains. Such domains include: evaluating users interaction with the ease of use, speed of use, error commitments and recovery, and overall satisfaction with the experience. Insights gathered from a usability evaluation can help create different iterations and adjustments to the design to better fit the needs of the user.

Another opportunity for future work include designing feedback directly on HERB. This includes visual and audio feedback in which there is much to be explored in terms of the aspects of both kinds of feedback. In visual, the most basic and accommodating to the users of HERB would be indicator lights. Although lights are simple enough, there is also much to consider in choosing the best way to represent HERB's status to the user. Examples of design elements that should be considered with lights include the actual icon or pattern, frequency of the display (is it steady or does it flash?), the colors used (will some colors alarm the users or create confusion and miscommunication?).

In addition, the best method of providing auditory feedback to the elderly can be further researched. Because hearing problems tend to occur as people age, the option of providing auditory feedback might not be the best way to communicate as a standalone. It must be done as a supplement to visual feedback. Some important aspects of auditory feedback that should be explored are: volume, frequency, and the actual content of the sound. Would the sound be best as verbal speech or basic tones? Developing a high-fidelity prototype and direct feedback from HERB are just a few opportunities for future work.

Appendix A: Contextual Observations, Residence on Fifth, assisted living for seniors:

Observation logistics:

Tue 10/6/09
- 8 residents observed during activities session
  (2 in wheelchairs, 4 using walkers, 2 not needing assistance)
- Planned activities
  - Game of "You be the Judge"
    Helper reads historical events and asks residents what they think should happen to the accused
  - Hatmaking (adorning hats with ribbons/flowers using glue gun)
  - Ice cream truck (at entrance)

Wed 10/7/09
- 4 residents observed
- Planned activities
  - manicures
  - discussion

Summary of observations:

- Caretakers adjust to limitations and interests
  - for shaky hands, helpers fill beverage cups less full
  - when reaching for something, helpers move object within reach
  - when handing something to a resident, may place item within grasp, rather than directly handing it over
  - helpers speak loudly, clearly and facing the person (so that listener could read lips)
  - for avid reader, helper brings over other reading material
  - helper opens cookie wrappers (for some) without prompting
  - made a clicking sound with her tongue, caretaker calls her "thinking sound" before responding with an answer
- Caretakers encourage interaction and social engagement with questions
  - hatmaking "would you like some flowers"?
  - during discussion "what do you think" (specifically directing question to person)
  - would point to things and ask resident to make a selection (generally yes/no, next) e.g. ice cream truck had large pictures with names of item in large letters; helper points and asks "do you want the drumstick?", if no, helper offers an alternate suggestion "do you want the ice cream sandwich?"
- Caretakers anticipates needs/comfort
  - regularly ask (suggest) if resident would like water, something to read, etc…
  - when asked "can I get a red ribbon", caretaker also brings scissors
- Residents
  - had baskets on their walkers to collect things, reading material, water bottles, food wrappers
  - very open to helper's suggestions, accepting of being helped
  - readily interrupt to give their opinions
  - bore easily, and fall asleep while sitting
  - some residents had no physical limitations so needed less physical help from helpers
  - approximate what is being said
  - have their family on top of mind and mistake conversations to reference their children

    - interested in seeing social interaction
        - tried to get student visitors to flirt with each other
    - are overconfident about their abilities
        - "I can see fine" but picks up an administrator clipboard thinking it's hers
    - despite some dexterity, may have limited strength
        - folding paper for origami but could not make a firm crease in the paper
- Environment
    - Some residents wore devices that would set off an alarm if they exit
    - Phones in every room but rang at higher than normal pitch (residents could not hear this frequency)

Implications for HERB project:

- Controller for elderly population
    - Cannot rely on audio feedback
    - Tangible devices will have to be tested for pressure sensitivity (what can someone with low strength reasonable be expected to push but not do so accidentally)
- Programmatic
    - HERB needs to anticipate accompanying items in "fetch" mode.
    - Opening packaged items and garbage collection
    - Provide limited options when clarification is needed
- Human Factors
    - Ways to provide social engagement

Implications for MHCI HERB UI project:

- Due to time limitations, assume HERB user can see, hear, speak and grasp reasonably well
- Our user may still be elderly but has the same abilities as any other healthy adult using a wheelchair.

For future consideration for user studies (out of our scope):

- Handicap people using service dogs (to study owner's commands/expectations/error correction)
- Role play of HERB and user (to study breakdowns in communication, assumptions, expectations)
- "Murderball" type event (to study what a very capable handicap person can't do for themselves)

Appendix B: Scenario and tasks that were introduced to the think-aloud participants.

You are an 80-year old man with arthritis. Your family wants to move you into an assisted living home, but you want to stay independent for a while longer, so you have the newest model of HERB, the robotic butler.

1. You are sitting in your lounge, are thirsty, and want some tea.
2. As it is winter, you are getting a bit chilly. You would like your brown sweatshirt to keep you warm.
3. You want to make a small lunch for when your nephew comes over later, but all your dishes are dirty.
4. Your nephew comes to visit you and knocks on the front door. Ask HERB to get the door.
5. Your nephew brought lunch and paper plates, so HERB no longer needs to do the dishes.

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