Developing Heuristics for Assistive Robotics

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I. Introduction

Heuristic evaluation is a popular means of quickly identifying likely design problems in an application's human interface [1]. Because of its simplicity, low cost, and broad applicability, this evaluation technique is arguably the one most often used.

In our work with assistive robotics, we are following in the tradition of developing a set of tailored heuristics to aid evaluators of specialized types of systems (e.g., [2]). Researchers and manufacturers of assistive robotics have an obligation to ensure that the systems they design and develop are safe and useful. Using an evaluation method that can expose interface problems before the system has gone into production can increase the likelihood of a usable design.

There are two common methods used to develop heuristics: empirical-based and research-based methods. Nielsen used the former by categorizing hundreds of usability problems and adapting the names of the resulting ten categories as a set of heuristics [3]. In many cases, new heuristics are developed using Nielsen's heuristics as a basis. Developers eliminate Nielsen's heuristics that are not congruent to their primary goal, modify the rest to suit their target domain, and add heuristics to complete the new set, if needed [4]. Desurvire et al., for example, employed a research-based method to develop a set of heuristics for game approachability drawing on education, learning, and game theories [5].

Validating the new heuristics is often done empirically by comparing the problems they find to those of usability testing or Nielsen's heuristics. Ling et al. claims the performance of the new set is often as good if not better than Nielsen's [4]. The reason is the new set is specific to the domain tested.

This paper presents a set of heuristics for assistive robotics. While heuristics have been previously developed to address human-robot interaction (e.g., [6]), there was no set of heuristics for the more specific area of assistive robotics prior to our effort. We describe the assistive robotic system we used as a validation testbed prior to explaining the heuristic development process, heuristics, and validation; see [7] for more detail.

II. Manus ARM

The Manus Assistive Robotic Manipulator (ARM) is a commercially-available, wheelchair-mounted robotic arm developed by Exact Dynamics [8]. It is designed to assist with general activities of daily living and can function in unstructured environments. The Manus ARM can be operated using a keypad (Fig. 1), joystick, or single switch using hierarchical menus. The Manus ARM has 6+2 degrees of freedom. The gripper maximally opens to 3.5 in (9 cm).

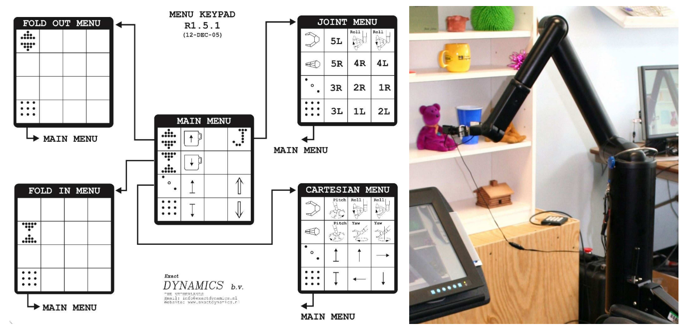

Fig. 1. Hierarchical menu used with 4 × 4 hexadecimal keypad (left; courtesy of Exact Dynamics); Manus robot arm (right).

III. Developing Heuristics

We began by examining how each of Nielsen's heuristics relate to the Model-Human Processor (MHP) [9]. This model seemed appropriate because of its emphasis on perceptual, cognitive, and motor aspects of human interaction with technology. Additionally, we examined literature for accessibility in human-computer interaction (e.g., [10]–[13]) and assistive robotics (e.g., [14]). Because robots designed for human assistance are inherently social, we looked at the literature of social robotics (e.g., [15]–[17]).

We distilled top-level heuristics from the MHP and found four critical gaps: safety, trust, errors, and flexibility. We filled the gaps by creating additional top-level heuristics from Nielsen [3] and the literature for accessibility and social robotics. The remaining heuristics from the literature review became more specific secondary heuristics under these top-level ones. The secondary level heuristics were explained with concrete questions/examples for assistive robotics as a tertiary level. The two lower levels of heuristics form sample guidance (not comprehensive) when looking for possible problem areas.

Table I shows the top and secondary levels of our assistive robotic heuristics. The nine top-level heuristics are presented in boldface type. Examples of the literature that inspired the heuristics are included in the "source" column. Not all sources are provided due to space limitations (see [7] for a more complete version).

TABLE I
HEURISTICS FOR ASSISTIVE ROBOTICS

Heuristics	Source
Provide appropriate amounts of information for decision-making, judgment, and prediction	[9]
○ Show what the system is doing and what state it is in	[18]
○ Provide option awareness to enable decision makers to know what courses of action are available, what their likelihoods of success are, and what their relative costs are	
○ Provide sufficient historical information to understand trends and make predictions	
Use existing long-term and working memory	[9]
○ Minimize process length	[14], [19]
○ Provide consistency and standards	[18]
○ Exploit previous knowledge in the world if reasonable	
○ Provide knowledge in the interface so that people do not have to remember it	
Reduce motor processing time	[9]
○ Accommodate the ability to choose among access devices	[14], [19]
○ Support shortcuts	[18]
Reduce mental processing cycles	[9]
○ Use simple language	[11]
○ Avoid having the user make mental translations	
Support flexibility to match differing expectations	[18]
○ Provide multiple ways to access a function/complete a task	
○ Provide user control and freedom of actions	[18]
○ Be consistent with how the human brain processes information	
○ Enable interface customization and retention of user's preferences	[10]
Aid in perception	[9]
○ Provide aesthetic and minimalist design	[18]
○ Present content appropriately	[10], [19]
Ensure safety	[19], [20]
○ Ensure robot does not have a physical form that can induce injury	
○ Ensure robot does not have behaviors that can induce injury	[10], [13]
○ Provide fail-safe mechanisms	
Prevent errors	[18]
○ Provide context-sensitive help when asked	[10]
○ Prevent capture errors	
○ Prevent description errors	
○ Prevent mode errors	
Maximize the user's trust	
○ Ensure robot performs in a predictable manner	[15]
○ Ensure robot performs in accordance with polite social etiquette	
○ Provide feedback and interaction that matches technical abilities	[16]
○ Reduce anxiety	

IV. VALIDATING OUR HEURISTICS

We conducted two heuristic evaluations of the keypad interface of the Manus ARM with four individuals. Two evaluators used our assistive robotics heuristics and the remaining two used Nielsen's heuristics [3]. Each evaluator began in the default folded state with the gripper closed. The evaluator was asked to place an object inside a cup, which was upside down, and return to the folded position when complete.

Using Nielsen's heuristics, we found a total of 13 non-duplicative errors. Using our assistive robotics heuristics, we found a total of 33 non-duplicative errors. When problems from the two evaluations were consolidated (eliminating duplicates), we identified a total of 39 problems; a full description can be found in [7]. The heuristic evaluation using our assistive technology heuristics uncovered 26 problems (67%) not found by Nielsen's heuristics. There were 7 problems identified by both types of heuristic evaluations, which is 18% (Fig. 2).

We expected that there would be at least some overlap in the problems found because we incorporated some of Nielsen's heuristics into the assistive robotics heuristics. We expected the number of problems found using the new set would be greater due to their greater specificity to assistive robotics and the additional detail they provide, which is consistent with [4].

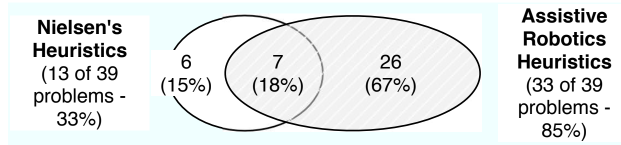

Fig. 2. Overlap between heuristic evaluations using Nielsen's heuristics and our assistive robotics heuristics, shown in Table I.

V. CONCLUSIONS

Based on the results of the head-to-head comparison of finding problems with Nielsen's versus our heuristics, we assert that our set of heuristics shows promise for evaluating assitive robotics applications.

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