A Multifunction Printer CUI for the Blind

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June 16, 2020

Abstract

Advances in interface design using touch surfaces creates greater obstacles for blind and visually impaired users of technology. Conversational user interfaces offer a reasonable alternative for interactions and enable greater access and most importantly greater independence for the blind. This paper presents a case study of our work to develop a conversational user interface for accessibility for multifunction printers (MFP). It describes our approach to conversational interfaces in general and the specifics of the solution we created for MFPs. It also presents a user study we performed to assess the solution and guide our future efforts.

1 Introduction

Manufacturers of multifunction printers (MFP) tout their latest user interfaces with touchscreen displays that minimize the interface controls providing customization and let users create complete workflows that are available with a few taps or swipes on built-in surfaces much like personal tablet devices. The machines look sleeker and permit more complicated interactions than were easily provided with physical push buttons. Unfortunately, blind and visually impaired office workers can no longer use machines with surface-only interfaces. In the past, blind workers could learn to feel for the physical buttons and accomplish many of the tasks required in their jobs. Learning a single model of machine, its functions, and where its buttons were located was not an ideal option, but it at least allowed some degree of independence. With the newest interfaces on office equipment, blind users have, for the most part been left out. To address this issue, our research group at the Palo Alto Research Center (formerly Xerox PARC) developed a conversational user interface that provides access to most of the important features that simply aren’t available to these users without assistance.

The MFPs we worked with offer five high-level functions: print, scan, copy, fax, and email. Our conversational agent does not support printing since that is mostly done from a computer or other device that already offers assistive features. The targeted use-case is blind and visually impaired individuals standing at a copier who want to make a copy, scan a document or send a fax or email. Many choices like single- or double-sided copying, number of copies, binding options, and image variations like lightening or darkening are available. The combination of choices and options available across all the functions amounts to nearly a hundred possible selections. Our solution covers about half of these and prioritizes the most frequently used options. While there might have been good multi-modal interface designs using the screen display to present large icons with high contrast to help the visually impaired, our goal was to create a solution that would serve people with total blindness, requiring everything to be available conversationally.

2 Challenges in Spoken Interfaces

Conversational and voice interactions have become much more common recently. Porcheron et al. 2018 collected data from family interactions with standalone, screenless smart speakers in the home. They point out that while these devices are marketed to help people get things done, little is known about what people are actually able to accomplish with their devices. From an ethnomethodological perspective, using Conversation
Analysis, they are trying to understand how conversational devices fit into human interactions and what is being achieved within dialogs. They identified very little actual collaboration between people and their devices. The collaboration they did find was around the mechanics of the conversation rather than in accomplishing an external goal.

Indeed, we have noticed that task-based, collaborative, conversational interfaces, as opposed to question answering or transaction processing, continue to be rare. Our interest is in developing interactions between people and technology with a shared goal. Moreover, we want to distinguish our interface from one that simply maps voice commands to individual functions on a machine. The trend for office equipment is to put controls on touch surfaces presenting users with a GUI interface that sighted users are very familiar with. GUI interfaces differ in many ways, most significantly in how they model tasks for users. They dictate the way that tasks are done and people learn to adapt to GUIs. Conversational interfaces must allow many different ways of saying the same thing coming from people with differing mental models of the task to be performed. Conversational interfaces have to be able to accept all of these speech inputs in addition to handling inconsistencies of language and general disfluencies. We have drawn from the work presented in Grosz and Sidner [1986] for our understanding of dialog, especially with regard to task-based, collaborative interactions such as the expert/apprentice flywheel example first discussed in Grosz [1978]. More recent research focuses on voice as an interface modality both for accessibility and hands-free/eyes-free use cases. Across the research it is apparent that there continue to be many challenges.

2.1 Problems specific to CUIs

Corbett and Weber [2016] describes the problem of discoverability, constraint, and affordances in their voice user interface for controlling Android devices. Their interest was an interface for individuals with limited hand dexterity, so visual clues and presentation were still possible. Yankelovich [1996] points out that speech interfaces are like command-line user interfaces in that functions are hidden. GUIs were invented in large part to bring hidden functionality to the surface. In our case, for example, many users are not aware that MFPs may have a built-in stapler or other binding options. Even double-sided versus single-sided printing may not be apparent to a new user.

Yankelovich goes on to point out the additional problem of users who, once they start speaking, assume the system has capabilities that it does not. Her approach is to provide carefully formed voice prompts. We have tried to adopt this principle but only to the extent that it won’t conflict with our goal of keeping the system conversational. For example, we make use of her suggested implicit confirmations where possible, so that the interaction can flow more naturally without turns dedicated specifically to confirming information.

2.2 CUIs for blind users

While there has been work that shows that personal assistants have been helpful in providing access to technology that might otherwise be inaccessible, there is also research indicating particular problems for blind users. Among other problems, Abdolrahmani et al. [2018] identified the problem of appropriate feedback from voice systems. Many conversational devices rely on visual cues to report certain events or states. For example, a light of some kind is often used to indicate that a microphone is listening. Amazon’s Echo device relies on a light ring to indicate different kinds of activity on the device. Similarly, small buttons for muting or initiating a conversation are not easily found without vision. The authors also describe the lack of control on voice outputs. Some individuals may require a slower delivery while many others who are accustomed to screen readers set to very fast rates may find listening to the responses frustrating.

Götzelmann et al. [2017] discusses issues of accessibility with 3D printers. They deal with the challenges of physically interacting with equipment without vision, which aligns closely with our own problem of using an MFP. They break down the workflow for 3D printing into discrete steps. We also face the problem they describe of a large number of parameters and alternatives that are available for each step of the process. They reduced the number of options to those that are most essential in order to reduce the scope and complexity of the problem. Our ambition, on the other hand, was to provide access to all of the options that are available on MFPs to blind users. Unfortunately, there were technical limitations in how our agent communicates with the device making our ideal impossible using our current architecture.
3 Focus Groups and Usability

To understand more about the experiences of our target users, we engaged with two different user groups. The first was a visit to the Association for the Blind and Visually Impaired (ABVI) in Rochester, New York. ABVI provides services to people with significant vision loss including training for skills needed for working and living independent lives. Our informal visit with them helped us to gain an initial understanding of the current situation for office workers with visual impairment, seeing some of the assistive devices available, and learning about challenges they face day-to-day in their work.

Subsequently, we partnered with the Vista Center for the Blind and Visually Impaired in Palo Alto, California. The Vista Center put together a user group of eleven people who were current or past office workers with significant experience using multifunction printers. Their ages ranged from 47 to 73 years old with a median of 62.5. All of them live with moderate to severe visual impairment with most having no functional sight.

We conducted a focus group to learn more about specific difficulties. Users expressed, in addition to the problems of touchscreen interfaces, a lack of accessible technology in their work environments resulting in reduced independence and often exclusion from work teams. They complained about complex choices across many options with poor navigational directions causing confusion, inefficiency, and frustration.

Following are some examples from comments we heard.

... if you want it collated, double-sided, stapled, whatever and you have to push the right buttons and all of those things, or otherwise you have to have a sighted aide or another oral aide, or even a student aide... and a lot of the districts just don’t have funding for a lot of that. Really frustrating.

When errors happen, there is little or no explanation of the error or the cause.

I can’t just look at the page to make sure it’s printing properly. I’m relying on just, knowing it is, and sometimes the first inkling that I know something was wrong, is that I hand the page to somebody, and they say, “Um, this only has like two-thirds of the printing on it.” Or, “This is really light in color.” And then I know that our toner cartridge wasn’t working right or two pages got stuck together when the paper was feeding through, and it didn’t feed right.

They also mentioned the difficulty of inconsistent designs across different brands of devices all of which lack verbal introductions or tutorials.

I have to ask somebody to make sure that the page is turned, so I know which way...

We heard about workarounds the employ to carry out many tasks. For example, distinguishing which job is the right one in the output tray is a frequent problem.

...[I] always check the output tray before I print anything, and I make sure that it is empty.

From the challenges and suggestions we heard, we developed a set of design recommendations for our conversational agent shown in Table 1.

4 Design Goals and Principles

Based on the principles we derived from the focus group sessions and our own prior work on conversational agents Dent et al. [2018], we formulated several goals and principles to apply in the solution.

Creating a good conversational interaction that allows individuals to be successful in task-based goals was a high priority. We wanted our agent to be collaborative. Keeping task objectives at the center of the design, we wanted the interactions to feel as normal as possible. We are aware of the risks of trying to copy human-like behaviors in agents Chefitz et al. [2018], which we avoid. We are interested, however, in modeling aspects of human-to-human conversation to improve our interactions but without setting up unmetetable expectations. For example, human conversation is strongly characterized by mixed-initiative
where individuals can seamlessly introduce new information or take the lead during a conversation. Our agent allows for similar flexibility. Users can provide information independent of system prompts to provide it. The agent must be prepared to recognize information that arrives outside of a pre-planned sequence.

We defined the following principles in developing our conversational design.

**Be Accommodating** As explained, users should be able to provide information whenever they want and they should be able to take the initiative in the conversation. They should be able to answer questions naturally with either fragments or complete sentences. They should be able to introduce and ask for multiple things within a single turn. The agent should allow for lulls in the conversation. When the agent has asked the user to perform an action, it might take some time before the action is complete. The agent should wait until users resume the conversation.

**Be Brief** Long utterances can be hard to follow and retain. When listing options, for example, provide them in manageable chunks allowing users to ask for more as they are ready.

**Be Helpful** If users have not provided required information to complete a task, try to give other relevant information or suggest alternatives that haven’t been mentioned before. If people ask for help, include the option of giving more information about related topics. Provide procedural help for new users. When the agent speaks, expect conversational mirroring. The agent should use language and structures that it can understand to give users clues about the best way to say things to maximize the chances of recognition of future utterances.

**Be Transparent** As much as possible convey to users what the agent is thinking and doing. If users’ utterances are ambiguous or unclear, confirm the most likely interpretation. Give cues about where the collaboration is in a process (e.g. “First…”, “Then…”, “Finally…”). Use acknowledgments whenever users supply new information (e.g. “OK”, “Got it”). Perform a final confirmation before invoking the printer especially for jobs that might use a lot of resources (e.g. “I need 500 copies of this document”).

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**Table 1: Focus Group Interface Design Recommendations**

| Feature (“What”)                          | Reduces OR Solves (“Why”)                                                                 |
|------------------------------------------|-----------------------------------------------------------------------------------------|
| Invitation to set defaults               | Repetitive “starting over” for each job; UI disorientation; cognitive overload from complex workflows; inefficiency |
| Invitation to choose a basic function, then add options | Reduce cognitive overload from complex feature lists; frustration                        |
| “Auditory” buttons and lexicon of sound cues | Undesired output from mistaken input                                                      |
| Voice-over walkthrough for frequently used options | Eliminates need to scroll through lengthy menus                                             |
| Invitation to ask for help at any time   | Avoids user “bail-outs” and job abandonment                                                |
| Invitation for a new user to take a tour of the device and interface | Facilitate new user orientation                                                          |
| User-prompted description of features, options, input process | Reduce need for workarounds, enable use of full feature set, support correct paper loading |
| Verbalization of error message/code, its meaning and troubleshooting support | Less frustration and confusion: minimize device damage from inappropriate troubleshooting |
| Verbal preview of output                  | Avoid need for “another pair of eyes” enables independence                                 |
| Query and confirmation for “unusual” or non-routine request | Less frustration from undesired device outputs, minimize resource waste (e.g., unnecessary copies etc.) |
| Verbal update of job status/progress and output specification | Avoid restarting job, resource waste, output collection error                              |
5 The Solution

The solution consists of a device that includes a controller, a microphone, and a speaker. We used a Raspberry Pi for the controller and after trying out several different microphones settled on one designed for conference room phones. In the range of relatively inexpensive microphones, this option performed best to capture voice signals from anywhere around the printer.

5.1 Architecture

Spoken language is captured at the device and sent to Google Cloud Speech-to-Text for automatic speech recognition processing. From Google’s service we obtain the textual representation which is fed into our our dialog system for natural language understanding and processing by the dialog manager. After making a decision about what to do next, the dialog manager communicates with the multifunction device and sends its generated response to Amazon Polly for speech synthesis. We also have a version the uses local libraries for speech recognition and synthesis that runs without depending on any cloud services. Figure 1 displays a schematic view of the architecture.

Before building our own hardware device, we experimented with smart speakers. We found that for interactions lasting more than a couple of turns, interactions with these devices is awkward. The services supplied by the manufacturers to support them limit the amount of control throughout the interaction. The devices also require a wake word, which we did not prefer, and provide buttons that are too difficult to find, given limited or no vision.

On our custom-made device, conversations with the system are initiated by pressing a large button. We explored using a wake word on our own device as well, but preferred the button to eliminate issues with wake word recognition. Copiers tend to be in rather noisy environments, which makes the wake word option even less reliable. Once the conversation is initiated, we open a listening channel that stays open until the task is completed. This eliminates the need to press the button on every turn allowing more natural conversational interactions.

The open channel introduces other complications, however. The voice signal processor has to determine when a user’s turn ends, and side conversations that are not directed at the agent have to be distinguished from questions and commands. The noise of the machine itself can also create difficulties in voice detection and recognition when the device is in operation during the conversation.

5.2 Dialog Strategy

To achieve natural-seeming interactions, we let users interrupt the agent, and also let the agent interrupt users. The agent might interrupt a user mid-question, for example, to announce that a copy job has finished or that a problem has been detected (e.g. out of paper). In order to support delivery of unprompted information, the system triggers production rules in response to the current context and the current utterance. Initiation of a new task, which can happen even while another one is in progress, pushes the new task onto a stack.

There are several strategies within the dialog manager designed to maximize the chance of successfully accomplishing tasks [Kamm 1995]. To address the problem of discoverability (see Section 2), and to assist
users dealing with unexpected issues [Myers et al., 2018], the agent has the ability to help in understanding the machine and how to interact with the conversational interface itself. Users can ask for descriptions of printer concepts and functions including options for each. A help system is available during the course of a task, and a how-to system can guide people through an unfamiliar task. The system recognizes when users encounter obstacles and provides a walkthrough skill where the agent can work through a process one step at a time. The agent may also employ fallback strategies that provide more context or information to guide users back on track. It also has the ability to direct users physical interactions with the machine. It can answer questions like, “Where do I find the feeder?” and “Where can I find my copied document?”

5.2.1 Procedures

The solution understands how to perform procedures. Accomplishing tasks in collaboration with a user requires maintaining a dialog state that represents the knowledge relevant to the current conversation. The state includes a list of all turns that have occurred up to the current point. Each turn includes the utterance and the list of dialog acts that have been parsed from it. Given a new utterance and its dialog acts, the agent updates its state with the new information. Only when utterances are unclear or ambiguous, will the agent ask for confirmation before moving on. Once the state updates are complete, the agent processes the top task from its stack of goals. Given the current goal, the agent decides the next thing to ask or say. The agent will ask for any missing information if it’s needed to proceed. Once all of the necessary information has been collected for a particular task, it will get a final confirmation that its understanding of the full job is correct. Once confirmed, it initiates the action on the printer and then reports the status results provided by the printer.

5.2.2 Diagnosis

Diagnosis is necessary when users encounter problems during the course of a procedure. The dialog agent consults a diagnostic engine to get a list of recommendations to solve a problem. The diagnostic engine might offer a recommended next step or suggest a condition that should be checked. The conversational agent determines which recommendation to follow based on the current state of the dialog. For example, if a solution has already been tried, it can be eliminated from consideration. The agent continues to iterate until all the recommendations have been tried, the problem is fixed, or the user decides to stop the process.

6 User Study

We conducted a user study to assess the success of the solution for our target user population. We also wanted to know how users felt about the solution and how effective they thought it would be in their work. Nine of the eleven individuals from our focus group participated in the usability study. The specific goals of the study were to

1. Assess participants’ ability to successfully complete a series of tasks on an MFP through verbal commands only,
2. Quantify quality of experience for ease and a perceived sense of naturalness of the interaction, and
3. Analyze conversational task completion against that of conventional tap/touch MFP

We did not have a baseline for conventional tap/touch interfaces for comparison, so data regarding the last item was collected as part of a pre-test survey, which was administered before the usability study. The survey collected data regarding frequency of copier use by task, friction points, workarounds, task confidence, and task avoidance.

For the study, each participant performed tasks related to seven different scenarios. A test administrator read aloud each scenario. Once the scenario was understood, participants used an MFP equipped with our conversational agent to accomplish the goals suggested by the scenario. They did not have to operate any other controls on the printer accomplishing the task through conversation only. So as not to prime users with the words known to be understood by the system, scenarios were intentionally constructed to omit a task’s identifying “keywords” requiring participants to articulate their own way of performing tasks.
As an example, the following scenario is designed to prompt a participant to ask the MFP for three copies of a given document without priming the words ‘copy’, ‘document’, etc.:

You are organizing a meeting for three coworkers. You want to hand out the meeting agenda at the meeting. Use the copier to accomplish your goal.

At the end of the scenario tests, participants answered questions from a post-test survey, which collected data regarding their perception of ease-of-use, ability to mitigate error, clarity, precision, benefits of voice over tactile interaction, frustrations, successes, efficiency, and quality of the overall experience. The survey included both open-ended questions for qualitative results and statements where they ranked their level of agreement for quantitative results. Two examples of open-ended questions were “How would you describe the agent’s personality?” and “What did you like least about using the conversational copier?”

For the quantitative statements, participants selected values from a Likert scale of 1 to 5 (corresponding to Strongly Agree, Agree, Neutral, Disagree and Strongly Disagree, respectively) for the following statements:

- The agent understood me.
- I was able to easily follow the agent’s prompts and responses.
- Mistakes I might have made were easy to correct.
- Mistakes made by the agent were easily gotten back on track.
- The agent spoke too fast.
- The agent spoke to slow.
- The agent was able to summarize, and confirm my request.
- The agent was repetitive.
- The agent was too wordy.
- The language the agent used was precise.
- The agent was likable.
- I knew how to ask for help if needed it.
• If I needed help, the agent was helpful.
• At times, I was frustrated, or impatient with the agent.
• I knew what to say to initiate a task.
• I knew when a task was successfully completed.
• I knew when the conversation for a task was over.
• The agent allowed me enough time to respond.

The overall success was apparent in the notable contrast between pre- and post-test survey results. In particular copier-related tasks identified in the pre-test survey as difficult, time-consuming, or avoided (multiple page documents, emailing, scanning, stapling, anything more than a simple one-page copy) were each successfully completed with the use of the conversational assistant. We present a brief overview of our findings here. Full test results can be made available.

In the first set of sentences, participants were asked about the agent’s behavior. The overwhelming majority of the participants found the agent likable (91%) and felt that it understood them (82%). A significant majority also thought that the agent allowed them enough time to respond (82%), and all the participants agreed that they were able to easily follow the prompts. Also, for most of the participants, the mistakes made by them or the agent were easy to correct, while about 10% of the participants experienced some difficulties getting back on track. See Figure 2 for the distribution of Likert responses for these statements.

Participants were asked to rate specific aspects of the agent’s language. While a majority of the participants thought the language used by the agent was precise, about 40% of them also felt that the agent was repetitive. However, they insisted that the repetition or confirmation may be a positive attribute in this case, and agreed that the agent was able to summarize and confirm their request in all tasks. Most of the participants felt the speed of the delivery was right, while a small portion (about 10%) felt the agent spoke too slowly. Also, only a few participants (about 10%) felt the agent was too wordy.

Participants were then asked if they knew how to ask for help, and if the agent was helpful when they needed it. About 45% of the participants responded that they did not know how to ask for help, while, only 55% of the participants felt the agent was helpful when they needed it. Also, about 60% of the participants felt frustrated or impatient with the agent at some point during the test. Moreover, about 75% of the participants agreed they knew what to say to initiate a task. While only 73% of the participants knew when the conversation for a task was over, all participants understood when a task itself was successfully completed.

7 Conclusion

We are encouraged by the results of the study and believe that high quality task-based conversational interfaces are possible and can be a great benefit to the blind and others who might otherwise have limited access to different types of technology. There are several technical items that we were not able to accomplish because of the time we had available for this project as well as the limitations created by our architectural design; however, these are solvable given more time and different kinds of technical access to the MFP devices. The bigger problem we hope to address with future research is to reduce the amount of time and expertise required to create these interactions. Modeling of the equipment, the tasks, the users, and the conversations are time-consuming require people from a variety of disciplines. We are hoping to continue the cross-disciplinary research needed for rich, truly collaborative interactions between people and technology.

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