SMARTBATHROOM: DEVELOPING A SMART ENVIRONMENT TO STUDY BATHROOM TRANSFERS

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ABSTRACT

Individuals' functional abilities change over time; they increase and then decrease over the lifespan, and in some they may fluctuate over the course of a day. While these fluctuations may not impact one's ability to engage in daily activities, they can be problematic for people aging with disability or a progressive chronic condition such as arthritis or multiple sclerosis, particularly when performing toilet or shower/bath transfers. Although various assistive technologies (AT) and environmental modifications are designed to facilitate bathroom transfers, they are static solutions, selected to match an individual's ability at one point in time rather than providing a dynamic environment that can adapt to support changing abilities.

The SmartBathroom Laboratory is being developed as part of the RERC TechSAge as a highly sensed, adjustable residential bathroom environment to accommodate a wide variety of research studies on task performance during bathroom transfers. These studies will focus on identifying the problems faced by people with functional limitations as they age as well as on exploring viable solutions to these problems. In this paper, we describe design and engineering requirements, challenges, and choices in the development of the SmartBathroom Laboratory.

INTRODUCTION & BACKGROUND

Challenges in the Bathroom Environment

Current technologies such as fixed grab bars are intended to compensate for physical barriers to transfer in the bathroom. However, many of these solutions have been designed primarily for young wheelchair users with significant upper body strength (Sanford, 2012) and whose abilities are more stable. Individuals aging with progressive chronic conditions may lack such strength due to varying functional abilities (Mak et al., 2003). For example, individuals with MS may experience days or weeks of reduced mobility before returning to baseline (Northrop & Frankel, 2010). Currently available AT for bathroom transfer may meet these needs some of the time; however, flexible solutions that can adapt to an individual's current ability may allow greater success in transfer (Gentile et al., 2005).

Findings from Previous Related Research

The design of accessible products and AT (e.g., wall-mounted grab bars, raised toilet, shower seat) have traditionally been designed around young veterans who, despite lower-body impairment, had upper-body strength to transfer to and from a wheelchair (Sanford & Megrew, 1996). However, the demographics of people with disabilities have changed dramatically. The American population is living longer and more people are aging with disabilities exacerbated by age-related frailty and chronic conditions (e.g., arthritis) that limit upper body strength and range of motion (Jones & Sanford, 1996). Thus, existing technologies do not compensate for the range of conditions and co-morbidities common among older adults (Sanford et al., 1999). In fact, standard AT and accessible designs may do more to exacerbate disability among older adults than to ameliorate it (Sanford et al., 1999; Sanford & Bosch, 2013).

The purpose of this research is to understand and improve on design in the home bathroom to reduce barriers to transfers

experienced by older adults, particularly for those with functional impairments.

Supporting Future Research

The SmartBathroom provides a laboratory for investigating how people with a variety of functional abilities perform bathroom transfers and the interactions between design and ability. The SmartBathroom will support research: (1) documenting weight distribution, posture, and other biomechanical evaluations during unassisted and caregiver-assisted trials; (2) predicting needs for physical support during bathroom activities based on biomechanical measures; (3) considering the efficacy of prompts that encourage safe practices to avoid falls during bathroom transfers; and (4) developing methods for automated fixture adjustments.

Development Plan Overview

To better study the constraints of the typical home bathroom, the team is retrofitting an existing bathroom in the Georgia Tech Aware Home Laboratory for conducting research in an actual home environment (Kientz et al., 2008). The SmartBathroom is now positioned as a core component of the larger Aware Home sensing infrastructure, enabling a more holistic understanding of an individual's current abilities.

In this paper, we describe developing the SmartBathroom, determining important parameters of transfer, prototyping solutions to measure those parameters, and scaling the system to the Aware Home environment.

APPROACH & SOLUTIONS CONSIDERED

We targeted adults age 50 and over with functional impairments who were able to ambulate to transfer. We planned to study toilet, shower, and bathtub transfers, and so drafted design requirements for the physical environment, fixtures, and technology components. Flexibility in design was a key consideration given the specific study goals and constraints of the bathroom environment.

Design Requirements for Simulating Transfers

The toilet is required to move vertically to improve transfer adjustments and horizontally to provide room for AT and caregiver assistance. To make room for this expanded area during toilet transfers and transform the tub into a walk-in shower for usability studies, the adjacent bathtub had to be removed. To meet the fluctuating needs of participants, grab bars had to allow vertical, lateral, and extension adjustments around the toilet. In the shower/bath, grab bars had to be adjustable between multiple positions on the wall as well as for mounting at various angles. (Figure 1)

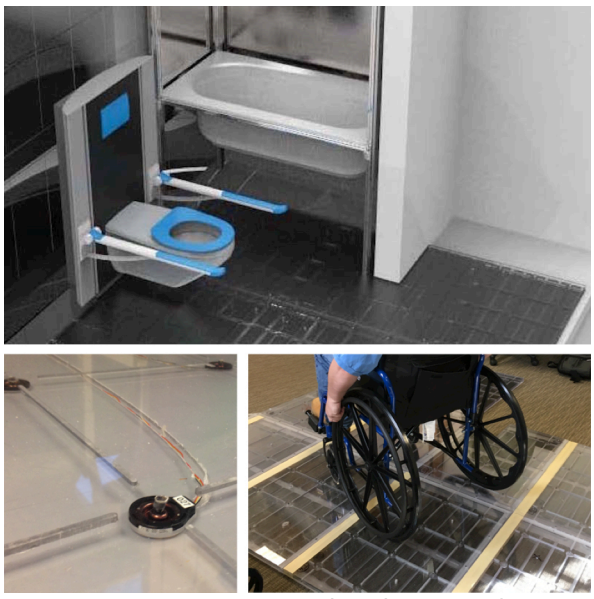

Figure 1: Top: Rendered image of SmartBathroom layout shows motorized toilet, bilateral toilet grab bars, and bathtub on lift. Bottom Left: close up of load cell in floor, Bottom Right: Testing wheelchair on full SmartFloor

The team investigated several options for physical space modifications and bathroom fixtures to meet these design requirements, and made four purchase and/or design choices. First, the Pressallt Height Adjustable Toilet was selected for its vertical adjustability, and the team designed a rig to support horizontal adjustment of the toilet. Next, for bilateral grab bars, we chose a 36" U-shaped wall-mount grab bar and two standard lengths of vertically-adjustable grab bars (24" and 36"; see Figure

2). Then we designed a motorized lift system for a bath-to-shower conversion capable of suspending a freestanding bathtub from the ceiling and lowering it to a curbless shower floor as needed. Finally, we designed custom shower walls with a grid of mounting points and custom grab bars with quick release pins for adjustable mounting and clamp down.

Technology Requirements for Measuring Transfers

Video cameras and/or Microsoft Kinects currently offer the best methods for capturing high-level toilet and bathtub/shower transfer task performance as they afford visual assessment of many key parameters such as posture, position of hands/grip, limbs, and overall task performance. However, embedded sensing solutions can provide more real-time, objective measures of parameters like weight transferred between floor and fixtures or grip strength used during transfer. By measuring foot movement and weight shift on the floor or the weight exerted on assistive devices, grab bars, toilet seat, walls, and bathtub while also measuring the location, strength, and manner of grip on the grab bars (e.g., hand and opposing thumb, hand no opposing thumb, palming the bar), we can objectively gauge transfer performance that can be mapped onto video-based posture and limb tracking data.

Figure 2: Example of woman performing toilet transfer using bilateral grab bars.

After a review of possible technologies and associated costs, we decided to first focus our development on designing and engineering technologies for capturing the most critical parameters for studying safe toilet transfer. The SmartBathroom toilet transfer technology is composed of : a SmartFloor to allow more precise tracking of foot movements and weight shifts; a SmartGrabBar to provide sensing that tracks weight exerted on the bars, grip position on the bars, grip manner, and grip strength on the bars; and, the toilet seat instrumented to measure weight and weight shifts.

Design & Engineering Challenges: SmartFloor

We considered a variety of solutions in the design and development of the SmartFloor (Figure 1) including commercial pressure mapping systems and a suspended floor before deciding on a grid of tiles floating on piezo-resistive load cells with minimal thickness. We selected 8”x8” tiles as a compromise between cost (i.e., the number of load cells required) and resolution (i.e., ability to isolate weight of each foot or object on the floor).

After several iterations with tile/load cell configurations with respect to floor thickness, floor movement, modularity of the design, and ease of replacing sensors and electronics, we arrived at a two-panel (top and bottom), CNC-routed, Lexan design. Grooves were cut into the top panel to form tile-like sections with setscrews at tile corners to concentrate the force on the load cells inset in the bottom panel. Further iterations resulted in a modular design with channels for embedded electronics and wires.

SmartGrabBar Development

In designing the SmartGrabBar grip detection system, the team tested a combination of location and force sensors. Short 4” combined force-position sensors were chosen for the top of the bar (where hands are likely to grip) for detecting multiple hands, grip location and force, and force sensors spanning the full length of the bar for measuring grip force on the sides and bottom of the bars. Iterative prototypes led to a replacement 3D-printed insert for the grip section of the Pressalit grab bar, featuring a flat surface to attaching sensors to improve sensor accuracy

and channels into the grab bar that protect sensor connections and hide the wires.

The SmartGrabBar weight measurement system was designed to measure force in all directions (like a joystick). We configured four single-axis traditional load cells at the corners of an aluminum rectangle positioned between the sliding mount of the grab bar and the grab bar itself so that the bars could be adjusted without reducing measurement accuracy.

DISCUSSION

Development of the SmartBathroom is underway. This research environment will enable investigations into transfer tasks as well as other tasks that people with functional impairments experience in the bathroom.

Our development procedure requires a highly collaborative effort between designers and engineers to integrate technology with the physical environment. We will continue this process by first completing the installation of the SmartFloor, a toilet, and SmartGrabBars around the toilet. Next, we will complete study trials of transfers in normative populations to hone basic settings and make necessary refinements. Then, we will research how our target population performs in our SmartBathroom study environment. We will focus on variables related to fatigue and other measurable parameters from the home environment (e.g., gait speed) and explore predictive algorithms that use these parameters to determine when and how bathroom configurations and automated adjustments can improve transfer performance.

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