AUTOBED: OPEN HARDWARE FOR ACCESSIBLE WEB-BASED CONTROL OF AN ELECTRIC BED

Phillip M. Grice, Yash Chitalia, Megan Rich, Henry M. Clever, Charles C. Kemp

Healthcare Robotics Laboratory, Georgia Institute of Technology, GA, USA.

ABSTRACT

Individuals with severe motor impairments often have difficulty operating the standard controls of electric beds and so require a caregiver to adjust their position for utility, comfort, or to prevent pressure ulcers. Assistive human-computer interaction devices allow many such individuals to operate a computer and web browser. Here, we present the Autobed, a Wi-Fi-connected device that enables control of an Invacare Full-Electric Homecare Bed, a Medicare-approved device in the US, from any modern web browser, without modification of existing hardware. We detail the design and operation of the Autobed. We also examine its usage by one individual with severe motor impairments and his primary caregiver in their own home, including usage logs from a period of 102 days and detailed questionnaires. Finally, we make the entire system, including hardware design and components, software, and build instructions, available under permissive open-source licenses.

INTRODUCTION

Persons with severe motor impairments may spend significant time in electric hospital beds. These beds assist in adjusting the occupant's position and may raise and lower to aid in transfers. Such beds are often controlled by physical buttons, either built into the bed frame or attached by a wired control pendant. These buttons may be difficult for a person with severe motor impairments to either reach or operate effectively. Therefore, if these individuals need to move their beds for better access to their surroundings, for relief from building pressure (Gillespie, et al., 2014), or for comfort, this task may require assistance from a caregiver.

Here we present the Autobed, a module for enabling web-based control of a standard fully electric hospital bed from Invacare, Inc. This module connects between the hand control pendant and the bed's motor control module (Fig. 1, right), requiring no modification of existing bed hardware. The Autobed module serves an HTML-based graphical user interface (GUI) with 6 buttons corresponding to the six movements of the bed: raising/lowering the upper body, raising/lowering the legs (the bed folds upward near the knees), and raising/lowering the level of the bed platform itself (Fig. 2).

Our results suggest that this module enhances the independence of individuals with severe motor impairments by enabling them to control their bed without the assistance of a caregiver. It also appears to facilitate the caregiver's work as it requires little effort for sustained operation, and reduces the need to adjust the patient's bed. By using a web-based interface, the Autobed avoids the cost or obstruction of a dedicated assistive input, instead relying on whatever human-computer interaction (HCI) technology the user already employs.

The idea for Autobed was originally presented by Mr. Henry Evans during our work together. Henry has quadriplegia and is mute as the result of a brain-stem stroke, and has only limited movement in his head and left arm and hand, although he has full sensation. Henry regularly uses a computer via a head-tracking mouse from NaturalPoint, Inc. Henry and his wife and primary caregiver Jane have used and tested multiple versions of the Autobed continuously in their own home, and feedback from both has guided the user-centered design process we employed with the Autobed.

Figure 1. Henry Evans using the Autobed via a web-browser and his existing head-tracking HCI (left). The Autobed module and bed's control pendant (right).

RELATED WORK

Environmental control units (ECUs) have been deployed in hospital and domestic settings for over half a century (Dickey & Shealey, 1987). However, ECU's often include specialized hardware for user input, raising the cost of the unit. Instead, the Autobed system allows those already using an assistive HCI device to multiplex the HCI's interface for also controlling the bed (Fig. 1, left).

Several attempts have been made in the past to incorporate robotic technologies into hospital beds (Van Der Loos, 2003), (Seo, 2005), (Basmajian, 2002). These experimental devices sought to address a larger set of challenges than a standard hospital bed, and remain experimental and unavailable. The Autobed, by interfacing with beds in commercial use, benefits users who already have much of the required equipment in their homes.

Recently, a large number of everyday devices are being equipped with wireless transmitters/ receivers, allowing them to connect to the internet, and establishing the category of "Internet of Things" (IoT) (Mattern, 2010). Here, we demonstrate one approach to converting a standard domestic electric bed into an IoT device.

Figure 2. The Autobed's user interface.

SYSTEM DESCRIPTION

In the standard Invacare bed, a separate motor drives each of the Invacare Full Electric hospital bed's three movements, and each can be run forward or backward to drive the attached mechanism as desired. All three motors are controlled from a single motor control board, to which a wired remote pendant connects. Six momentary switch buttons on this remote each complete low-voltage, low-current circuits, which activate mechanical relays on the motor control board, in turn activating the associated motors. By electrically completing these control circuits, and so mimicking the effects of the remote pendant's physical switch, we are able to electronically activate each motor and control the bed.

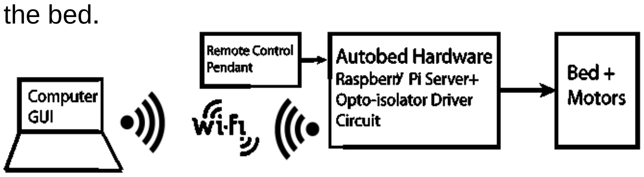

Fig. 3: High-level Schematic of Autobed.

The Autobed consists primarily of a small, low-power Raspberry Pi computer. This computer connects to the user's home Wi-Fi network, and serves an HTML-based GUI with six large, responsive buttons (see Figure 2) to any devices on the local network via an Apache 2.0 web server. This interface then sends commands via a websocket connection back to a Python Tornado-based server on the Raspberry Pi. This server then uses the 3.3V General-Purpose Input/Output (GPIO) pins on the Raspberry Pi to activate one of six optoisolators which complete the bed's control circuits and drive the motor relays, mimicking the pendant buttons. These optoisolator circuits are connected in parallel to the handheld remote pendant, which continues to operate normally through the Autobed, even when the Autobed module is not powered (Fig. 3).

The web interface sends a command every 75ms while a GUI button is depressed. Upon receiving a command, the Raspberry Pi server drives the indicated function for 155ms. This allows for smooth motion even if commands are delayed, but keeps the interaction on the order of 0.1 seconds, in which range users typically perceive interactions as fluent. This timing also provides accurate control of the bed, as each 155ms active period moves the head angle and bed height <1% of their total travels, and moves the legs of the bed only ~1.5% of its total travel (see Table 1).

Table 1. Approx. travel time for all bed functions.

Actuator	Up	Down
Head	25s	24s
Bed	25s	21s
Feet	10s	10s

The Autobed connects in-line with the remote control pendant, so it is not necessary to modify the bed hardware. However, the Invacare Owner's Manual indicates that owners should "use only authorized Invacare replacement parts and/or accessories otherwise the warranty is void" (Invacare, 2007).

The Raspberry Pi and optoisolator circuit are housed in a plastic enclosure, providing mechanical protection for the system. The enclosure exposes a female RJ45 socket to attach the standard control pendant, a male RJ45 cable which connects to the motor control board socket in place of the hand pendant, and a power cord.

RESULTS

We installed an initial version of the Autobed in the Evans' home on June 24th, 2014, and installed a second version, with an interface similar to that described above, on October 14th, 2014. We installed the version, detailed here, on October 12th, 2015. Complete design details, with build instructions and links to all software, can be found at (Grice, 2016).

<u>Data Collection</u>

We conducted all experiments with the approval of the Georgia Tech IRB and the informed consent of Henry and Jane Evans. To examine the use of the system by an individual with severe motor impairments in his own home, we logged the date and time (to the second) of all commands received by the Autobed in the Evans' home between November 1st, 2015 and February 10th, 2016, a period of 102 complete days. Because Henry had used earlier versions of the Autobed for over a year, and had used this latest version for 19 days before logging began, we treat the data as representative of steady-state usage. While multiple commands may be received within 1 second, we treat any second in which a command was received as a full second of usage to simplify analysis.

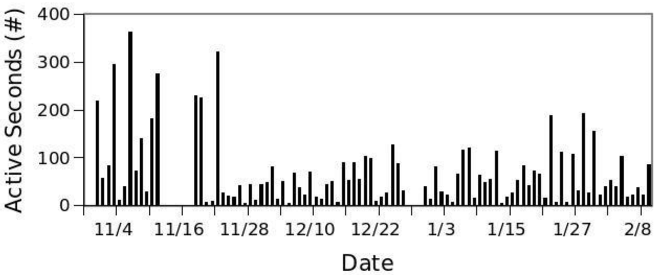

Figure 4. Daily use over the trial period.

At the end of the 102 days we asked Henry and Jane Evans each to complete a questionnaire composed of both Likert items and open-ended questions. Questions related to their adoption and use of the Autobed, and were based on the Technology Acceptance Model (Davis, 1989), in particular asking about factors contributing to Perceived Usefulness and Perceived Ease of Use, based on (Chen, 2014) and (Davis, 1989). In addition, we also asked for their insights into recorded usage trends, and how they believed the Autobed impacted their lives, as well as any challenges or opportunities for improvement.

Usage Statistics

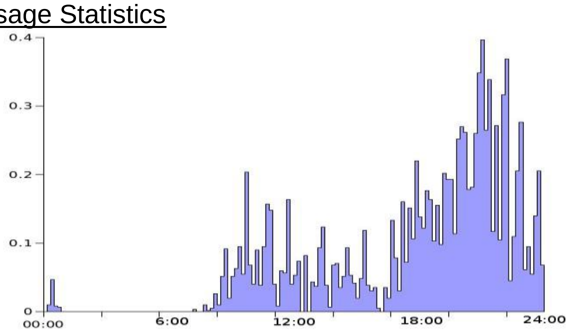

Fig. 5: Frequency of use throughout the day.

Figure 5 shows a histogram of the Autobed's use throughout the day averaged over all 102 days. The data show regular use from approximately 8:30 AM through midnight, with increased use in the evening hours, especially around 8-9 PM. Both Henry and Jane 'strongly agreed' with these data being accurate.

We also examined the distribution of function use between the three controls on the bed based on number of active seconds in the full trial period. Most (91.7%) of use involved adjusting the head of the bed. After that, most of the remaining use (7.5%) involved adjusting the legs, and only 0.5% of the active seconds involved adjusting the bed height. Both Henry and Jane also 'strongly agreed' that these data are correct.

We also examined the duration of sessions of interaction between the user and the Autobed. We define a session as a series of commands which may be separated by periods of inactivity less than 1 minute.

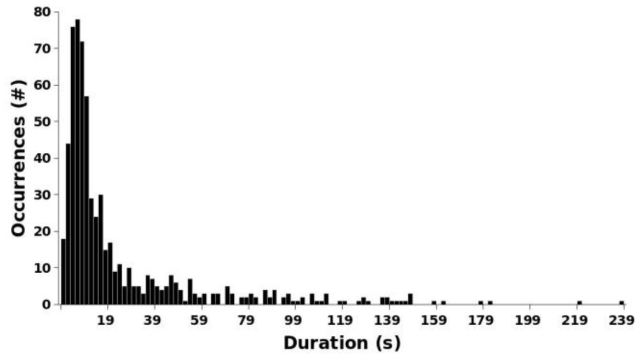

Fig. 6: Lengths of Autobed Interaction Sessions.

The median session duration is 10s, though the shortest lasted only 1 second, and the longest lasted 238s (3 minutes 58 seconds) (Fig. 6).

Henry Evans, "agreed" or "strongly agreed" with all six Likert items regarding Perceived Usefulness, and "slightly agreed" or "agreed" with all items regarding Perceived Ease of Use. Both Henry and Jane "strongly agreed" that Henry uses the Autobed often, that it is reliable, and that it makes Henry more independent.

DISCUSSION

In the questionnaire, Henry indicated that comfort is the main reason he uses the Autobed. He primarily uses the head controls to relieve pressure on his body, and especially his buttocks, a specific point that Jane also cited to explain the primary use of the head adjustment. Henry also "need[s] to raise [his] feet occasionally," but stated that he "rarely need[s] to adjust" the bed height "because it doesn't affect comfort." It appears that the more frequent use in the evenings than during the day reflects the fact that Henry is less frequently in his bed during afternoons than evenings. Henry indicated that the Autobed makes his life easier because it "prevents [him] from lying in pain til [sic] [his] caregiver arrives," and because it "maximizes [his] productive time." Henry also stated that "[the Autobed] has become part of my life. I love it."

Pressure Ulcer Prevention

The generally accepted solution to prevent pressure ulcers is to turn the patient once every two hours (Ostadabbas et al., 2011). However, this may be difficult to achieve, especially for family caregivers with other duties. The Autobed allows patients to take some measures for themselves to relieve pressure, and is especially useful for individuals such as Henry who retain sensation and can recognize pressure build-up. While Henry did not respond to this item, Jane "strongly agreed" that the Autobed helps Henry maintain and improve his health. Both Henry and Jane indicated that the Autobed helps Henry relieve pressure build-up.

Caregiver Perspective

Despite prior research highlighting the importance of designing assistive technologies to be usable for caregivers (Kintsch, et al., 2002), Henry still finds that this is a limitation of many assistive technologies. Henry regularly emphasizes the importance of assistive technologies both being easy for caregivers to use and making the caregiver's life easier (Evans, 2016). Our results suggest that the Autobed meets this requirement. Jane "strongly agreed" with all items relating to Perceived Usefulness of the Autobed as a caregiver, except she "disagreed" that the Autobed improves her performance in caregiving, stating that "it has nothing to do with attitude or capability." She "strongly agreed' that the Autobed is easy to use, and easy to learn to use as a caregiver, but "disagreed" that it was easy to control and that her interaction was clear and understandable, stating that "[she has] never tried it" and "[she doesn't] interact at all with the Autobed except if a wire becomes loose," both of which indicate that the Autobed requires little attention from a caregiver, and emphasizes that Henry is the user.

CONCLUSION

The Autobed represents an open-source method of enabling web control of a commercially available hospital bed to assist individuals with severe motor impairments. By using a web-based interface, a user with motor impairments does not need a dedicated interface such as for an ECU, and can effectively manage his own comfort. We show that the device is reliable, and requires little interaction from caregivers, enhancing the likelihood of adoption, while granting the motor-impaired user increased independence.

BIBLIOGRAPHY

Basmajian, A., Blanco, E. E., Asada, H. H., & IEEE. (2002). The marionette bed: Automated rolling and repositioning of bedridden patients. *Robotics and Automation, 2002. ConferenceProceedings. ICRA'02. IEEE International Conference on*, *2*, pp. 1422-1427.

Chen, T. L. (2014). Haptic interaction between naive participants and mobile manipulators in the context of healthcare. *Dissertation.*

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS quarterly*, 319-340.

Dickey, R., & Shealey, S. H. (1987). Using technology to control the environment. *American Journal of Occupational Therapy , 41* (11), 717-721.

Evans, H. (2016). Evaluating Assistive Devices. Retrieved from https://www.youtube.com/ watch?v=LCvp1Ioh9pA. Cal-Tech MedE105. *Guest Lecture.*

Ostadabbas, S., Yousefi, R., Nourani, M., Faezipour, M., Tamil, L., Pompeo, M., et al. (2011). A posture scheduling algorithm using constrained shortest path to prevent pressure ulcers. *Bioinformatics and Biomedicine (BIBM), 2011 IEEE International Conference on*, (pp. 327-332).

Gillespie, B. M., Chaboyer, W. P., McInnes, E., Kent, B., Whitty, J. A., & Thalib, L. (2014). Repositioning for pressure ulcer prevention in adults. Cochrane Database of Systematic Reviews (4).

Grice, P. M., Chitalia, Y., Rich, M., Clever, H., Evans, H., Evans, J., & Kemp, C. C. (2016, February 3). Autobed: A Web-Controlled Robotic Bed. Retrieved from http://www.webcitation.org/6f1U8gndP

Invacare, Inc. (2007, August). *Owner's Operator and Maintenance Manual: IVC Bed Series* [Rev. F]. Ohio, Elyria.

Kintsch, A., & DePaula, R. (2002). A framework for the adoption of assistive technology. *SWAAAC 2002: Supporting learning through assistive technology*, 1-10.

Mattern, F., & Floerkemeier, C. (2010). From the Internet of Computers to the Internet of Things. Springer.

Seo, K.-H., Oh, C., Choi, T.-Y., & Lee, J.-J. (2005). Bed-type Robotic System for Bedridden.

Van Der Loos, H. M., Ullrich, N., & Kobayashi, H. (2003). Development of sensate and robotic bed technologies for vital signs monitoring and sleep quality improvement. *Autonomous Robots , 15* (1), 67-79.