# Robot Bedside Environments for Healthcare

JOHNELL O. BROOKS[1], IAN D. WALKER[2], KEITH E. GREEN[3], JOE MANGANELLI[3], JESSICA MERINO[2], LINNEA SMOLENTZOV[1], TONY THREATT[3], AND PAUL M. YANIK[2]
Department of Psychology[1]/Electrical and Computer Engineering[2]/Architecture[3]
Clemson University
Clemson, SC 29634
USA
jobrook,iwalker,kegreen,jmanganelli,jmerino,linneas,tthreatt,pyanik@clemson.edu

*Abstract:* - Our trans-disciplinary and trans-generational team is realizing **home+**, an intelligent physical environment featuring a suite of networked, robotic components distributed across any domestic interior. **home+** is aimed at increasing the quality of life of both healthy individuals and persons with impaired mobility and cognitive functioning by intelligently supporting their interaction with their home environment. This paper is focused on a key discrete component of the larger **home+** project: an Assistive, Robotic Table **[ART]**. Physically, **ART** is the hybrid of a typical nightstand found at home and the over-the-bed table universally found in hospital patient rooms, comprised of: a smart storage volume that physically manages and delivers personal effects; a table surface that gently folds, extends, and reconfigures to support work and leisure activities; and an accessorized headboard. These aspects of **ART** recognize, communicate with, and partly remember each other in interaction with human users and, as we envision, with other **home+** components.

*Key-Words:* - Architectural robotics, Aging-in-place, Healthcare, Assistive robotics

## 1 Introduction

Medical facilities and healthcare personnel are overextended and costly; and with the greying of the population there is a smaller segment of the population to both care for and pay for the well-being of the older and clinical population. While in hospitals, technology has become pervasive and indispensable during medical crises; in our homes, technology supporting health and well-being proliferates as software systems and potentially, but much more slowly, as assistive "humanoid" robots [9], [10].

Meanwhile, the everyday environments in which people live everyday lives – even those homes integrating "Universal Design" – remain essentially conventional, low-tech and ill-adapted to dramatic life changes. Despite an overwhelming preference to live at home [2], and a surprising receptiveness to new technologies in the home [7], [8] and outside it [1], many people with reduced mobility, temporarily or indefinitely, are resigned to live in expensive care facilities staffed with costly and overextended healthcare personnel. This urgent crisis places increasing strain on healthcare and family support systems, and represents a failure of science, engineering and architecture to support a population wishing for independent living. The dramatic demographic shift to an older population, globally, highlights this failure and demands urgent response.

Our approach to aging in place [6], [11], [12] represents a significant departure for robotics in healthcare. **home+** is aimed at increasing the quality of life of people inclusively –older and younger people, healthy people and those with temporary or long-standing difficulties with mobility and cognitive functioning – by intelligently supporting their interaction with their home environment. This paper is focused on a key discrete component of the larger **home+** project: an Assistive, Robotic Table [**ART**]. Physically, **ART** is the hybrid of a typical nightstand found in residential bedrooms, and the over-the-bed table universally found in hospital patient rooms, comprised of: a smart night stand that physically manages and delivers personal effects, a continuum table that gently folds, extends, and reconfigures to support work and leisure activities, and programmable, interactive lighting. These three components of **ART** recognize and communicate with each other in interaction with human users. Facilitated by a novel ceiling-suspended sensor parasol that tracks intimate human capabilities [12], **ART** "ages in place" with the people in it.

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We envision **ART** supporting and enhancing people in domestic environments over the greater part of their lifetime. To realize this considerable ambition, **ART** will be developed to accommodate three target groups characterizing three conditions of many people over long time periods: (1) those wishing to age in place, (2) hospital and rehabilitation patients who plan to return to their own home, and (3) high-functioning independent individuals.

Under recently awarded funding, fundamental research involving hardware, sensing and usability is being conducted by Clemson University investigators (the first three authors here) in ECE (Robotics), Architecture (Intelligent Environments) and Psychology (Human Factors) in university labs as well as in our purpose-built **home+** lab, a complete apartment dwelling of our design, realized within the *Greenville Hospital System University Medical Center* [GHS], South Carolina, USA. Our team's key three year deliverable is the full-scale, working prototyping of **ART** to perform "awaking" and "going-to-bed" scenarios for the three target groups defined in the previous paragraph.

This research enables advances in each of the participating communities: (1) for Geriatrics and Rehabilitation, in providing technological means to increase independence; (2) for computer science, a novel "sensor parasol" and associated decision-making software designed to capture and analyze close-range human behaviors in intimate living spaces without the difficulties and privacy concerns of camera-based sensing and sensors attached to the body [12]; (3) for architectural design, the combination of high aesthetics and high-technology in a novel interactive, "architectural robot"; (4) for Psychology, the innovative approach to human mobility and its metrics; and (5) for robotics, a novel morphing "continuum" (table) surface with associated human interface that behaves in a "soft" and life-like way well-suited to interacting with people in intimate physical surroundings.

While there is previous work in adaptable housing for aging in place [8], and specific applications of intelligent machines to aging in place [7], the main thrust of this work represents a departure from other approaches: the creation of intelligent, adaptive physical-digital *environments* for aging in place. **ART** features intelligent behavior and robotic elements in contrast to more typical assistive technologies or medical robotics designed as *substitutes for people*. We envision **ART** and the larger **home+** vision as integral to one's living space. **ART** aims to augment the domestic interior to become a more inviting, responsive and accommodating environment for aging in place, encouraging inhabitants to do tasks for themselves, yet providing assistance when needed.

## 2 Definition and Envisioned Operation of ART

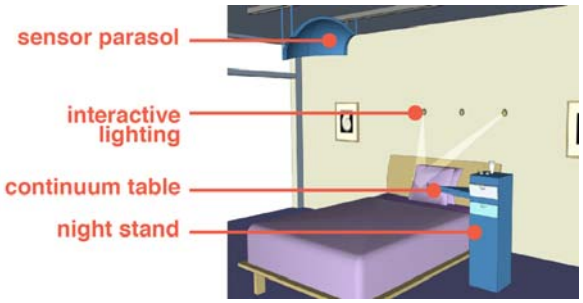


**Figure 1.** An early concept sketch of **ART**, with its key aspects identified.

We envision **ART** having four key components (Figure 1):

• ***A smart night stand*** manages, stores and delivers personal effects, including medical supplies, and communicates to caretakers when eyeglasses and other belongings are not moved over a period of time. It accommodates audio and touch screen computing technologies.

• ***A continuum table*** gently folds, extends, and reconfigures to support work and leisure activities.

• ***Interactive lighting,*** intended for installation behind the bed, sofa, or chair, allows for user and intelligent control of task lighting (on/off, dimming and direction).

• ***A sensor parasol***, ceiling suspended, tracks intimate human needs and capabilities. Physically, we envision this novel "sensor parasol" as a carefully arrayed suite of motion sensors mounted to a morphing surface allowing for detection of human behaviors in an intimate living space (e.g. near and around bed, sink, reading chair) without resorting to potentials invasive cameras and body-worn sensors.

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**Figure 2.** Alternative "Sketches" of what **ART** might look like (our iterative design process has just begun).

These four aspects of **ART** recognize and communicate with each other in interaction with humans and, we envision, with other **home+** components. *Note that figure 1 and figure 3 (to come) are merely sketches of how ART might look and behave.* Our team has facilitated early explorations of **ART** in engagement with a graduate course for Architecture and ECE students taught by the authors (figure 2 shows some of these). These figures represent not a fixed, pre-determined design, only the current state of our research team's continuing iterative design and evaluation over the ongoing development of ***ART***.

## 3 Scenario for a Full Scale, Functioning, Intelligent Prototype

Integrating the hardware, software and sensing aspects of **ART**, two scenarios follow of how **ART** might look and operate, focusing on "Andrea" "Getting out of bed" and "Going to sleep". These two scenarios best afford the research team the opportunity to demonstrate a wide-range of human/system behaviors and consequently define the research scope of the key deliverable for this research: the iterative design, performance and evaluation of a full-scale **ART** prototype operating autonomously in our purpose-built **home+** lab supporting numerous participants representing three target groups.

"Andrea" is a 58-year-old English Professor living independently and actively. In the first scenario, "Getting out of Bed," Andrea is in a hospital room following her treatment from a fall from which she sustained a shoulder injury (table 1 and figure 3 – left). **ART** considers such context as time of day, Andrea's personal data, and in a novel way, her behavior at close range via the sensor parasol. Using this information, the system detects Andrea's activities and gestures to plan and execute appropriate responses.

The second scenario, "Going to Sleep," and **ART**'s participatory role, is described in (table 2 and figure 3 – right). Here Andrea has been released from hospital and is convalescing at home, where a "home" version of **ART** has been installed. Andrea's capabilities are still restricted, the sensor system detects this and tunes ART's responses accordingly, in order to both help Andrea at the moment and also aid her recovery.

In the tables (1 and 2) the scenario is broken down into the interrelated activities of the three key players: Andrea (column 1), **ART**'s hardware system (column 2), and the software system coupling the two together (column 3). The events, in chronological order down the table, for the two scenarios, are detailed in column 4.

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**Figure 3.** Our early renderings of **ART** and "Andrea" interacting. [left] – Getting out of bed during a hospital stay; and [right] – Going to sleep at home.

**Table 1.** Scenario 1. Getting out of Bed.

| User | Hardware System | Software System | Scenario Step |
|---|---|---|---|
| | | 1 | ART initiates its morning reminder service for family visits, nephew's birthday, etc. |
| | 2 | | ART displays the day's appointments: Dr. visit, nephew's birthday, etc. |
| 3 | | | Andrea decides to read for a while before beginning her day. She gestures for the novel she has been reading (overriding system expectations). |
| | 4 | | ART's nightstand component senses the gesture. |
| | | 5 | ART locates the stored novel in its inventory. |
| | 6 | | ART's nightstand retrieves the novel and extends the overbed table to offer it to Andrea. |
| 7 | | | Andrea reaches for the book. She reads for twenty minutes to complete the previous night's chapter and then replaces the book. |
| | 8 | | ART's nightstand component stores the book. |
| | | 9 | ART logs the location of the stored novel. |
| | | 01 | ART plays a prerecorded message from Andrea's young grandchildren which she enjoys. |
| | | 11 | Previous data show a decline in mobility. |
| | 12 | | The bed lowers to facilitate Andrea's transition to a standing position |
| 13 | | | Andrea gets out of bed |

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**Table 2.** Scenario 2: Going to Sleep.

| User | Hardware | Software | Scenario Step |
|---|---|---|---|
| 1 | | | Andrea sits on the edge of the bed |
| | 2 | | The pressure mat beneath the bed detects her presence |
| | | 3 | Previous data show a decline in mobility |
| | 4 | | The bed rises to a reclining configuration to reduce back strain. |
| 5 | | | Andrea reclines on the bed |
| 6 | | | Andrea reaches (gestures) to ART's bedside table for the novel she has been |
| | 7 | | ART senses the gesture |
| | | 8 | ART uses current context to initiate transfer of Andrea's novel |
| | 9 | | The nightstand retrieves the stored novel, approaches, and extends the overbed |
| 10 | | | Andrea has difficulty lifting the heavy hardcover novel. |
| | 11 | | ART's nightstand senses the slowness of the transfer |
| | | 12 | ART executes exception handling: repositioning book by extension of table |
| | 13 | | The nightstand repositions the book closer to Andrea to ease the handoff |
| 14 | | | Andrea obtains her book |
| 15 | | | Andrea reaches (gestures) to actuate the overhead reading light |
| | 16 | | The environment senses the gesture |
| | | 17 | ART determines reading session beginning, brightens overhead reading light |
| | 18 | | The environment slowly brightens the reading light |
| 19 | | | After reading, Andrea replaces the book and dims the lights |
| | 20 | | The side-table stores the book |
| | | 21 | ART adds the book to its inventory database. |
| | | 22 | ART logs Andrea's reading time as a possible wellness metric. |
| | | 23 | ART uses current context to initiate storage of Andrea's reading glasses. |
| | 24 | | The side table offers the receptacle in which Andrea's eye glasses are stored |
| 25 | | | Andrea places her bifocals in receptacle, gently pushes (gestures) nightstand |
| | 26 | | The sidetable stores away the bifocals and withdraws to its resting position |
| | | 27 | ART adds Andrea's glasses to its inventory database. |
| | | 28 | ART uses current context to initiate posing the room into sleep configuration. |
| | 29 | | The bed lowers to a lying configuration |
| | 30 | | Low level lighting slowly dims and turns off |
| | 31 | | ART plays soft music until Andrea falls asleep |
| 32 | | | Andrea goes to sleep |

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## 4 Conclusion

Our research team – trans-generational and trans-disciplinary - has previous experience in creating robotic environments [3], [4], and has already begun pilot work on this project on its human factors aspect, its sensing aspect, and its overall, rough-but-working "proof of concept" demonstration of **ART** (created in hardware and software as a "sketch" prototype over several weeks) (see video link [5]). Collectively, these early efforts establish the opportunities, challenges and overall viability of realizing our ambition, and demonstrate the effectiveness of the team, but represent only a beginning. **ART** has the potential to be life changing, allowing the aging population to age in place; allowing clinical populations more independence; and allowing healthcare professionals to increase the quality of their interactions with their patients.

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