Design and Evaluation of a Nonverbal Communication Platform between Assistive Robots and their Users

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Abstract. Inevitably, assistive robotics will become integral to the everyday lives of a human population that is increasingly mobile, older, urban-centric and networked. *How will we communicate with such robots, and how will they communicate with us?* We make the case for a relatively ``artificial" mode of nonverbal human-robot communication [NVC] to avoid unnecessary distraction for people, busily conducting their lives via human-human, natural communication. We propose that this NVC be conveyed by familiar lights and sounds, and elaborate here early experiments with our NVC platform in a rehabilitation hospital. Our NVC platform was perceived by medical staff as a desirable and expedient communication mode for human-robot interaction [HRI] in clinical settings, suggesting great promise for our mode of human-robot communication for this and other applications and environments involving intimate HRI.

Keywords: assistive robotics, nonverbal communication, human factors, human-centered design.

1 Introduction

The overwhelming demands on healthcare delivery, alone, will compel the adoption of assistive robotics as integral to the everyday lives of a human population that is increasingly mobile, older, urban-centric and networked. We consequently envision a future *ecosystem* comprised of assistive robots of *wide-ranging functionality* --- not only the highly-functioning humanoid but also the ubiquitous Roomba. Across this ecosystem, *how will we communicate with such robots, and how will they communicate with us?*

Towards a response, we build upon our lab's research developing an Assistive Robotic Table [ART] [1-4] and make the case for a relatively ``artificial" mode of *nonverbal human-robot communication* [NVC] to avoid unnecessary distraction for people, busily conducting their lives via human-human, natural communication. In this way, robotic artifacts, living and working with us and for us, do not run the risk of demeaning what it means to be human. We propose that this NVC be conveyed by

N. Streitz and C. Stephanidis (Eds.): DAPI/HCII 2013, LNCS 8028, pp. 505–513, 2013.

familiar Audio-Visual means: lights and sounds. Informed by an understanding of cognitive, perceptual processes, our NVC platform affords a communicative dialogue that conveys the purpose of accomplishing tasks. The employment of learning algorithms will offer both user and robot the capacity to interrupt the dialogue and modify utterances. A user-friendly tablet interface allows for the addition of new utterances to the platform. Our hypothesis: *that our NVC platform will be perceived as a desirable and expedient communication mode for HRI, proving to be particularly effective in clinical settings, and promising to be apt and productive in intimate HRI applications at home, as well as in spacecraft and other extreme environments.*

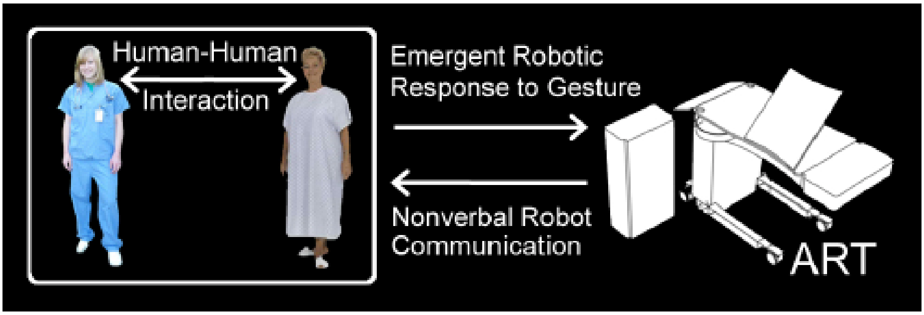


Fig. 1. Proposed Human Robot Interaction

2 NVC: Theory and Related Work in NVC

With respect to human-machine communication, research has suggested that people tend to react adversely to robots issuing commands to them in spoken language or dictating the terms of their interaction in spoken language [5-7]; instead, people have been shown to be relatively more receptive to non-verbal communication emanating from robots [5, 7, 8]. But whatever side one takes in the human-machine communication debate, nonverbal communication has received much more attention from investigators working with humanoid or zoomorphic robots [9-12] (e.g., where the robot is communicating in the manner of, respectively, a human being and household pet) than with investigators employing robots that are not humanoid or zoomorphic. It has been shown that people can easily interpret the meaning of nonverbal utterances (see [12-13] for overviews of this literature). As well, people who are ill or in pain tend to reduce their level of verbal communication, making more use of nonverbal communication [14]. It is noteworthy, as well, that the nonverbal communication of American Sign Language is reportedly more effective ``than spoken English because of the linearity of spoken language" [15]. Collectively, these findings and observations further underscore the need for, and desirability and promise of, a novel NVC-approach like ours to HRI for robots of wide-ranging appearances and behaviors.

Closer to our own investigations reported here, the related research employing non-humanoid, non-zoomorphic robots conveying nonverbally has been limited to human-robot communication that remains uni-directional: participants in previous studies do not communicate with the robot(s) but instead, assume the role of *the recipients* of the robot's utterances (e.g., [8, 16-18]). In our research trajectory, beginning with the experiments presented in this paper, *we envision a bi-directional "communication loop" and add to the aforementioned investigations:* larger sample sizes, focus groups with assessments employing not only interviews and questionnaires but also tablet interfaces for direct user-modifications, EEG headsets for measuring user satisfaction, and NVC evaluation within the real-world situation of a rehabilitation hospital where the stakeholders --- clinicians, post-stroke patients, and their intimates --- can advance it. ``There has been little research," of the kind proposed here, situated ``in the wild" and ``focused on bi-directional human-robot communication employing models of nonverbal communications as both input and output" [19] (Fig. 1).

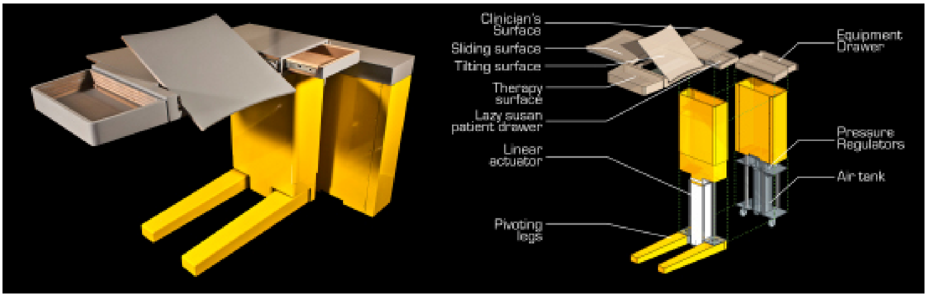


Fig. 2. Assistive Robotic Table (ART)

3 Experiment Overview

In our investigation, we designed and evaluated several alternative modes of nonverbal, robot communication towards establishing an effective NVC loop (as conceptualized in Fig. 1) --- one that is efficient, expedient, user-extendable and user-customizable. For this and future experiments, we embed our developing NVC platform in a real-world context, the Roger C. Peace Rehabilitation Hospital of the Greenville Hospital System University Medical Center, where medical clinician's and their post-stroke patients determine its effectiveness. Soliciting user-input over the course of our research will allow the NVC platform to ``evolve," and ensures utility for a broad range of users.

The robot we employ for this investigation is a novel one developed in our lab: the Assistive Robotic Table [ART] presented in figure 2. The result of participatory design and evaluation with clinicians, including doctors, nurses, occupational therapists, physical therapists, and speech therapists, at the Roger C. Peace Rehabilitation Hospital (hereon identified as ``RCP"), ART is comprised of a cantilevered, over-bed table. The robotic table has two degrees of freedom: it raises and lowers from its base and has a tilting work surface. At the extreme tip of the table surface is a continuum-robotic surface supporting post-stroke patient therapy, actuated by twelve pneumatic muscles (with, theoretically, infinite degrees of freedom).

In our study, clinicians were told that they would evaluate a non-verbal communication platform consisting of lights and sounds. The clinicians were told that the sounds were designed for specific actions that ART would perform. The lighting or display type (individual LEDs or LED screen) would also communicate what actions ART would perform. As these are the first steps in the development of our NVC, the following scenario helps define the character and vision of our NVC as integrated into ART.

4 Scenario

Joanne, a post- stroke patient, is rehabilitating at RCP. Next to Joanne is ART, a robotic table that assists Joanne in her rehabilitation. Joanne's sister, Amy, enters Joanne's room. Joanne asks Amy to borrow her computer to check her email. To accommodate the computer, Joanne would like ART to raise and position its flip tray for her. Joanne still feels a little unsteady holding things; ART can provide the needed support for this activity. While Joanne and Amy continue their exchange, the following nonverbal dialogue occurs between Joanne and ART:

Joanne: [Gestures ART to kindly rise and tilt, as if to say, ``ART, please rise and tilt for me."]

ART: [Displays **two quick light flashes** and a **beep beep** sound , as if to say, ``Yes, I am pleased to do that for you."]

All the while, Joanne and Amy are chatting, catching up on recent news in their lives and the world. A few moments later:

Joanne: [Gestures for ART to raise, but ART does not comprehend at first].

ART: [Displays **blinking lights** and a sound that, if written, might be **ant ant**, as if to say, ``Hmmm, I don't know what you are asking of me. I am puzzled."]

Joanne: [Makes the gesture once more in a way that ART comprehends, learns from, and responds with the correct behavior.]

{\itshape To reinforce ART's actions},

Joanne: [Runs her hand along ART's sensors at the perimeter of the table, in what appears to be a ``pet" to convey, ``Thank you."]

ART: [Displays **gradient on/off light pattern** and a **purrr** sound, as if to say, ``I understand that I performed the task correctly!"]

ART communicates with Joanne nonverbally; consequently, ART neither competes for Joanne's attention nor detracts from Joanne and Amy's intimate conversation. As an intelligent machine, ART operates at a level that lies between an application-specific robot and a humanoid.

5 Method

5.1 Participants

Volunteers for this study consisted of research team members and clinicians at RCP. Eight members of the research team participated in the pre-study activities. Thirteen subject-matter experts --- all clinicians including doctors, occupational, physical, speech therapists, and environmental service technicians --- participated in the research study. Given the small sample size, descriptive statistics were assessed (i.e., no statistical validity could be determined). In the interest of protecting the privacy of this small, exploratory sample population and based upon the conditions of the approval for this study-design by the *hospital's* institutional review board, demographic data are not presented here.

5.2 Procedure

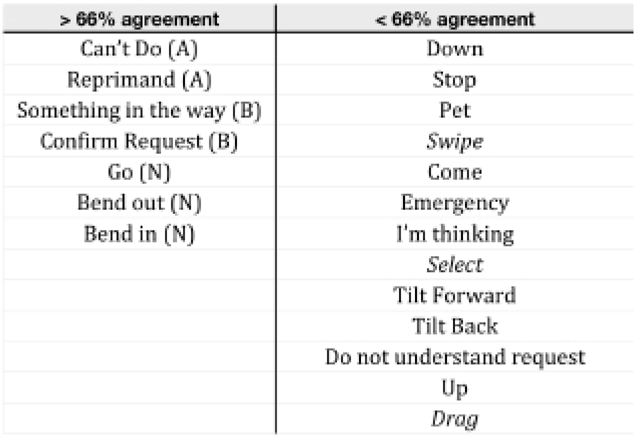
To develop the NVC, eight members of the research team, who were not subject-matter experts, participated in brainstorming activities to provide a list of twenty actions by which the NVC could be matched to ART (e.g., *up, down, forward, back, correct action, something is in the way, I don't understand*). The lab members then met in small groups to generate potential sound and lighting sequences to describe the actions. Regarding which sounds and lights were best matched to a given action, there was consistency, both within the groups (e.g., by a group discussion) and between the groups (e.g., after all the focus groups were conducted, each team member completed a survey about his or her sound and lighting contribution). This information served as the beginning for the research sessions. Each focus group session was conducted in less than sixty minutes. The survey was completed in less than sixty minutes.

Data for this descriptive study were collected through structured interviews and recorded on a personal computer. Approval from the appropriate institutional review boards was obtained prior to data collection. Clinicians at RCP were interviewed in focus groups of 3-5 over three days. Each clinician had participated in previous research sessions for ART, were familiar with the research efforts, reviewed the study's informational letter, and had given consent to participate. The clinicians were told the purpose of the study was to evaluate lights and sounds, two features to be added to ART, as each related to patient-clinician communication with an assistive robot. Each session had one research moderator and a note-taker for every two participants. The clinicians sat across from the research moderator at a long table with the note-taker beside the volunteer. Audio speakers to play the sounds were placed on the table in front of the clinicians equidistant from each other and the clinicians.

Two feedback methodologies were used: open-ended response and a forced-choice methodology. Open-ended questions were used to determine clinician preferences for NVC in healthcare environments. The forced choice methodology required the clinicians to verbally select their preference from a choice of *A, B, or Neither* after each sound played (two sounds for each of the 20 ART actions). Similarly, the clinicians chose between two lighting prototype designs (individual LEDs or LED screen) that were presented. The clinicians were told that the lighting would display information regarding the 20 ART actions. Finally, on a sheet of paper showing three architectural-drawn views of ART, each clinician marked where he or she thought the light communication displays should be located (Fig. 4) and verbally answered how he or she would customize the display. Each focus group took less than sixty minutes.

6 Results

Figure 3 shows the percentage preferences of the clinicians for the 20 sounds tested. More than two-thirds (66%) of the clinicians had to select the sound for it to be evaluated as a preferred sound. Interestingly, a specific *Can't Do* sound was chosen by all clinicians in the study. The clinicians maintained a majority preference for the *Reprimand* (92%), *Something in the way* (84%), and *Confirm request* (76%) sounds.



> 66% agreement	< 66% agreement
Can't Do (A)	Down
Reprimand (A)	Stop
Something in the way (B)	Pet
Confirm Request (B)	*Swipe*
Go (N)	Come
Bend out (N)	Emergency
Bend in (N)	I'm thinking
	Select
	Tilt Forward
	Tilt Back
	Do not understand request
	Up
	Drag

Fig. 3. Clinician Agreement on Sounds

Of the seven sounds that had a preferred choice, three sounds (*Go, Bend Out, Bend In*) had a preference for *Neithe*r sound. The *Bend Out* and *Bend In* sounds relate to an added therapy surface feature (see figure 2) that will be used by clinicians to help expedite stroke patient recovery. Overall, the clinicians did not feel that a sound was required for these movements because clinicians would be interacting with the patient during these sessions. Because the *Go* sound is an important feature designed for the mobility of ART, it will be retested and evaluated in a session with an interactive prototype to ensure that the sound is not required. The remaining sounds that did not have majority preference will also be retested in a future research session with an interactive prototype.

Figure 4 shows the clinicians' location preferences for selected lighting display prototypes as a ``heat map". Four participants chose an LED screen, six participants chose the individual LEDs, and three participants chose both displays. The green color represents the individual LEDs, and the blue color represents a LED screen. The color shade variations describe the number of participants who placed the lighting type in the same location. From this data, we can see a trend for the lighting displays. The individual LEDs were drawn on the edges of ART, while the LED screens were drawn primarily on ART's table top surface. Clinicians' preferences for customization of the lights included the brightness of the LEDs and the colors displayed, primarily red, green, yellow. However, one participant noted that red and green should not be used due to patients who are color blind.

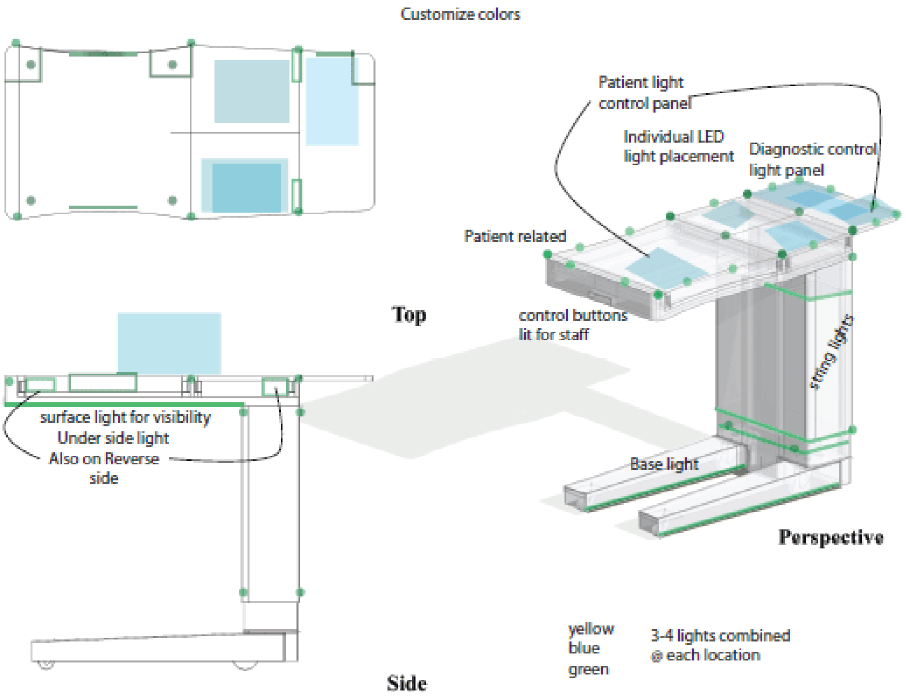


Fig. 4. Clinician Lighting Location Heatmap

At the beginning of each study session, clinicians were asked the following: *If ART had the ability to communicate, would the clinicians communicate with ART?*. The clinicians unanimously agreed that they would like to communicate with ART. Clinicians then answered 12 open-ended questions regarding what types of information are appropriate in the healthcare setting, how the information should be communicated, and the interaction with stroke patients. Finally, clinicians were asked again if they would communicate with ART. Again, 100% of the clinicians said that they would like to communicate with this assistive robot.

Interestingly, the clinicians proposed a different nonverbal communication focus than the research team; the clinicians proposed patient care terminology instead of “the state of ART” terminology (e.g., up, down, emergency) proposed by the research team. A content analysis, developed by frequency analysis, showed that 10 clinicians preferred that ART communicate orientation information (e.g., day, date, time, schedule, nurse's name) to the patients. Eleven clinicians stated that they would program ART to give the patients clinical reminders (e.g., bed safety, fall safety, therapy assistance) to assist in patient care. Despite no overwhelming majority, clinicians also stated that they would like ART to increase their ability to care for the patient by ART communicating to the clinician the patient's vital signs, if the patient attempted to get out of bed, and if the patient attempted to perform their therapy homework.

After the first focus group, the research team determined that clinicians were proposing a different communication focus than the research team (patient care versus the state of ART). Two additional questions were subsequently added to our interview: *If ART had the ability to `communicate' the way the research team proposed, would you use our NVC platform?* and *Do you think stroke patients would use the platform the research team proposed?*. All clinicians who responded to these questions (N=9) said that they and their patients would communicate with ART, given the researchers' proposed platform. Additionally, two participants stated that their decision to use our proposed platform would also depend on the patient's condition. This line of questioning was designed to capture whether or not the clinicians had a change of mind concerning the NVC embedded in ART.

7 Discussion

This pilot study sought to understand clinician preferences for an NVC platform comprised of lights and sounds for a robot envisioned for intimate human-robot interaction. This study provided: (1) insights on methodologies to iteratively design and evaluate NVC platforms, (2) a sense of how clinicians view an NVC platform, (3) the preferences of users (clinicians, here) of an NVC platform for two features (lights and sounds), and (4) a sense of whether clinicians and post-stroke patients might use an NVC that was integrated into an assistive robot intended for their use. Following this research phase, our lab will conduct two additional phases in spring 2013. For the first of these two next phases, clinicians will evaluate two lighting patterns (using individual LEDs) for each of the 20 ART actions and sounds (that did not receive a majority preference for specific ART actions) with the working ART prototype. In the last of the anticipated research phases, clinicians will evaluate a refined list of lighting patterns and sounds embedded within our final ART prototype.

In NVC research, researchers should consider both clinician and patient input, ambient monitoring, the ability of the NVC platform to ``understand" (i.e., learn of) its users, and the ability of an assistive robot like ART to convey information. NVC platforms must be integral with the robot, developed to accept multiple sources of input, act on the data given, and present data back to the user. More broadly, a dynamic NVC like ours may improve job performance of caregivers and increase patient satisfaction.

Acknowledgment. This research was supported by the U.S. National Science Foundation under award IISSHB-116075.

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