

ARNA, a Service robot for Nursing Assistance: System Overview and User Acceptability

Shamsudeen Abubakar, *Student Member, IEEE*, Sumit K. Das¹, Chris Robinson, *Student Member, IEEE*, Mohammed Nasser Saadatzi¹, M. Cynthia Logsdon, Heather Mitchell, Diane Chlebowy, Dan O. Popa²

Abstract—Using robots capable of collaboration with humans to complete physical tasks in unstructured spaces is a rapidly growing approach to work. Particular examples where increased levels of automation can increase productivity include robots used as nursing assistants. In this paper, we present a mobile manipulator designed to serve as an assistant to nurses in patient walking and patient sitting tasks in hospital environments. The Adaptive Robotic Nursing Assistant (ARNA) robot consists of an omnidirectional base with an instrumented handlebar, and a 7-DOF robotic arm. We describe the novelties in its mechanisms, controller and instrumentation. Experiments with human subjects that gauge the usability and ease of use of the ARNA robot in a medical environment indicate that the robot will get significant actual usage and are used as a basis for a discussion on how the robot's features facilitate its adaptability for use in other scenarios and environment.

I. INTRODUCTION

According to the International Federation for Robotics (IFR), with an average year-on-year sales growth rate of 21% between 2017 and 2021, robots that support a human in providing a service as opposed through automation, these robots are in high demand [1]. Of the varied fields in which service robots are used, those used in manufacturing including Autonomous Ground Vehicles (AGVs) for logistics support and inspection and maintenance, and medical robots for assisted surgery, physical therapy and rehabilitation have the fastest growth with 41% and 50% increase in their sales between 2017 and 2018. Service robots for use in domestic environment are also another notably rising group.

This demand for service robots is partially driven by the need for physical Human Robot Interaction (pHRI) capabilities to achieve tasks in a dynamic environment. In addition, safety requirements for human user(s) who are often near the robot, service robots often need to be effective in cluttered, unstructured spaces. Some collaborative robots that have been used as service robots in the manufacturing sector include an object fetch and delivery system in a warehouse in [2], a collaborative mobile production assistant in [3] and a part-assembly arm used in [4]. In the healthcare industry, collaborative service robots have been used in the

surgeries, patient monitoring and mobility; the latter tasks falling into a category of tasks for a nursing assistant robot [5-7].

There is a need for more works in the study of usability and acceptability of the human users that have to work closely with service robots that are capable of pHRI. In particular, there are only few research works that yield insights related to improvements and reassurance on the design and development of service robots that would impact the actual usage of the robots. In [8], a study of human-robot interaction with several humans in a manufacturing workshop is presented, but the focus of the work is on how sociological factors like intercultural communication and anti-oppressive practice can impact the humans working in such environment. [9] is a literature survey-based discussion on the challenges of obtaining safety standards in manufacturing environments with humans and pHRI capable robots. Works of this nature that have been done with service robots used in the healthcare sector include [10] where Nima et al. analyze the challenges and benefits of robot-assisted surgery. One of their conclusions is the need for more works that evaluate robot-assisted systems with quantitative metrics in order to facilitate improvements in the development and adoption of such systems. In [11], the development of a stiffness sensor for use with a human-lifting robot is presented but the authors do not present details of the questionnaire survey used to evaluate patients' comfort with the sensor and robot system. In [12], a more detailed analysis of the questionnaire-based study was presented but was focused on the perception of users on being touched by a robot and not their whole interaction with the robot in carrying out a task.

In this paper, we describe work with the Adaptive Robotic Nursing Assistant (ARNA), a service robot capable of providing physical assistance to a human user in healthcare environments. We present the system description of ARNA, including its mechanisms, control system and sensor interfaces. Novel contributions of this work include its multi-sensor instrumentation board for heteroceptive sensing, and the use of a neuroadaptive controller that provides tunable pHRI with different users. Currently, the ARNA robot is also being deployed in our laboratory building to help sanitize surfaces of common use during the Coronavirus Pandemic. This is achieved with a shared/supervisory control scheme. The robot's use to help during this pandemic is intended to be similar to efforts like those in [13] and [14] that feature other robots used during the 2014 Ebola crisis.

We also report results from user experiments conducted

¹ Member, IEEE

² Senior Member, IEEE

This work has been supported by US National Science Foundation under the grants 1849213 and 153412 through the Kentucky EPSCOR KAMPERS project. We would like to acknowledge the efforts of Joe Tabler, Emily Legg and Penelope Jankoski in conducting the user experiments and analyzing user data.

The authors are with Next Generation Systems at the Department of Electrical and Computer Engineering, and the School of Nursing at University of Louisville, KY, USA.

with ARNA in patient sitting and patient walker scenarios with 24 human subjects. Sensor data and questionnaire responses collected during the experiments were used to analyze user preferences and interaction performance over trials and controller settings. We also discuss results of using an established approach to analyze their answers to questionnaires to measure the robot's usefulness and ease of use with the Technology Acceptance Model (TAM). The usability and ease of use results indicate that the robot will find frequent use in providing patient walking and patient sitting assistance to nurses in a healthcare environment.

The paper is organized as follows: in Section II we describe the hardware and software subsystems of ARNA and in Section III, we describe the experiments with human subjects. In Section IV, we present an analysis and discussion of results from the user experiments and insights on the design, use and adaptability of the ARNA robot and Section V concludes the paper and discusses future work.

II. SYSTEM

The primary tasks which are intended to be achieved by the ARNA robot can be defined as:

- **User sitter:** This is a task wherein the robot monitors a user and responds to remote commands. In a hospital room, this can be useful for monitoring bedridden patients for their vitals or providing entertainment. Such item fetch-and-retrieve capability can be used by a bedridden patient.
- **User walker:** In this mode, the robot provides ambulatory support to a user while transporting an object. It can transport objects by holding or dragging them with the end effector of the robot's arm (such as IV pole, part on a wheel platform) or having the object otherwise attached to it on the arm-riser platform (such as a hospital bed) - while a user controls its motion while walking behind it or riding on the footrests attached to the robot.

To carry out these tasks and potentially other complex tasks, the ARNA robot has been designed to perform the following functions:

- Autonomous navigation in unstructured environments.
- Pick and place of certain classes of objects in the environment.
- Heteroceptive sensing of environments and human health.
- Interface with a human user via physical and teleoperative means.

A. Hardware Platform

Fig. 1 shows the ARNA robot, a mobile robot equipped with a 7-DOF robotic arm. Constructed in-house and designed to be capable of transporting heavy loads, it has a base footprint of 1.14m x 1.14m and weighs 226.7 kg. The base uses 4 mecanum wheels to provide a capability for omnidirectional motion for efficient navigation of the cluttered and unstructured spaces in which the robot is envisioned to be used. While the robot's arm has a stated

reach of 0.8m, a riser mechanism on the ARNA robot is used to extend the arm's effective reach to 1.2m. Connecting platforms such as those that attach the arm to the riser, and the one that connects the handlebar to the force/torque sensor are designed to be adaptable for attaching another kind of arm or input interface. The connecting platform is also implemented to allow the connection of the ARNA robot to other objects such as a hospital bed or a tote bin for used for delivery in a hospital.

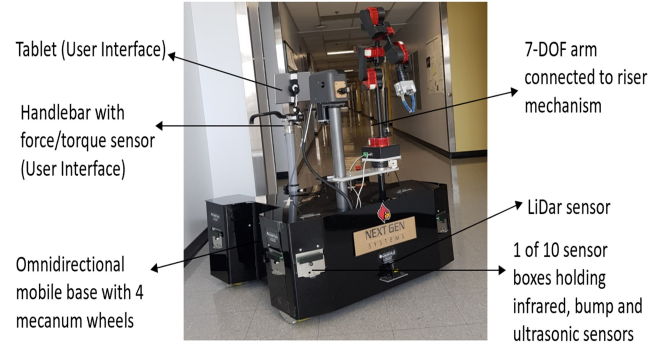


Fig. 1: ARNA robot

B. Instrumentation

A sensor system for environment sensing, early warning and emergency stopping is a key component of the ARNA robot. Fig. 2 shows the sensor suite that has been strategically installed on the robot.

This includes 12 ultrasonic sensors distributed around the robot for detecting approaching obstacles and infrared (IR) sensors that are placed close to the ground and act as level sensors to detect changing heights of surfaces that the robot is navigating. Imaging sensors include an ASUS Xtion Pro Camera and Hokuyo URG LiDAR. These sensors are used in a Simultaneous Localization and Mapping (SLAM) system that facilitates autonomous navigation of the robot. Emergency halting of the robot is implemented using bump sensors that when collided with, say by an object suddenly, causes an immediate stopping of the robot by disconnecting all motors from their power supply.

Sensors that facilitate PHRI with the robot include an ATI Axia 80 force-torque sensor that is installed under the handlebar to sense user interaction forces. The adapter for installing this sensor is modular in a way that facilitates quick change for maintenance and using another device for the user to use in interacting with the robot. Another force-torque sensor, Delta model by ATI-IA USA, is installed under the 7DOF arm of the robot. We used data from this sensor in [15] for locating and estimating external forces and torques on the robot's arm in order to detect collisions and user interaction.

A novel component of the ARNA instrumentation subsystem is the protocol for reading data from sensors with serial readouts from the IR, ultrasonic and bump sensors. These sensors connect to a microcontroller unit (MCU), which is in turn connected to the robot computing system running Robotics Operating System (ROS). A novel protocol provides a bi-directional asynchronous sensor data over the

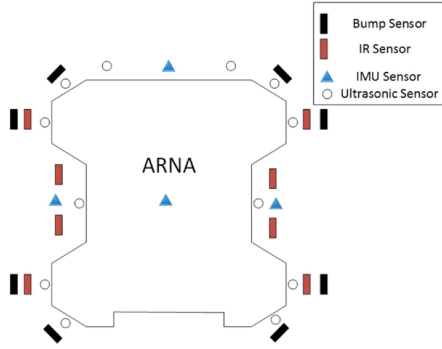


Fig. 2: Top-view diagram of sensors placed around the ARNA robot. Physically, sensors were installed and wired to modular sensor boxes that include bump, IR, IMU, and ultrasonic units.

native hardware USB-Serial. Efficiently designed definition files facilitate packet parsing in both directions - to and from ROS and the MCU - and are used to create individual ROS topics for all available data streams. Fig. 3 below shows the architecture of this protocol and how it is interfaced with ROS through a bridge node.

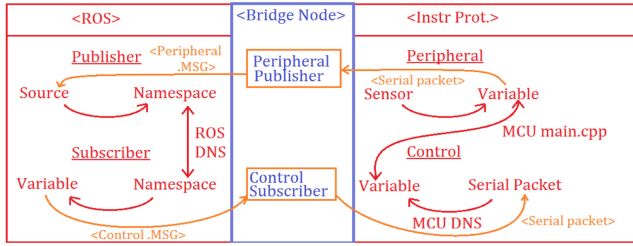


Fig. 3: Architecture of a novel protocol that was implemented to interface serial readout sensors to ROS.

In its essence, the novelty of this protocol is a firmware-level implementation of topics used in the ROS network. By using customized structured message types that are passed as shown in 3, a lot of overhead is removed from the protocol while allowing a significant proportion of error rejection, increasing speed and fidelity at the same time. Fig. 4 shows a latency comparison of the novel bridge instrumentation protocol used on the ARNA robot and a typical implementation with the commonly used ROSSerial library.

C. Interfaces

Several devices are used to facilitate user interaction with the ARNA robot including a Bluetooth-capable joystick for teleoperation. A handlebar with a force/torque sensor provides a pHRI interface as described earlier and an android tablet, shown in Fig. 5, that is used to develop and deploy apps to connect to the robot and issues commands through on-screen buttons and voice commands. The robot is implemented to facilitate a relatively easy hardware and software incorporation of other interfaces like array of skin sensors placed on the handlebar or a integrating with a

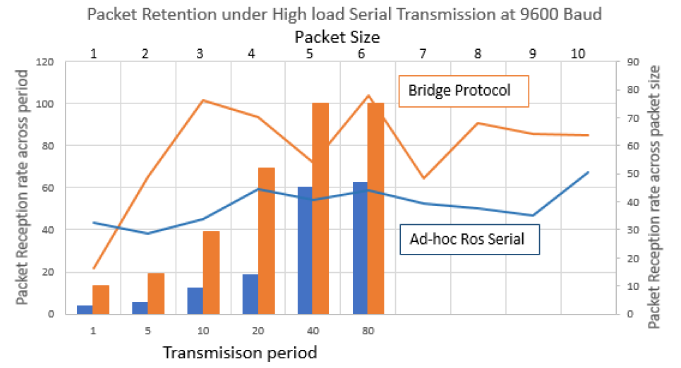


Fig. 4: Packet transmission as a function of transmission period and average throughput over packet size between the bridge protocol and brute force ROS Serial.

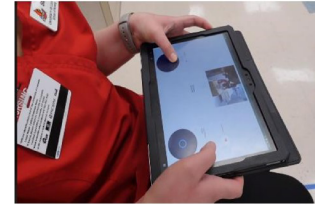


Fig. 5: User using tablet interface showing camera feedback, and divot controls for base and arm teleoperation.

human-located sensor interface like the Myo armband for recognizing activity of a nurse or rehabilitating patient [16].

D. Control

The ARNA robot is envisioned to be used with users of different physical capabilities - like in different patients with different levels of physical strength in a hospital - and in different scenarios - like with supporting objects of different weights in industry. Impedance and admittance control are two main approaches to having this sort of control. For core trajectory tracking the ARNA robot, our main approach is the Neuroadaptive controller (NAC), a feedback linearizing control strategy.

As presented in the seminal work on NAC in [17], it is two-loop neural network-based control algorithm with Lyapunov styled proofs of stability. Compared with the PID and adaptive impedance/admittance control strategies, the NAC is model agnostic to a wide class of models and requires less effort to tune. In [18], we experimentally showed that using the NAC to physically interact with a robot requires a smaller interaction effort, e.g. force to achieve a motion objective that other classical controllers. We also demonstrate the ability of the NAC to be used to actuator torques at the joints of a robot arm using a Force/Torque sensor located at the base of the arm [19].

The quality of human intent estimation is a critical factor in the utility provided by a robot in pHRI. The ARNA robot design also use a Neural network-based approach to estimate human intent in the Adaptive Interface module shown in Fig. 6 above. We show in a previous work [20] that using this strategy in conjunction with the NAC for tracking control

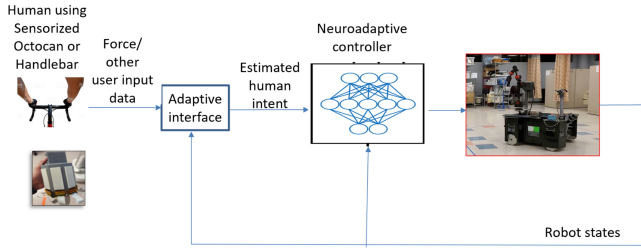


Fig. 6: ARNA's Impedance control with adaptive interface strategy that uses Neuroadaptive controller as core controller.

resulted in a better overall experience for the user with respect to effort and task completion-based metrics than a direct mapping of user efforts to actuator commands.

For navigation control, we build on implementation and research in [21] which presents our previous work on trajectory generation and obstacle avoidance for the Neptune robot which is a smaller mobile manipulator robot with some of the core components of the ARNA robot.

E. Software Architecture

Computing resources on the robot include two single board computers - Æ Nvidia Jetson TX2 and VersaLogic EPU 4562 Blackbird - and a Netgear Nighthawk AC1900 router to provide high-fidelity local network for interfacing and remote control of the robot. Robot Operating System, ROS, framework is the primary implementation platform, which means software development is fundamentally modular and is suited for leveraging useful robotics software that are open-source available.

For different use case scenarios with the ARNA robot, different levels of autonomy would be appropriate. To facilitate the effective usability of the robot for different use cases with different task description and accomplishment requirement and sensor data requirement, we implement software of the ARNA robot using a novel software architecture named Directed Observer Lead Assistant (DOLA) framework.

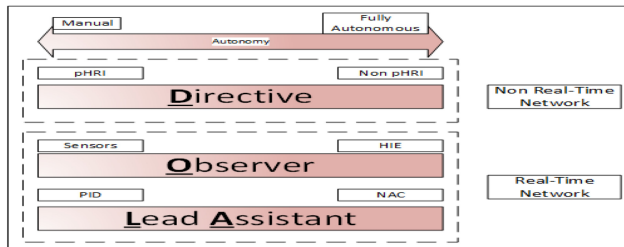


Fig. 7: Directive Observer Lead Assistant (DOLA) software framework used on the ARNA robot to facilitates its functioning in different autonomy levels, from manual to fully autonomous.

The three main functional blocks of the architecture of the DOLA framework shown in Fig. 6 are:

- 1) Directive: The Directive block defines the user instructions or directives to be followed during any HRI

process. The details of the tasks to be performed are stored in this functional block, and data from the human-machine interfaces are included here as user commands.

- 2) Observer: During HRI, the Observer block monitors the user parameters and estimates the user's intentions in real-time. This ensures safety and facilitates adaptability to different users.
- 3) Lead Assistant: This block contains real-time controllers for the robot such as the Neuroadaptive controller described in Section II-D and low-level PID controllers.

Overall, DOLA is an agile framework that facilitates efficient task completion in the presence of varied use conditions and autonomy levels while maintaining safety and usage standards.

III. USER EXPERIMENTATION

ARNA was designed and developed with some input from experienced nurses whose input was also essential in the design of the experiments described in this section where test users used the robot in patient walking and sitting scenarios.

The experiments described in this work were conducted at a hospital room simulation suite located at School of Nursing (SoN), University of Louisville, Kentucky, USA. The test users were students from the nursing school who volunteered and were physically capable to perform the required tasks in the experiments. The university's Institutional Review Board granted approval to conduct the experiments under IRB no. 17.0609. Each experiment session involves the users performing the experiment initially signing consent forms and then an experiment administrator describing the tasks to be performed to the test users. The tasks are carried out by the users while being monitored by the experiment administrator. Quantitative data describing robot's states are recorded during the experiments and at the end of each task, questionnaires are filled out by the users.

The seminal work in [22] presents the Technology Acceptance Model (TAM), which is a method for analyzing user data collected through Likert-scaled questionnaires in order to estimate the Perceived Usefulness (PU) and Perceived Ease of Use (PEOU) of a new technology as part of a set of measures that are related through hypotheses that predict the actual use of new technological devices and systems in a certain field. The work presents statistical analysis of how questions with certain themes such as productivity, time use, clarity and controllability correlate with each measure. It has been used in pHRI related works to evaluate human-robot cooperation in production systems [23], care-giving robots [24] and several other applications are reviewed in [25]. In this work, we evaluate the PU and PEOU of the ARNA robot in patient sitter and patient walker tasks from test users' answers to questionnaires under themes suitable for PU and PEOU evaluation as presented in [22].

A. Patient Walker

The patient walker task refers to a task where the ARNA robot is used as a user walker to provide ambulation assistance with stability support to a patient. For these patient walker experiments, the user navigated the robot through the handlebar while the robot's arm held an IV pole. The user objective during each run of the patient walker experiment was to have the user move along a desired path that is marked on the floor of the simulated hospital environment with the robot while the robot holds an IV pole. Another test user acting as a nurse walked alongside the user and robot in a supervisory role while holding an emergency stop to stop the robot should the user and/or robot get into a dangerous situation. Fig. 8 shows a typical scenario in the patient walker experiments and the desired path of travel in a sample run.

At the end of the experiment, the "nurses" filled out a Likert scaled questionnaire with that was used to evaluate the PU and PEOU of the ARNA robot as a patient walker. The 24 test subjects for these experiments were divided into 12 nurse-patient dyads. For each dyad, 9 runs were performed with one test user acting as a nurse while the other acted as patient after which, the roles were reversed, and another 9 runs were performed. Axia is the name of the force/torque sensor through which user efforts were sensed and is the control input, and as such the control gain settings were named Axia1, Axia2 and Axia3. The 9 runs consist of 3 runs for each control gain setting. Average of answers of the respondents for PU and PEOU questions for each control gain setting is shown in Table I.

The questions asked to evaluate Perceived Usefulness of the Patient Walker feature of the ARNA robot are:

- 1) The robot is responsive to your commands to move in the desired direction (No (1)/Yes (5))
- 2) I did not often feel like I was going to lose my balance (No (1)/Yes (5))
- 3) What is the speed of the walker? (Too fast (1)/Too slow (5))
- 4) I get sufficient stability support from the walker (No (1)/Yes (5))
- 5) The walker is helpful in completing the walking task (No (1)/Yes (5))
- 6) I am satisfied with the robot as a mobility aid (No (1)/Yes (5))

For the evaluation of Perceived Ease of Use of the ARNA robot in Patient Walker, we asked:

- 1) The walker is difficult to operate (No (1)/Yes (5))
- 2) It is easy to learn to use the walker (No (1)/Yes (5))
- 3) It is easy to avoid bumping into objects (No (1)/Yes (5))

B. Patient Sitter

The patient sitter task primarily involves the ARNA robot being used in a user sitter task mode in a hospital environment. This utility is particularly useful in a nursing assistant robot as fetching items for hospitalized patients is one of the

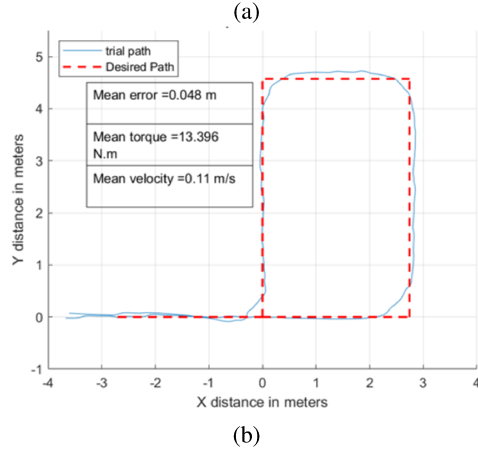


Fig. 8: (a) Users during patient walker task experiment in the simulated hospital room (b) Sample path taken by user during patient walker experiment

TABLE I: PU and PEOU metrics for different control settings in the patient walker experiments. Each metric has a minimum score of 1 and maximum of 5.

Metric	Mean	Std Dev
PU Axia1	3.00	1.36
PEOU Axia1	3.28	1.37
PU Axia2	3.06	1.30
PEOU Axia2	3.33	1.38
PU Axia3	3.16	1.25
PEOU Axia3	3.42	1.35

mundane and repetitive tasks performed by nurses and nurse assistant in hospitals.

In the patient sitter experiments for this work, the task was performed by teleoperation of the robot base and arm through a tablet interface in the simulated hospital room. The teleoperation mode is a useful one - as feedback from the users show - and is a versatile one as it can be applicable in a home or industry. This kind of multi-environment use was in mind during the design and development of the ARNA robot.

As illustrated in the Fig. 9, the sitter task in these experiments is divided into 4 four parts:

- 1) Using tablet interface, a user teleoperates the ARNA robot to the location of item to be fetched. In the

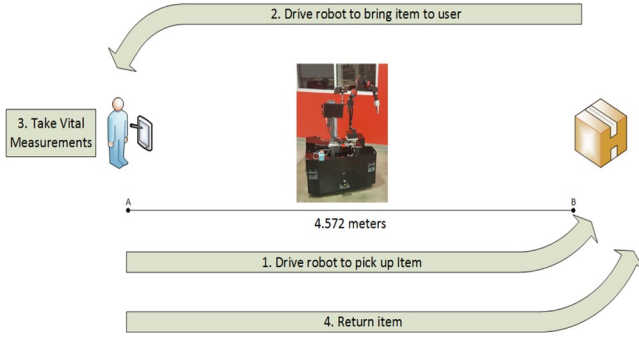


Fig. 9: Patient sitter experiment description.

experiments in this work, the item is a box containing instruments used to measure human vitals.

- 2) With the robot at the location of the item, the tablet interface is used to teleoperate the arm to fetch the item.
- 3) The user teleoperates the ARNA robot to within arm's reach of the user. Then the user collects the item, uses it, and returns the item to robot.
- 4) The user teleoperates the ARNA robot to return the item to the place from which it was originally picked.

At the end of the experiments, the user fills out a questionnaire from which the PU and PEOU of the sitter use of the ARNA robot is evaluated. Table 2 shows an average measure of the PU and PEOU measures for the patient sitter task.

For Perceived Usefulness of the Patient Sitter function, we asked:

- 1) How quickly does the robot arrive at its destination using the tablet interface? (Slow (1)/Fast (5))
- 2) How safe do you think the robot is while you are controlling it with the tablet interface? (Unsafe (1)/Safe (5))
- 3) What would you say the speed of the robot is when moving around the room? (Slow (1)/Fast (5))
- 4) How safe do you think the robot is when navigating to the desired place? (Unsafe (1)/Safe (5))
- 5) How stably did the robot gripper grasp the item? (Unstable (1)/Stable (5))
- 6) How safe do you think the robot arm is when it hands over the fetched items? (Unsafe (1)/Safe (5))

For Perceived Ease of Use, the questionnaire consisted of:

- 1) How convenient is it to drive the robot with the tablet interface? (Not convenient (1)/ Very convenient (5))
- 2) How much attention does it take to drive the robot to the desired place while avoiding obstacles? (High (1)/Low (5))
- 3) How easy is it to drive the robot to the desired place while avoiding obstacles? (Difficult (1)/Easy (5))
- 4) How convenient is it to tell the robot where to go using the interface? (Not convenient (1)/Very convenient (5))
- 5) How easy is it to grab items with the robot arm using the tablet interface? (Difficult (1)/Easy (5))

TABLE II: PU and PEOU metrics for different control settings in the patient sitter experiments. Each metric has a minimum score of 1 and maximum of 5.

Metric	Mean	Std Dev
PU	3.78	1.12
PEOU	2.99	1.22

All these questions were chosen in line with themes found to be suitable for Perceived Usefulness and Perceived Ease of Use in [22].

IV. DISCUSSION

The measure of PU and PEOU averages shown in Tables I and II for the patient sitter and patient walker experiments were obtained by averaging responses to questions corresponding to each metric. For the walker experiments described in Section 3.1, different control settings in Axia1, Axia2 and Axia3 yielded comparable averages, suggesting the users were able to adapt to controlling the robot in different scenarios. This adaptability came with change in average completion times, trajectory errors and velocities as shown in Table III.

TABLE III: Measures of run performance in the patient walker experiments.

	Controller setting		
	Axia1	Axia2	Axia3
Average completion time (s)	101.73	92.0	91.36
Average Trajectory error (m)	0.57	0.47	0.43
Average velocity (m/s)	0.21	0.22	0.225

One of the hypotheses of the TAM model is the existence of a relationship between PU and PEOU in how they affect predicted actual use of a technology. To evaluate that relationship in this work, we compute the p-value and R^2 correlation coefficient, which shows how much a dependent variable depends on a stated independent variable, and p-value. Table IV shows this values for the Patient walker experiments. With a p-value < 0.0008 in the tested controller setting scenarios, the hypothesis of PU depending on PEOU as presented in the TAM model is found to be true.

TABLE IV: Statistical analysis of PU and PEOU metrics for different control settings in the patient walker experiments.

Independent variable	Dependent variable	p-value	R^2
PEOU Axia1	PU Axia1	2.37e-06	0.308
PEOU Axia2	PU Axia2	0.0008	0.171
PEOU Axia3	PU Axia3	0.0001	0.209

For the sitter experiments, average task completion time is 209.52s, which includes an average item pickup time of 49.66s and average item use time of 30.12s. While the time taken for robot teleoperation and item pickup are significant,

for a bed-ridden user in a hospital or an engaged worker in a factory floor for whom transporting an item is otherwise impractical, the sitter task performance of the ARNA robot would indeed be useful. Statistical analysis showed that for the sitter scenario, PU had a 27.2% dependence on PEOU (i.e. $R^2 = 0.272$) with a p-value of $3.1e-05$.

In general, the TAM-inspired user acceptability studies show the usefulness and ease of use of the ARNA robot's core functionalities of walking and sitting in their current implementation are well accepted in a hospital environment. While this study was done in a simulated hospital room and could be done with more users, the built-in capacities for extending the robot - such as varied interface adapters and configuration of the robot - provide a good foundation for relatively easy improvement of the robot in order to improve its usability. In this regard, we are currently working on adapting the robot for use in sanitizing surfaces as a contribution to efforts aimed at dealing with Coronavirus outbreak. Future work includes conducting longitudinal studies with actual potential users in hospitals and factories. These studies would be done with a goal of doing a more complete TAM analysis of the ARNA robot by using improved TAM models such as those in [25].

The design and implementation of the components of the ARNA robot is executed to facilitate its use in other unstructured and cluttered environment. Its primary functional capabilities of user walking and user sitting are adaptable to different applications in healthcare and manufacturing industries. For example, patient walking described in the user tests in Section III can be configured to provide physical rehabilitation assistance by setting the Human Intent Estimator module of the Control loop in Section II-D to enforce a desired prescribed motion dynamic that facilitates appropriate physical rehabilitation of the user. Another example of such extension is using the data from the force/torque sensor at the base of the robot's arm in a manner similar to our work in [15] and [19] to detect human interactions and collisions in human-robot collaborative assembly task. Also having a riser mechanism that gives the arm an extended vertical reach allows it to be used in object picking in an industrial setting. While these extensions on the current versatile implementation of the ARNA robot allows it to be relatively easy to adapt for use in different environment, a narrowing of some of these features might be necessary to allow the cost of the robot to be within a price-point that would facilitate its wide adoption in hospitals and other environments.

In general, the adaptable mechanisms of the ARNA robot, the use of a neural network based control strategy and a novel low-latency instrumentation protocol that fits well into the novel DOLA software architecture in the ARNA robot means there are good foundations for the deployment of the robot for use in different applications with different autonomy levels.

V. CONCLUSION AND FUTURE WORK

In this paper, we presented an overview of the functional subsystems of the ARNA robot, a service robot configured as a mobile manipulator for pHRI. Novelties in this robot include its neuroadaptive control system and interfaces, and sensing instrument protocol. Experimental results from a cohort trial with 24 human subjects are presented and results of preliminary user studies show the robot's usability as a service robot. In particular, results indicate good usefulness and ease of use of the essential user sitter and user walker features of the robot.

At the time of completing this publication, the ARNA robot is being deployed in our lab to sanitize commonly touched surfaces such as work desks, doorknobs, elevator buttons and so on. ARNA's end effector is being retrofitted with a UV-C lamp and a sprayer, and we hope to report on results on these efforts towards fighting the Coronavirus pandemic in the near future.

While its primary design target is for use in a hospital, ARNA can also be used for part fetching, transport and manipulation in a manufacturing environment. Therefore, in future work, we intend to customize the robot for use in logistics warehousing and conduct more extensive user testing in both hospital and manufacturing environments.

REFERENCES

- [1] "World Robotics Service Robot Report," *International Federation of Robotics*, 2019.
- [2] M. Wise, M. Ferguson, D. King, E. Diehr, and D. Dymesich, "Fetch and freight: Standard platforms for service robot applications," *Workshop on autonomous mobile service robots* 2016.
- [3] "HelMo the mobile robot system" <https://www.staubli.com/en-us/robotics/product-range/mobility/helmo-mobile-robot-system/>.
- [4] V. Tlach, I. Kuric, Z. Sagova, and I. Zajacko, "Collaborative assembly task realization using selected type of a human-robot interaction," *Transportation Research Procedia* 40 (2019): 541-547.
- [5] A. Shademan, R. S. Decker, J. D. Opfermann, S. Leonard, A. Krieger, and P.C. Kim, "Supervised autonomous robotic soft tissue surgery," *Science translational medicine* 8, no. 337. 2016
- [6] D. Ming, R. Ikeura, Y. Mori, T. Mukai, and S. Hosoe, "Measurement of human body stiffness for lifting-up motion generation using nursing-care assistant robot-TRIBA" *IEEE SENSORS*, pp. 1-4. IEEE. 2013.
- [7] K. Niechwiadowicz and Z. Khan, "Robot based logistics system for hospitals-survey," *IDT Workshop on interesting results in computer science and engineering*. 2008
- [8] M. Bakajic, T. Becker, and S. Boahen, "An analysis of participants' experiences of HELMO workshops," *Laurea University of Applied Sciences Otniemi*. 2013
- [9] A. Markis, M. Papa, D. Kaselautzke, M. Rathmair, V. Sattinger, and M. Brandstotter, "Safety of Mobile Robot Systems in Industrial Applications," in *Proceedings of the ARW & OAGM Workshop* 2019.
- [10] N. E. Nayati, E. Momi, and G. Ferrigno, "Haptics in robot-assisted surgery: Challenges and benefits," *IEEE reviews in biomedical engineering* 9 (2016): 49-65.
- [11] K. J. Vanni, and S.E. Salin. "Attitudes of Professionals Toward the Need for Assistive and Social Robots in the Healthcare Sector," *Social Robots: Technological, Societal and Ethical Aspects of Human-Robot Interaction* Springer. p. 205-236. 2019
- [12] L. J. Jue, W. Ju, and B. Reeves, "Touching a mechanical body: tactile contact with body parts of a humanoid robot is physiologically arousing," *Journal of Human-Robot Interaction* 6, no. 3 (2017): 118-130
- [13] K. Kraft, and W. D. Smart, "Seeing is comforting: Effects of teleoperator visibility in robot-mediated health care," in *Proceedings 2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. 2016 (pp. 11-18). IEEE.

- [14] J. S. Park, J. S. Lee, J. Y. Ko, Y. I. Cho, and J. G. Song, "Robot cleaner having floor-disinfecting function," *U.S. Patent 7,251,853*. 2007
- [15] S. K. Das, I. B. Wijayasighe, M. N. Saadatzi, and D.O. Popa, "Whole body human-robot collision detection using base-sensor neuroadaptive interaction," *IEEE 14th International Conference on Automation Science and Engineering (CASE)*, pp. 278-283. IEEE, 2018.
- [16] Sathiyarayanan, Mithileysh, and S. Rajan, "MYO Armband for physiotherapy healthcare: A case study using gesture recognition application," *8th International Conference on Communication Systems and Networks (COMSNETS)*, pp. 1-6. IEEE, 2016.
- [17] F. L. Lewis, S. Jagannathan, and A. Yesildirek, "Neural Network Control of Robot Manipulators and Nonlinear Systems," Taylor and Francis, London, 1999.
- [18] I. Ranatunga, S. Cremer, F. L. Lewis, and D. O. Popa, "Neuroadaptive control for safe robots in human environments: A case study," *IEEE International Conference on Automation Science and Engineering (CASE)*, pp. 322-327. IEEE, 2015.
- [19] S. K. Das, M. N. Saadatzi, S. Abubakar, and D. O. Popa, "Joint Torque Estimation using Base Force-Torque Sensor to Facilitate Physical Human-Robot Interaction (pHRI)," *IEEE 15th International Conference on Automation Science and Engineering (CASE)*, pp. 1367-1372. IEEE 2019
- [20] S. Cremer, S. K. Das, I. B. Wijayasinghe, D. O. Popa, and F. L. Lewis, "Model-Free Online Neuroadaptive Controller With Intent Estimation for Physical Human-Robot Interaction," *IEEE Transactions on Robotics*. 2019.
- [21] J. Rajruangrabin, and D. O. Popa, "Enhancement of Manipulator Interactivity through Compliant Skin and Extended Kalman Filtering," *IEEE Conference on Automation Science and Engineering (CASE)*, pp. 1111 - 1116. IEEE, 2007.
- [22] F. D. Davis, R. P. Bagozzi, and P. R. Warshaw, "User acceptance of computer technology: a comparison of two theoretical models," *Management science* 35, no. 8 (1989): 982-1003.
- [23] B. Christina, J. Nelles, C. Brandl, A. Mertens, and Christopher M. Schlick. 2016. TAM reloaded: a technology acceptance model for human-robot cooperation in production systems. International conference on human-computer interaction, pp. 97-103. Springer, Cham, 2016.
- [24] T. L. Mitzner, C. C. Kemp, W. Rogers, and L. Tiberio, "Investigating healthcare providers' acceptance of personal robots for assisting with daily caregiving tasks," *CHI'13 Extended Abstracts on Human Factors in Computing Systems*, pp. 499-504. 2013.
- [25] P. C.Lai, "The literature review of technology adoption models and theories for the novelty technology," *JISTEM-Journal of Information Systems and Technology Management* 14, no. 1 (2017): 21-38.