Deployment of a Socially Assistive Robot for Assessment of COVID-19 Symptoms and Exposure at an Elder Care Setting

Caio Mucchiani[1], Pamela Cacchione[1], Michelle Johnson[1], Ross Mead[2] and Mark Yim[1]

***Abstract*— This work investigates the deployment of an affordable socially assistive robot (SAR) at an older adult day care setting for the screening of COVID-19 symptoms and exposure. Despite the focus on older adults, other stakeholders (clinicians and caregivers) were included in the study due to the need for daily COVID-19 screening. The investigation considered which aspects of human-robot-interaction (HRI) are relevant when designing social agents for patient screening. The implementation was based upon the current screening procedure adopted by the deployment facility, and translated into robot dialogues and gesturing motion. Post-interaction surveys with participants informed their preferences for the type of interaction and system usability. Observer surveys evaluated users' reaction, verbal and physical engagement. Results indicated general acceptance of the social agent and possible improvements to the current version of the robot to encourage a broader adoption by the stakeholders.**

Fig. 1: COVID-19 symptoms and exposure screening of an older adult by Quori.

I. INTRODUCTION

The current COVID-19 pandemic has greatly impacted older adults living in group settings, since the risk for severe illness from COVID-19 increases with age [2]. Given the high contagiousness ratio of the disease, especially via community spread [3], extreme caution and use of personal protective equipment (PPE) is needed when assisting older adults with their Activities of Daily Living (ADLs) or Instrumental Activities of Daily Living (IADL) [4], as these activities require human contact. Long term care facilities implemented these steps to mitigate physical proximity between older adults and their clinicians and caregivers. Such preventive measures also limited the personnel and restricted visitors, directly affecting ongoing human subjects research at these locations. Specifically, the deployment of robots which interact with multiple people.

Endowing SARs with health screening capabilities can potentially benefit staff and older adults, allowing physical distancing (since multiple people are generally involved in the procedure), and permitting robots to be even more engaging at a personal level, rather than at a general, impersonal way. As a result, an investigation on the theme is needed, which can combine subjective and behavioural measures deemed essential to inform the stakeholder acceptance and usability of the system as well as the improvement of its functionalities. Therefore, a health screening interaction can provide information on these aspects of the interaction:

- Favors the healthcare worker assessment of the patient instead of the robot
- Favors the robot assessing a patient through a routine screening instead of a healthcare worker in close proximity with the patient
- Modifications to the robot such that the former can be improved, and the robot potentially favored over a healthcare worker.

We deployed an affordable SAR robot (Quori) at a Program of All-Inclusive Care (PACE) Center for older adults (Fig. 1). The robot screened PACE participants and employees (clinicians and caregivers) for symptoms and exposure of COVID-19 through dialogues and gestures. Every stakeholder (clinician, caregiver and older adult) who consented participated in the study. Data collection included observer and post-interaction surveys with every participant. Results inform aspects of human-robot-interaction (HRI) to consider when deploying robots amidst the COVID-19 pandemic. Despite the current relevance to the pandemic, this screening method will be useful also during the annual flu season, which also threatens the older adult population.

This paper is divided as follows. A brief literature review is presented in Section II. An introduction to our SAR hardware platform and its modifications is described in Section III-A, and deployment methods, experimental results and discussion presented on Section IV. Section V presents conclusion and future work.

This work was funded by the NSF grant PFI:TT 1827673 Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

[1] University of Pennsylvania
[2] Semio INC
caio@seas.upenn.edu, pamelaca@nursing.upenn.edu, ross@semio.ai, johnmic@pennmedicine.upenn.edu, yim@seas.upenn.edu

II. Literature Review

Recently, numerous works discussing the direct impact of the COVID-19 pandemic in robotics research and development have been presented [25], [26], [27], [28], [29]. A thorough review discussing these impacts on robotic applications, along with possible solutions is found in [32]. As shown in Fig. 2, robotic applications ranging from sanitization (UVD Robots), item delivery in hospitals (Zali Robot), equipment monitoring (Tommy Robot) and health check-ups (Misty II Robot [1]) have been increasingly developed worldwide. Similarly, robotic assisted surgery (RAS) adoption has shown direct and indirect benefits towards the pandemic. Directly, as less staff (especially surgical teams at the bedside) may be needed to perform various surgeries and consequently reducing the risk of cross contamination between staff and patients. Indirectly, robots may reduce the hospital stay in some procedures, making more rooms available for COVID-19 patients [25]. Expensive robots, however, are difficult to budget for, limiting adoption. Affordable robot solutions are preferred [30]. Stringent cleaning requirements may also impose additional challenges to the hospital staff and therefore logistical planning can become an issue.

Human subjects studies in HRI were negatively affected by the pandemic, greatly limiting HRI research. An overall analysis of such impact, both in terms of research praxis, as well as research topics is discussed in [31]. Efforts to investigate the potential uses of robots for COVID-19 testing have been recently adopted, since robots can facilitate and increase testing capabilities while minimizing risks of transmission. Testing robots may be patient facing (directly collecting biological material from subjects) or non-patient facing (associated with laboratory testing procedures and teleoperation) [26]. The former has the potential of drastically decreasing the exposure of testing staff and the latter minimizes exposure of laboratory technicians. Despite these benefits, few systems have been developed for testing, namely robot arms and teleoperated robots [26]. Other approaches in COVID-19 robotics response include temperature screening [42], [43] and a cough detection algorithm [33].

III. Deployment Methods: Adapted COVID-19 Screening Procedure, Hardware and Software Implementations

The current COVID-19 screening procedure at the PACE Center is illustrated in Fig. 3. A total of 3 people interact with the older adults from arrival to being granted access to the day center or sent home, depending on the assessment of their symptoms, body temperature and blood oxygen level measurements (each repeated at maximum twice). The new proposed procedure performed by the robot (Fig. 4) summarizes the main screening routines (Symptom and Exposure), in addition to the temperature screening (not functionally done by the robot). A dialogue between the participant and the robot was coordinated by a finite state machine (described in Sec. III-C). Voice recognition to switch between states (based on the participant's responses) was not utilized. Possible complications with muffling voices by mask usage or difficulty in having the robot near the participant due to COVID-19 preventive measures were the main contributing factors. Therefore, researcher's input (through a joystick) based on the observed response from the participants were the finite state machine guard conditions. A detailed description of the entire system's implementation follows.

[1] https://www.mistyrobotics.com/

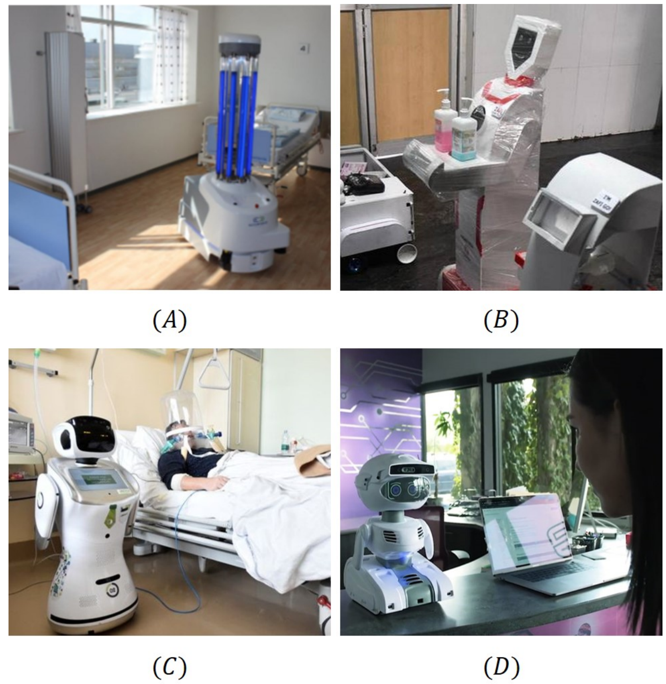

Fig. 2: (A) UVD robots help in infection prevention (UVD Robots Denmark) (B) "Zafi" Robot deployed in Chennai to aid in items transportation (C) "Tommy" robot in Italy aids hospital staff by monitoring parameters from equipments in the room (D) "Misty II" robot performs health check monitoring with options for temperature check and equipment sanitization.

A. Hardware and System Review

Previously, the thematic analysis completed for this study [40] indicated all stakeholders expectancy for the robot to be polite and personable. In addition, the importance of design and programming to meet the individual needs of an older adult (either due to their physical or cognitive challenges) was found to be preferred over how the robot should look like. All participants were concerned about the safety of the robot. This is consistent with previous study findings [1], [17], [7], in which any device perceived by older adults, caregivers, or clinicians as unsafe would decrease the use of the technology. This original analysis informed the current SAR platform (Quori) hardware and software design.

1) Quori SAR: Quori [24], [41] consists of a humanoid upper body attached to a omnidirectional mobile base. The original modular Hardware (shown in Fig. 5 left) is described

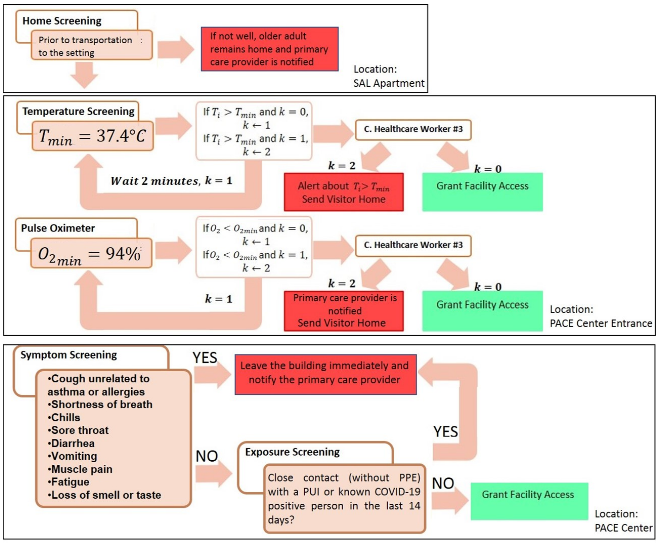

Fig. 3: Screening Procedure at the PACE Center.

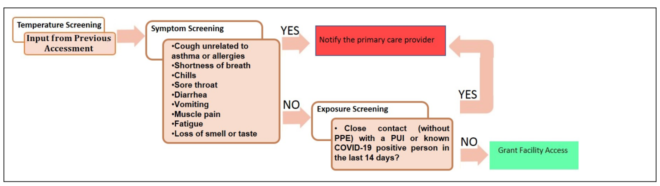

Fig. 4: Screening Procedure performed by the robot.

as a:

- Holonomic Mobile Base: Inspired by the design in [34] and mobility in [35], the base has three actuators for generating linear and angular velocities as well as orient the upper body of the robot, measuring 480 mm in diameter and 203 mm in height.
- Spherical Projection Head: To maximize flexibility and minimize cost, Quori's head consists of a retro-projected animated face (RAF) using a portable projector, a lens (or mirror), and a projection surface. Such technique is highly versatile since any face can be projected, and highly expressive, as previously shown in the literature [36], [37], [38]. Vibration noise is minimized by a rigid connection between the spherical surface and the projector.
- Gesturing Arms: As the purpose of Quori is human-robot interaction and expression, gesturing becomes an important and desired aspect on a social robot. The arms (not meant for manipulation) and two DOF shoulders are designed so that the arm can rotate continuously. Safety concerning proximity to humans was also considered by limiting the torque on the drive motors as well as using lightweight materials and low inertial, and stiffness arm.
- Spine In order to support the torso, a 1-DOF spine allows the robot to demonstrate different levels of engagement by leaning forward or backward. The spine can also minimize possible vibrations due to the robot's motion, resulting in natural and more appealing motion.

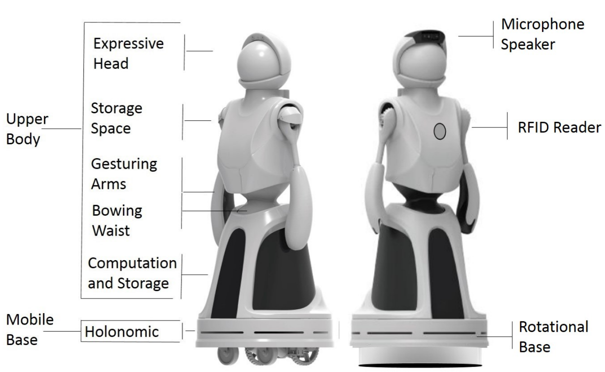

Fig. 5: Quori (left) and hardware modifications for deployment in the proposed study (right)

2) Hardware Modifications: Due to the nature of COVID-19 transmission, avoiding crowds and human contact is highly desired. Therefore, the robot would remain in one fixed location where the assessment would occur, and continuously navigating the environment was discarded. In addition, since the check-in procedures mostly required dialogue and indication of directions (for medical appointments for instance), the holonomic base was simplified to a purely rotational one. Another modification to the original hardware was the addition of the Radio Frequency Identification (RFID) reader to the robot. Relying on RFID for person identification is preferred as the subjects were wearing face masks, which imposed challenges to the implementation of facial recognition. The reader uses USB communication, has a 1m range and emulates a keyboard. To facilitate comprehension for hearing impaired older adults and promote physical distancing, external speakers were located near the participants. Lastly, since body temperature can vary depending on the location of the measurement, and older adults and employees would only be admitted to the facility with body temperature under 37.4^{o}C, no temperature screening device was added to Quori. Temperature screening dialogue, however, was included in the dialogue simply to provide more context and completion to the overall interaction.

B. Software Implementation

An overview of the software framework is seen on Fig. 6. The robot architecture uses Robot Operation System (ROS)[2] for its main implementation. The core body motion of the robot runs on a *Whole body Serial* node, and the gesturing arms driven by anti-cogged brushless DC motors[3] running a PID controller (which considers torque and speed limits for the motion as safety precaution during interaction), implemented on an *ArmController* node. We have utilized a simple facial expression consisting on periodic blinking eyes with the intent to generate empathy and not overstate the

[2]www.ros.org
[3]http://iq-control.com/

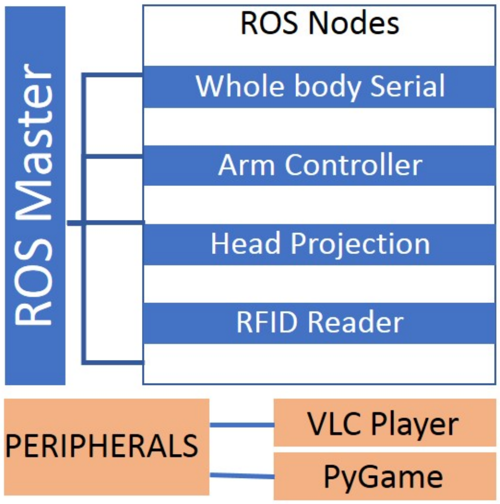

Fig. 6: The software implementation framework. The ROS Master node controls the robot's movement and facial expression. The peripherals manage the finite state machine abstraction for the dialogue.

robot's intelligence, implemented on the *Head Projection* node. Dialogues were input to a text-to-speech engine [4] and *mp*3 files were generated and played by the *VLC Player* peripheral. A low pitch and speed voice was preferred since those can impact the ability of the older adult to hear the interaction [46]. Finally, switching between states was done with a joystick using *PyGame* implementation.

C. State Machine Implementation

The interaction was implemented as a finite state machine (Fig. 7). To begin, the *RFID Reader* node utilized the USB reader device and RFID tags (*STATE* 0). The robot greeted the participant by name and prompted them to remain steady while it (in a "Wizard of Oz" manner) checked their temperature (*STATE* 1). After a 5 second delay, the robot engaged in a symptom check routine (*STATE* 2), inquiring users' input on a list of symptoms (shown on Fig. 4). If the participant answered *YES* to any symptoms on the list, the robot referred (vocally and pointing) the user to a physician's room (*STATE* 3) and the interaction ended. Otherwise, the robot engaged in an exposure check dialogue (*STATE* 4), asking if the participant has had any close contact with a COVID-19 positive person in the last 14 days without a mask. Once again, a positive response referred the user to a physician (*STATE* 3), otherwise to a caregiver (*STATE* 5), finishing the interaction in sequence.

IV. Deployment Results

The experimental set-up for the deployment is show in Fig. 9. The robot was placed at the dining hall of the PACE Center and participants instructed to interact with it (standing up or seated, depending on their mobility limitations) at a $1m$ distance. Third (Fig. 1) and first-person (Fig. 8) view

[4]www.kukarella.com

TABLE I: Participants Demographics

Gender	Male 11	Female 28	Total 39
Age	25-50 10	51-60 12	61 or older 17
Race	African American 36	Other 3	Total 39
Status	Employee 22	Member 17	Total 39

TABLE II: Access to Technology

Experience with or use a
Computer 28
Tablet or e-reader 20
Cellphone 38
Exercise daily* 24

cameras were used to record every interaction and an external bluetooth speaker placed near the participant as previously mentioned.

A total of 39 participants interacted with the robot (see Table I for demographics). Almost all participants were African-Americans, 61 years and older and had cellphones (Table II), with the majority having access to a computer and roughly half to tablets or e-readers on a daily basis. To analyze responses subjective and behaviorally, post-interaction and observer surveys were conducted by the research team. The subjective investigation considered two surveys: one based on the Almere [6] model for assessing technology acceptance for older adults, focusing on system usability (Fig. 12); a second (discussed in Sec. IV-A) with open-ended questions about positive and negative aspects of the robot, preference among human, robot or phone screening, and recommendation of use. The behavioral evaluation by an observer also considered a survey (Fig. 10), which informed the research team additional reactions of the participants while interacting with the robot. The evaluation criteria included ability to see and hear the robot, facial expression of the participant (smiled, frown) during interaction, physical response, difficulty (or lack of) in understanding and following instructions and possible frustration. Robot errors were also monitored (Fig. 11). Initially, given the equivalent

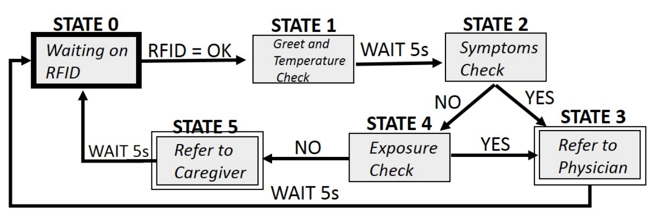

Fig. 7: Finite State Machine abstraction for the dialogue and interaction implementations. The State Machine starts at *STATE* 0 and finishes at *STATE* 3 for any "YES" answer and *STATE* 5 for "NO" answers. A detail description of the dialogues' content is shown in Fig. 4

Fig. 8: First-Person view camera installed on the robot.

ratio of members (17) to employees (22), groups had their responses separately analyzed, and expressive differences in results (if any) reported as follows. Care was also taken to avoid the observer (or "Hawthorne") effect [45] during the interactions. All participants were consented prior to each interaction. The study was approved by the Institutional Review Board (IRB) of the University of Pennsylvania.

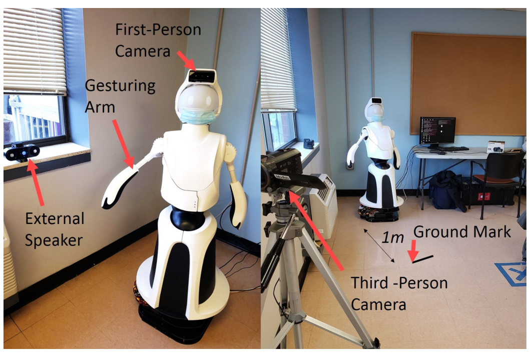

Fig. 9: Experimental setup of the system in the common area. External speakers were mounted on different locations to facilitate complohension depending on whether participants were standing up or seated. A ground mark distant 1m was set to standardize interactions.

A. Discussion

According to Fig. 10 almost no participant had trouble seeing the robot, was frustrated, upset or bored with it. No participant seemed scared or became unsteady during the interaction. Almost all participants talked back to the robot when questioned by it, smiled (heard as a laugh) and seemed comfortable with it. However, 44% of participants had trouble understanding the robot and 36% trouble hearing it. These were correlated, as participants often complained they could not adequately hear the robot, despite maximum volume of the external speaker. It was observed high background noise from the room's television and employees conversation. A surprising 77% of participants seemed uncomfortable during the interaction. Although not pain related (as only one participant reported pain), a few factors could have contributed for this observation, specifically:

- The repetitiveness of a daily screening procedure (especially for the older adults, since most were screened twice before arriving to the center)
- The inability to hear the robot and not knowing what to answer at times, robot errors due to mispronunciation of names and words (Fig. 11).
- Possible embarrassment in answering to certain symptoms' screening questions (namely "vomiting" and "diarrhea").

With respect to the system's usability (Fig. 12), the great majority of participants strongly agree they would use the robot frequently, were confident using it, felt it was easy to use and its functions were well integrated. Participants also think little to no prior knowledge or assistance would be needed before using the robot, and found the system consistent and of low-complexity in general.

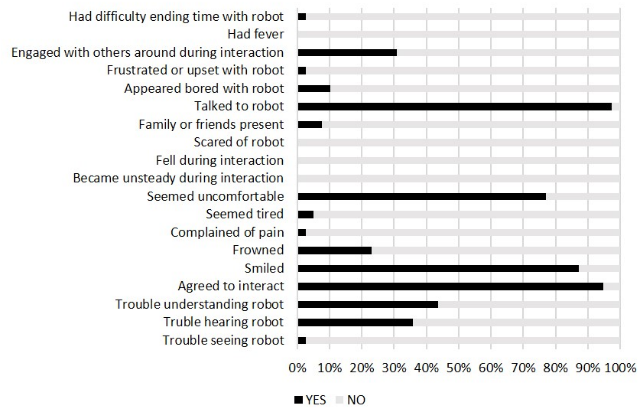

Fig. 10: Observer survey results assessed by the research team during interactions.

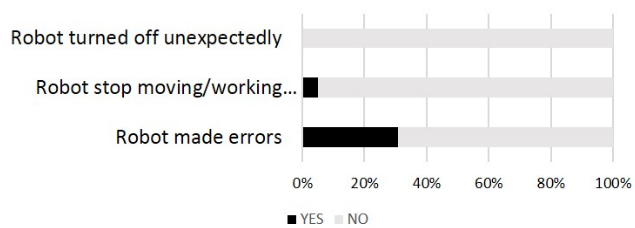

Fig. 11: Observer survey results regarding the robot's observations.

B. General Observations

Participants were asked whether they would recommend the robot to a friend (Fig. 13 top). All employees answered positively and 94% of older adults would recommend the robot. When asked about their preference among different COVID-19 screening methods, employees preferred the robot over any other method, although almost 30% did not have a strong opinion. For older adults, more than half preferred human assessment over the robot, the latter in fact was

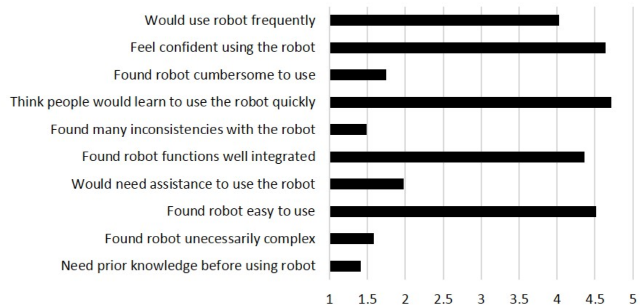

Fig. 12: Agreement Scores for system usability, with 1 (strongly disagree) and 5 (strongly agree) scores.

rated the least screening method preferred (11.8%). This is an interesting finding, since despite most older adults recommended the robot, they would still prefer the human assessment over it. Preference towards person over robot screening included arguments such as "a person can handle the information", "computers make mistakes", "you can ask a person a question", "I can relate to a person" or "I am old-fashioned". Arguments for robot screening were "it avoids physical contact", "responses can be kept confidential" and "it is easy to interact". A couple of participants would get closer to the robot (speaker) to hear it but all participants complied with the physical boundaries imposed by the interaction (e.g. staying behind the ground mark), useful indicator for systems with optimal distance for voice or facial recognition. We also asked subjects positive and negative aspects about the robot (Fig. 14). Being straight to the point, friendly, call participants by their names and having a clear voice were the most positive aspects. Most participants did not have any negative comments, but difficulty hearing the robot was widely noticed.

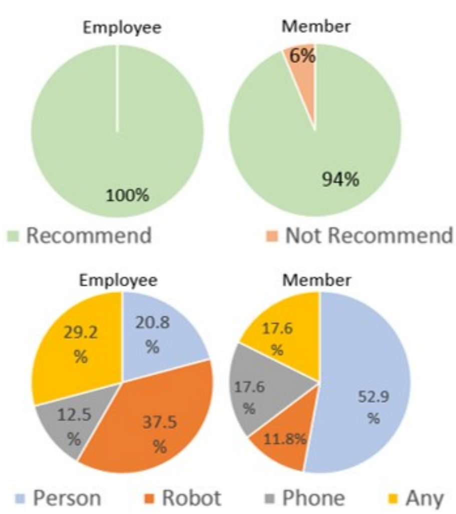

Fig. 13: (Top) Members (older adults) and employee's response on recommending the robot and (bottom) preference towards different types of COVID-19 screening procedures.

C. Anecdotal Conclusions and Observations

- Getting older adult participants was difficult. The pandemic drastically limited the number of PACE members allowed inside the day center.
- The robot was not allowed in confined spaces (i.e. an office) and we had to set it up in a common area. This resulted in excessive background noise (such as television and employees' conversations) challenging comprehension for hearing impaired older adults.
- Placing the external speaker at different locations had an impact on the interaction. Specifically, when the device was placed to the right of one participant (and to the left of Quori), when prompted to "look at me for five seconds while I measure your temperature" by the robot, the participant turned towards the speaker instead of the robot.
- Quori's slow low pitch voice (to facilitate older adult's understanding) seemed to affect younger participants, as one commented "the robot talks too slow and made me a little impatient".
- Additional comments by participants considered the robot easy to speak with, quick to interact, pleasant, and suggestions included more interactive movements and sense of humor.

V. Conclusion and Future Work

This study investigated interactions of a SAR robot at an elder care PACE center for COVID-19 symptoms and exposure screenings. The system dialogue was implemented as a finite state machine using ROS framework, and state guard conditions manually input by the researcher in lieu of a voice recognition or user input system. Subjective and behavioral measures were extracted from post-interaction surveys with participants and observers. Overall results indicate acceptance of the robot as a screening method, in view of its easiness of use, direct and straight to the point behavior, as well as friendly aspect, although the older adult population still preferred a person assessment instead. Despite additional speakers' use, difficulty hearing the robot (especially among older adults) was still noticeable, emphasizing the challenges in designing social robots deployed at common areas and for different age groups.

Objective measures from the study will be evaluated next. Audio volume responses and video analysis can optimize autonomous systems on dealing with complicating factors such as population age difference and facial mask usage. Future deployments with more diverse groups can inform additional needs and improvements to the system not captured in this study. Finally, empowering the robot with other functionalities such as COVID-19 testing and ambient sanitizing can be explored as future work.

References

[1] Sefcik, J.S., Johnson, M.J., Yim, M., Lau, T., Vivio, N., Mucchiani, C. and Cacchione, P.Z., 2018. Stakeholders' perceptions sought to inform the development of a low-cost mobile robot for older adults: A qualitative descriptive study. Clinical nursing research, 27(1), pp.61-80.

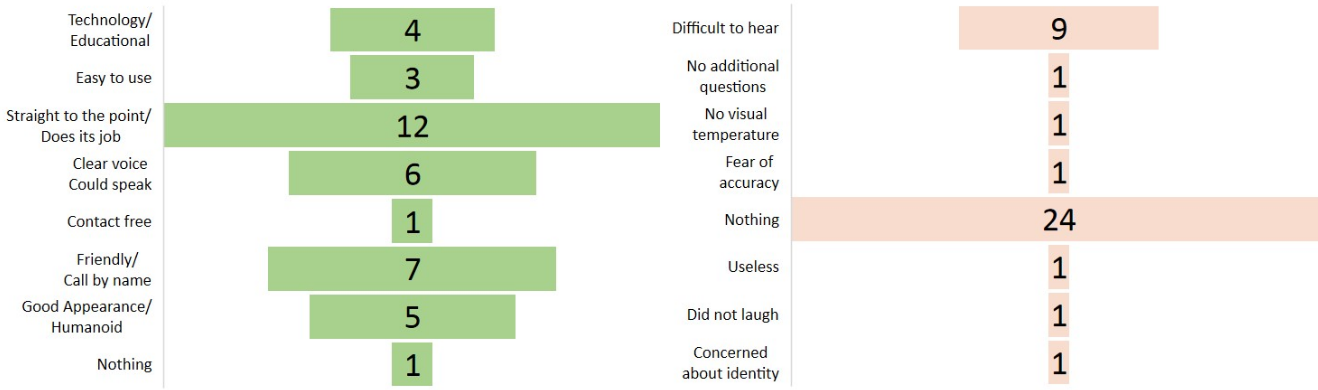

Fig. 14: (Left) Positive and (Right) negative aspects of the robot interaction by the participants.

[2] Centers for Disease and Control Prevention (CDC) - https://www.cdc.gov/coronavirus/2019-ncov/need-extra-precautions/older-adults.html - Accessed on 08/21/2020

[3] Centers for Disease and Control Prevention (CDC) - https://www.cdc.gov/coronavirus/2019-ncov/faq.html - Accessed on 08/21/2020

[4] CA. Smarr et al. “Domestic Robots for Older Adults: Attitudes, Preferences, and Potential,” in Int J Soc Robot (2014) 6:229–247 DOI 10.1007/s12369-013-0220-0

[5] J. Pineau, M. Montemerlo, M. Pollack, et al. “Towards robotic assistants in nursing homes: Challenges and results,” in Special issue on Socially Interactive Robots, Robotics and Autonomous Systems, Vol. 42, No. 3 - 4, pp. 271 - 281, 2003.

[6] M. Heerink, B. Kröse, V. Evers, and B. Wielinga, “Assessing Acceptance of Assistive Social Agent Technology by Older Adults: the Almere Model,” International Journal of Social Robotics, vol. 2, no. 4, pp. 361–375, Dec. 2010.

[7] Johnson MJ, Johnson MA, Sefcik JS, Cacchione PZ, Mucchiani C, Lau T, Yim M. Task and Design Requirements for an Affordable Mobile Service Robot for Elder Care in an All-Inclusive Care for Elders Assisted-Living Setting. International Journal of Social Robotics. 2017:1-20.

[8] D. Seifer and M. Mataric, “Defining Socially Assistive Robotics,” in proceedings of the IEEE 9th International Conference on Rehabilitation Robotics June 28 - July 1, 2005, Chicago, IL, USA, 465-468.

[9] Kidd, C.D., 2008. Designing for long-term human-robot interaction and application to weight loss.

[10] Fasola, J. and Mataric, M.J., 2010, September. Robot exercise instructor: A socially assistive robot system to monitor and encourage physical exercise for the elderly. In 19th International Symposium in Robot and Human Interactive Communication (pp. 416-421). IEEE.

[11] Wada, K., Shibata, T., Saito, T. and Tanie, K., 2004. Effects of robot-assisted activity for elderly people and nurses at a day service center. Proceedings of the IEEE, 92(11), pp.1780-1788.

[12] Kim, E., Newland, E., Paul, R. and Scassellati, B., 2008. Robotic tools for prosodic training for children with ASD: A case study. In International Meeting for Autism Research (IMFAR).

[13] Breazeal, C.L., 2004. Designing sociable robots. MIT press.

[14] Ekman, P., Facial expressions//Handbook of Cognition and Emotion/Eds. T. Dalgleish, M. Power. Sussex.

[15] Graneheim, U.H. and Lundman, B., 2004. Qualitative content analysis in nursing research: concepts, procedures and measures to achieve trustworthiness. Nurse education today, 24(2), pp.105-112.

[16] Hsieh, H.F. and Shannon, S.E., 2005. Three approaches to qualitative content analysis. Qualitative health research, 15(9), pp.1277-1288.

[17] Mucchiani, C., Sharma, S., Johnson, M., Sefcik, J., Vivio, N., Huang, J., Cacchione, P., Johnson, M., Rai, R., Canoso, A. and Lau, T., September. Evaluating older adults' interaction with a mobile assistive robot. In 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (pp. 840-847). IEEE.

[18] Costa, J.T. and Yim, M.,Designing for uniform mobility using holonomicity. In 2017 IEEE International Conference on Robotics and Automation (ICRA) (pp. 2448-2453). IEEE.

[19] Mucchiani, C., Torres, W.O., Edgar, D., Johnson, M.J., Cacchione, P.Z. and Yim, M., 2018, August. Development and Deployment of a Mobile Manipulator for Assisting and Entertaining Elders Living in Supportive Apartment Living facilities. In 2018 27th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN) (pp. 121-128). IEEE.

[20] Collins, F. and Yim, M., Design of a spherical robot arm with the spiral zipper prismatic joint. In 2016 IEEE International Conference on Robotics and Automation (ICRA) (pp. 2137-2143). IEEE.

[21] Krosnick, J.A. and Alwin, D.F., 1987. An evaluation of a cognitive theory of response-order effects in survey measurement. Public Opinion Quarterly, 51(2), pp.201-219.

[22] Cacchione, PZ, Caio, M., Lima, K., Mead, RR., Yim, M., Johnson, M. (In review?). Older adults, clinicians and caregivers preferences for design features of an affordable mobile service robot in the care of older adults. Special Issue: Interaction in Robot Assistive Elderly Care. Frontiers in Robots and Artificial Intellegence.

[23] Bradley, M.M. and Lang, P.J., 1994. Measuring emotion: the self-assessment manikin and the semantic differential. Journal of behavior therapy and experimental psychiatry, 25(1), pp.49-59.

[24] Specian, A., Eckenstein, N., Yim, M., Mead, R., McDorman, B., Kim, S. and Matarić, M., 2018. Preliminary system and hardware design for Quori, a low-cost, modular, socially interactive robot. In Workshop on social robots in the wild.

[25] Kimmig, R., Verheijen, R.H. and Rudnicki, M., 2020. Robot assisted surgery during the COVID-19 pandemic, especially for gynecological cancer: a statement of the Society of European Robotic Gynaecological Surgery (SERGS). Journal of gynecologic oncology, 31(3).

[26] Cresswell, K., Ramalingam, S. and Sheikh, A., 2020. Can Robots Improve Testing Capacity for SARS-CoV-2?. Journal of medical Internet research, 22(8), p.e20169.

[27] Esterwood, C. and Robert, L., 2021. Robots and COVID-19: Re-imagining Human–Robot Collaborative Work in Terms of Reducing Risks to Essential Workers. Available at SSRN 3767609.

[28] Zemmar, A., Lozano, A.M. and Nelson, B.J., 2020. The rise of robots in surgical environments during COVID-19. Nature Machine Intelligence, 2(10), pp.566-572.

[29] Chen, B., Marvin, S. and While, A., 2020. Containing COVID-19 in China: AI and the robotic restructuring of future cities. Dialogues in Human Geography, 10(2), pp.238-241.

[30] Khan, Z.H., Siddique, A. and Lee, C.W., 2020. Robotics utilization for healthcare digitization in global COVID-19 management. International journal of environmental research and public health, 17(11), p.3819.

[31] Feil-Seifer, D., Haring, K.S., Rossi, S., Wagner, A.R. and Williams, T., 2020. Where to next? The impact of COVID-19 on human-robot interaction research.

[32] Shen, Y., Guo, D., Long, F., Mateos, L.A., Ding, H., Xiu, Z., Hellman, R.B., King, A., Chen, S., Zhang, C. and Tan, H., 2020. Robots under COVID-19 Pandemic: A Comprehensive Survey. IEEE Access.

[33] Wei, W., Wang, J., Ma, J., Cheng, N. and Xiao, J., 2020. A Real-time Robot-based Auxiliary System for Risk Evaluation of COVID-19 Infection. arXiv preprint arXiv:2008.07695.

[34] El-Shenawy, A., Wellenreuther, A., Baumgart, A.S. and Badreddin, E., 2007, October. Comparing different holonomic mobile robots. In 2007

IEEE International Conference on Systems, Man and Cybernetics (pp. 1584-1589). IEEE.

[35] Costa, J.T. and Yim, M., 2017, May. Designing for uniform mobility using holonomicity. In 2017 IEEE International Conference on Robotics and Automation (ICRA) (pp. 2448-2453). IEEE.

[36] Delaunay, F., De Greeff, J. and Belpaeme, T., 2009, September. Towards retro-projected robot faces: an alternative to mechatronic and android faces. In RO-MAN 2009-The 18th IEEE International Symposium on Robot and Human Interactive Communication (pp. 306-311). Ieee.

[37] Moubayed, S.A., Skantze, G. and Beskow, J., 2013. The furhat back-projected humanoid head–lip reading, gaze and multi-party interaction. International Journal of Humanoid Robotics, 10(01), p.1350005.

[38] An active customisable robotic head with interchangeable

[39] Sefcik JS, Johnson MJ, Yim M, Lau T, Vivio N, Mucchiani C, Cacchione PZ. Stakeholders' Perceptions Sought to Inform the Development of a Low-Cost Mobile Robot for Older Adults: A Qualitative Descriptive Study. Clin Nurs Res. 2018 Feb;27(1):61-80.

[40] Cacchione, PZ, Mucchiani, C., Lima, K., Mead, RR., Yim, M., Johnson, M. (In review). Older adults, clinicians and caregivers preferences for design features of an affordable mobile service robot in the care of older adults. Special Issue: Interaction in Robot Assistive Elderly Care. Frontiers in Robots and Artificial Intellegence.

[41] Mead, R., Yim, M., Matarić, M.J., Kim, S. and McDorman, B., 2015. Quori: A community-driven modular social robot platform for human-robot interaction. In 2015 International Conference on Social Robotics (ICSR 2015) Robot Design Competition.

[42] Gong, Z., Jiang, S., Meng, Q., Ye, Y., Li, P., Xie, F., Zhao, H., Lv, C., Wang, X. and Liu, X., 2020. SHUYU Robot: An Automatic Rapid Temperature Screening System. Chinese Journal of Mechanical Engineering, 33(1), pp.1-4.

[43] Rane, K.P., 2020. Design and development of low cost humanoid robot with thermal temperature scanner for COVID-19 virus preliminary identification. International Journal, 9(3).

[44] Choi, M.T., Yeom, J., Shin, Y. and Park, I., 2019. Robot-assisted ADHD screening in diagnostic process. Journal of Intelligent and Robotic Systems, 95(2), pp.351-363.

[45] R. Allen, A. Davis, "Hawthorne Effect," in Encyclopedia of Child Behavior and Development, pp 731-732

[46] Kurakata, K., Mizunami, T., Sato, H. and Inukai, Y., 2008. Effect of ageing on hearing thresholds in the low frequency region. Journal of low frequency noise, vibration and active control, 27(3), pp.175-184.