Final report for Grand Challenges Project – June 2021

Improving health and well-being with personalized, pervasive technology

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Summary Statement

The long-term objective of the project was to develop pervasive systems capable of monitoring language, activity, and the physical state of users; modeling the user's cognitive and emotional state to identify needs for intervention; and intervening through language-based conversation and/or calming physical responses. The project is summarized in the figure below.

We have leveraged current wearable medical sensing (the Empathica E4) that collects physiological data (heart rate, electrodermal activity, accelerometer, and body temperature) and audio interfaces (Amazon Echo with Alexa), while advancing the state of the art through development of novel algorithms for language processing to support conversation and the development of instrumented garments that provide active compression or “smart hugs.”

We have completed the human subject study with college students and with older adults. We have made significant progress on the development of the conversational assistant (CA), on the robotic compression garment, and of the AI Hub software that connects the different components. We have submitted an IP disclosure (see details later) on the calibration and usage of the smart garment via voice.

Research Results

Human subjects research

As detailed below, to date, we have tested nearly 40 student participants, with each participant typically tested in 4 sessions, and 20 older adults tested in either a single session (12 older adults) or in 6 to 8 different sessions (8 older adults). The human subjects testing procedure has also been adapted to allow:

1. Collection of physiological heart rate data using a Polar chest strap, so as to allow cross-validation of the E4 fitness tracker heart-rate data and data processing stream.
2. Inclusion of a brief imagined "at home scenario" – the "injured arm scenario" – in which participants are asked to use the CA to schedule specific medication and other reminders, so as to broaden the types of calendar-related dialogue with the CA.
3. Inclusion of specific types of occasional "malfunctions" in the Conversational Assistant (e.g., garbled speech sounds), so as to allow assessment of participants' responses to the types of malfunctions that are likely to sometimes occur in many actual CA systems, and further enhancing the ecological validity of the experimental setup.
4. Modification of the in-person/in-lab testing procedure to allow continued collection of conversational dialogue with the CA during the Covid-19 pandemic, when in-person testing was not possible. This modification also affords the unique opportunity to compare participants' interactions with the CA when they were in a lab-based setting (pre-March break, Spring 2020) versus at home, under stressful, somewhat isolated and uncertain conditions (post-March break Spring 2020), using our already existing probes of anticipated stressful daily events, and retrospective assessment of those events.

5. Complete transcription and anonymization (plus independent cross-checks) of all the recorded audio interactions with the CA, including some 120 calendar-related interaction sessions, 16 at-home scenarios, and 22 sessions of the Trier Social Stress task.
6. A sociolinguistic analysis of the transcriptions of the CA interactions, at home scenarios, and the Trier Social Stress Task. This analysis approach, using the Linguistic Inquiry Word Count, was successfully used for the published 2020 paper of Ferland & Koutstaal (see publications listing) but with an earlier subset of participants and a subset of the testing sessions.
7. Created and administered at-home scenario-based interactions with 12 older adult users who (due to Covid-19 restrictions on in-person testing) interacted with the CA over the video-conferencing platform Zoom. Based on the success of this new remote testing protocol, and follow-up one-on-one interviews with 9 of these older adult users about their typical daily routines, we have now launched more extensive, multi-day calendar- and daily-life CA-based conversational interactions with older adults. This is the first phase of the externally funded project (NSF, "AI-DCL: Addressing sociotechnical challenges of conversational agents and interventions in the context of elderly care").
8. Developed annotation schemes for the transcribed dialogs, including annotation for interfacing with the Conversational AI toolkit MindMeld (https://www.mindmeld.com/docs/index.html) and annotation for XTrans – a multi-platform, multilingual, multi-channel transcription tool that supports manual transcription and annotation of audio recordings (https://www.ldc.upenn.edu/language-resources/tools/xtrans).

System building

We have cleaned the heart rate, activity and galvanic skin response data obtained from wearable devices in the participants recruited in Spring 2019, Fall 2019 and Spring 2020 (total 22 participants). The results indicate that, as expected, heart rate and electrodermal activity measures show a robust response to a standardized stressor (the Trier Social Stress task). The results also show that the interaction with the conversational agent does not elicit any measurable stress response, as physiological measures obtained during the interaction are identical to those obtained during a restful relaxation period (in a subset of participants). We developed the SMARTHUGS HUB - the application that integrates data from the wearable device and the compression garment together with the conversational agent. A high-level architecture of the HUB is shown in Figure 1 below. As part of the HUB, we have developed a

simple conversational agent to enable the user to interact with the wearable device in order to troubleshoot and calibrate it. This is part of the IP disclosure described next.

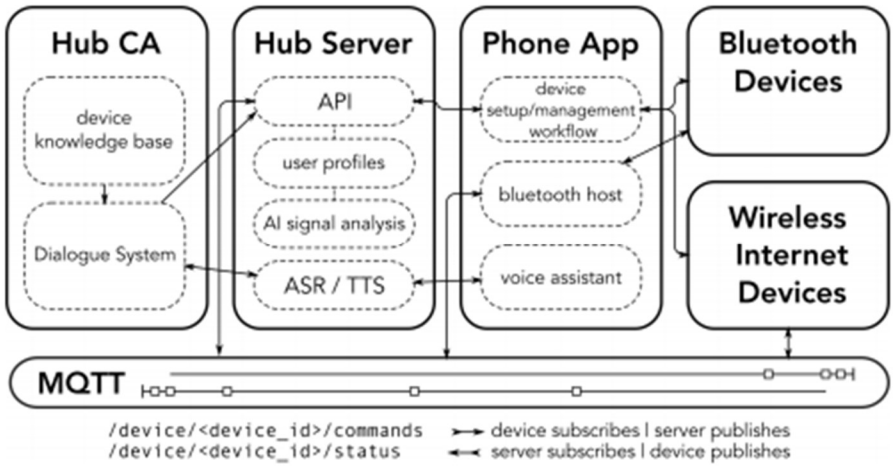

Figure 1: Architecture for Everyday Living AI Hub and end-point user interaction flow.

Robotic Compression Garment Development

Multiple generations of prototype active compression garments were developed. Initial results of this garment development and testing, which were presented at the 2019 International Symposium on Wearable Computers (ISWC), showed generally positive user experiences with on-body compression, and emphasized the importance of garment customization and calibration to adjust to individual preferences. A second generation of active compression garments was developed and tested in Fall 2019, specifically to study whether they can be used to enhance attention and focus in healthy individuals (using meditation training as an example application). The majority of participants reported an improved sense of focus while wearing the garments, though the finding of variable individual preferences was also observed (reinforcing previous studies). IRB approval was received for intervention testing of active compression garments for users in stress-inducing scenarios in spring 2020, but testing was paused indefinitely as the COVID pandemic prevented in-person human subject testing. In lieu of live user testing, additional garment platform development was completed, along with an extensive user preference assessment that was conducted remotely (via surveys) to better understand people's strategies and opinions regarding remotely delivered compression for emotional communication.

An IP disclosure to the UMN Office of Technology Commercialization has been submitted related to this system concept and design ("Voice-assisted Smart Garment Calibration and

Usage", submitted to UMN OTC on 24 June 2020). The final garment prototype (shown below in Figures 2 and 3) included integration of wireless control and optional voice command, providing infrastructure for the garment to connect and interact with both the digital hub and/or conversational agent platforms. It was successfully demonstrated in June 2021 and is documented in detail in a pending submission to the 2021 International Symposium on Wearable Computers (ISWC) Design Exhibition.

Figure 2: Robotic compression garment schematic (top), and physical prototype (bottom)

Conversational Assistant

The CA is designed to help users keep track of their daily calendars and monitor their stress levels. The design and implementation of the CA has gone through multiple stages. First, using a basic proposed workflow for the CA, we conducted the human subject experiments using the

experimental protocol described above. We then transcribed the spoken interactions between participants and the 'prototype' CA and performed sociolinguistic analysis on user statements to determine what kinds of user behaviors and language we can expect from users interacting with our proposed system. After gathering the user data, we were next able to refine our design and implementation of a real prototype system.

The prototype CA we have developed is implemented in the open source conversational AI platform MindMeld (https://www.mindmeld.com/) , and is further integrated with Google Calendar to store event information and user notes. The CA is designed to interact with a user throughout the day and supports two primary types of interactions:

1. "Morning" interaction. Users update their calendar for the day, including any events or activities they expect to occur. The CA also asks users to estimate their stress levels throughout the day associated with each event and asks users to flag any events on their schedule that they are particularly worried about or looking forward to for follow-up conversation later.
2. "Afternoon" interaction. Users review the calendar events they put in at the beginning of the day and are prompted for reflections on each event, including retrospective/actual stress experienced throughout the day. Users are also asked to identify times that they felt the most stress, or when they encountered unexpected stress.

As part of developing the CA, we have also developed supporting data for training and testing, particularly in the case of handling language related to time. We asked a number of researchers to contribute samples of their own calendar events, including complicated temporal expressions that imitate how humans actually talk about time ("I need to take the trash out every Wednesday, except after holidays."). We further created and validated a scheme for annotating these calendar events/temporal expressions and are continuing to improve support for more complicated types of time-related language.

Significant progress has been made in the development of the CA, and we are actively working towards two target activities, additional human subject studies with the prototype and the expansion of the CA into more social abilities, based on the current human subjects studies being run with older adults. To date, the analysis of conversational data from the studies with younger adults appears as a case study at SIGCHI 2020, and details of the implementation of the CA were presented at the 2021 International Workshop on Health Intelligence (W3PHIAI) at AAAI.

Budget

Grand Challenges Award: $325,000, 1/01/2019--6/30/2021.

External funding

1. Minnesota Department of Human Services, “Natural language conversational agent technology for MnCHOICES Certified Assessors”, (PI: Serguei Pakhomov; Co-I: Maria Gini), $300,000, 5/31/2019-5/31/2021.
2. NSF, “AI-DCL: Addressing sociotechnical challenges of conversational agents and interventions in the context of elderly care”, (PIs: Maria Gini, Wilma Koutstaal, Michael Kotlyar, Martin Michalowski, Serguei Pakhomov, and Bradley Holschuh). $299,998, 9/01/2019-8/31/2021.
3. National Association of Broadcasters, “Jukebot, a conversational agent for radio stations” (PI: Maria Gini), $75,000, 1/1/2020-10/31/2020.
4. MnRI, “Conversational agents and interventions in health care,” (co-PIs: Maria Gini, Wilma Koutstaal, Michael Kotlyar, Martin Michalowski, Serguei Pakhomov, and Bradley Holschuh), $22,500, January 2020.
5. NIH, “Feasibility of using wearable technology for just in time prediction of smoking lapses,'' (PIs: Michael Kotlyar, Serguei Pakhomov; Co-I’s: Maria Gini, Paul Thuras), R21DA049446, $425,104, 08/01/2020 - 07/31/2022.

Graduate, professional, and undergraduate students

A large group of students at all levels, ranging from undergraduates to post bac, Master’s and PhD students, from the departments involved in the project have participated in the various parts of the research. Four undergraduate students received an Undergraduate Research Opportunity award to work on the project. All the students worked on all the aspects of the project, including design, implementation, building hardware, testing, doing human subject experiments, and data annotation. They have been vital to the project's success. In addition, some high-school students in the Mentor connection program have contributed to the project and experienced academic interdisciplinary research.

Communication, publicity, dissemination

A short video, SmartHugs, Grand Challenges, Phase III, provides a high-level summary of the project.

Conference

The International Conference on Artificial Intelligence in Medicine (AIME 2020) got connected with the President's office via this grant. The AIME conference started in 1995 and so far, has been held in different countries, always in Europe. AIME was held for the first time in the US at the University of Minnesota on August 26-29, 2020, with Martin Michalowski as co-chair and

local organization chair. The conference was held virtually. President Gabel gave opening remarks at the conference thanks to this Grand Challenges grant.

Website

We have created a website, http://smarthugs.umn.edu/ for the project. The website includes the description of the project, related publications, this final report, and a short video that describes the project.

Publications

1. Libby Ferland, Ziwei Li, Shridhar Sukhani, Joan Zheng, Luyang Zhao, and Maria Gini, "Assistive AI for Coping with Memory Loss,'' *International Workshop on Health Intelligence (W3PHIAI) at AAAI,* 2018. (https://aaai.org/ocs/index.php/WS/AAAIW18/paper/view/17360/15619)
2. Libby Ferland, Thomas Huffstutler, Jacob Rice, Joan Zheng, Shi Ni, and Maria Gini, "Evaluating Older Users' Experiences with Commercial Dialogue Systems: Implications for Future Design and Development,'' *AAAI Workshop on Reasoning and Learning for Human-Machine Dialogues (DEEP-DIAL)*, 2019. https://www-users.cs.umn.edu/~gini/publications/papers/ferland-deepdial19.pdf
3. Joan Zheng, Raymond Finzel, Serguei Pakhomov, and Maria Gini, "Spoken Dialogue Systems for Medication Management,'' *International Workshop on Health Intelligence (W3PHIAI) at AAAI,* 2019. https://www-users.cs.umn.edu/~gini/publications/papers/zheng-w3phiai-19.pdf
4. Esther Foo, Walter Lee, Crystal Compton, Simon Ozbek, Brad Holschuh, "User Experiences of garment-based dynamic compression for novel haptic applications", *International Symposium on Wearable Computing*, September 2019, pp 54-59. (https://doi.org/10.1145/3341163.3347732)
5. Esther Foo, Walter Lee, Simon Ozbek, Crystal Compton, Brad Holschuh, "Iterative design and development of remotely-controllable dynamic compression garment for novel haptic experiences", *International Symposium on Wearable Computing*, September 2019, pp 267-273. (https://doi.org/10.1145/3341163.3346935)
6. Libby Ferland, Jude Sauve, Michael Lucke, Runpeng Nie,, Malik Khadar, Serguei Pakhomov, and Maria Gini. (2020) "Tell Me About Your Day: Designing a Conversational Agent for Time and Stress Management". In *International Workshop on Health Intelligence (W3PHIAI) at AAAI,* February, 2020, New York. https://www-users.cs.umn.edu/~gini/publications/papers/ferland-w3phiai2020.pdf
7. Libby Ferland, Wilma Koutstaal, How's Your Day Look? The (Un)Expected Sociolinguistic Effects of User Modeling in a Conversational Agent. *CHI'20 Extended Abstracts,* April 25–30, 2020, Honolulu, HI, USA ACM 978-1-4503-6819-3/20/04. (https://doi.org/10.1145/3334480.3375227)
8. Foo, Esther, Justin Baker, Crystal Compton, and Brad Holschuh. "Soft Robotic Compression Garment to Assist Novice Meditators." In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*, pp. 1-8. 2020. (https://dl.acm.org/doi/pdf/10.1145/3334480.3382919)

9. Libby Ferland. Enhancing User Modeling in Conversational Agents for Improved Personalization in Elder Support Applications. In *Doctoral Consortium, International Conference on Artificial Intelligence in Medicine (AIME 2020)*.
10. Shreya Datar, Libby Ferland, Esther W Foo, Michael Kotlyar, Brad Holschuh, Maria Gini, Martin Michalowski and Serguei Pakhomov. "Measuring Physiological Markers of Stress During Conversational Agent Interactions." *5th International Workshop on Health Intelligence (W3PHIAI-21) at AAAI,* 2021. https://www-users.cs.umn.edu/~gini/publications/papers/shreyadatar2021w3phiai.pdf
11. Granberry, R., Compton, C., Woelfle, H., Barry, J., and Holschuh, B. "Enhancing performance and reducing wearing variability for wearable technology system-body interfaces using shape memory materials". *IOP Flexible and Printed Electronics Special Issue on E-Textiles.* (https://iopscience.iop.org/article/10.1088/2058-8585/abf848)
12. Foo, Esther W., Lucy E. Dunne, and Brad Holschuh. "User Expectations and Mental Models for Communicating Emotions through Compressive and Warm Affective Garment Actuation." *Proceedings of the ACM on Interactive,Mobile, Wearable and Ubiquitous Technologies*, 5.1 (2021): 1-25. (https://dl.acm.org/doi/10.1145/3448097)
13. Raymond Finzel, Esha Singh, Martin Michalowski, Maria Gini and Serguei Pakhomov. Everyday Living Artificial Intelligence Hub. *2nd Workshop on Data Science with Human-in-the-loop: Language Advances (DaSH-LA)* at NAACL 2021. (https://www.aclweb.org/anthology/2021.dash-1.pdf)
14. Dahunsi, B., Compton, C., Woelfle, H., Subash, N., Pettys-Baker, R., Priebe, M., and Holschuh, B. "Dynamic, Discreet, Robotic Compression Garment for Real-Time Stress Assessment and Intervention", submitted to the *2021 International Symposium on Wearable Computers (ISWC) Design Exhibition*, June 2021.

Talks

In addition to the professional and community visibility afforded by lab tours we have given public talks with coverage of the Grand Challenges Investigation:

1. Holschuh, B. "Wearable Technology using Active Materials", invited talk to at the "Wearable Technology, Materials and Applications II", workshop at the 2019 UMN Biomaterials and Pharmaceutical Materials (BPM) Industrial Partners for Research in Interfacial and Materials Engineering (IPRIME) Annual Meeting, May 29 2019.
2. Holschuh, B. "Soft-Robotic Textiles using Integrated Active Materials", invited talk at the 2019 Industrial Fabrics Association International (IFAI) Smart Fabrics Virtual Summit, May 15, 2019.
3. Holschuh, B. "Garment-based Wearable Technology: Principles, Applications and Challenges", invited talk given (virtually) at the International Conference of Clothing and Textiles *2020*, Busan City, Republic of Korea, May 2020.
4. Gini, M. "Will a chatbot be our future companion?", talk to the American Association of University Women, Minneapolis branch, December 2020.

Videos

SmartHugs, Grand Challenges, Phase III **,** June 2021. Available at https://youtu.be/IygiRompItI.

Garment-Based Dynamic Compression System for Novel Haptic Applications, presented at ISWC 2019. Available at https://www.youtube.com/watch?v=-DWn8G7i-r0&feature=youtu.be

Posters

1. Arun, V., Huffstutler, T., Finzel, R., Pakhomov, S., Gini, M. (2019) “Artificial Emotional Intelligence: Dialogue Systems in Medicine,” Presented at the University of Minnesota Undergraduate Research Symposium. April 25, 2019, Minneapolis, MN
2. Annika Sougstad (2019) "Physiological Data Analysis for Stress Prediction and Intervention", presented at the Grace Hopper Celebration of Women in Computing, October 2019.
3. Libby Ferland, Wilma Koutstaal. A Sociolinguistic Analysis of Interactions with an Intelligent Digital Assistant. Presented at the Center for Cognitive Sciences, University of Minnesota, Spring Research Day, June 12, 2020.