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Privacy and Social Implications of Distinct Sensing Approaches to Implementing Smart Homes for Older Adults

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Abstract— **Two distinct approaches to smart home design, namely Distributed Direct Sensing (DDS) and Infrastructure Mediated Sensing (IMS), have distinguishing features and implications resulting from their implementation. These two distinct smart home approaches have not been directly compared pertaining to their technical performance or their acceptance by the end users. It is also unclear what the perceived privacy and obtrusiveness concerns are when it comes to the implementation of these two different approaches in homes. The study presented here aimed to evaluate acceptance of these two sensing approaches by older adults and assess the perceived privacy and obtrusiveness concerns and ultimately define their social implications.**

I. INTRODUCTION

Two distinct approaches to smart home design, namely Distributed Direct Sensing (DDS) and Infrastructure Mediated Sensing (IMS), have distinguishing features and operate under different assumptions and infrastructure. DDS involves the installation of a new sensing infrastructure into the home with the purpose of sensing the presence, motion, or activities of its residents through sensors that are physically located throughout the home. As is typically the case with DDS systems, several sensors are installed in the residence and an associated sensor network is implemented to transfer the sensor data to a centralized monitoring system in order for the datasets resulting from different sensors to be merged and processed to allow for activity inference. With IMS systems, on the other hand, it is the existing home infrastructure, such as the plumbing or electrical systems, that is used to mediate the transduction of events as infrastructure activity is used as a proxy for a human activity. The argument for IMS is that it has the potential to reduce the installation and maintenance barriers and therefore, lead to more widely spread adoption as a more cost-effective solution when compared to the cost of implementing and maintaining the activity sensing infrastructure. However, the two distinct smart home approaches have not been directly compared pertaining to their technical performance or their acceptance by the end users. It is also unclear what the perceived privacy and obtrusiveness concerns are when it comes to the implementation of these two different approaches in homes.

This study aims to assess older adults' and their caregivers'/ family members' perceptions of the two sensing approaches and their privacy considerations associated with specific smart home examples. Furthermore, we discuss social implications of these distinct sensing approaches.

II. BACKGROUND

When exploring acceptance of smart home technology, prior work on technology acceptance and privacy consideration can inform the emerging issues. Models that predict adoption or inform design of technology contribute to a useful framework to guide the design and evaluation of smart home technologies. The Technology Adoption Model (TAM) [1] includes two central concepts: usefulness (in achieving personal goals), the primary determinant of adoption and use of a technology; and ease of use or usability, the secondary determinant. Since smart home technologies do not in principle require operation by residents, the ease of use determinant does not apply. Value Sensitive Design (VSD) [2] is a theoretically grounded approach to design and goes beyond the goal orientation of usefulness. It stresses the importance of addressing human values in design, especially those of ethical import. VSD is an *approach* to design not a comprehensive typology of human values important in design (though important ones are identified). These models comprise a framework for smart home development in which the following considerations are central to adoption and sustained use these technologies: end-user perceptions of usefulness in achieving critical goals and protecting human values that are especially salient in the home environment.

Preliminary questions that have bearing on the potential usefulness of smart home technologies include those about validity and reliability. Testing must empirically establish that given smart home sensors reliably "pick up" pertinent data that accurately represent what they purport to measure (e.g., activity level, sleep quality). Usefulness will ultimately be determined by end users, their families, and health care providers. Criteria will include how well this approach is perceived (and ultimately found) to support independence and health-related quality of life.

Five values, along with attributes, issues, or other values they subsume, are identified from the literature as especially important to the design and development of smart homes:

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privacy [3-8]; autonomy [6-8]; independence [8]; social contact or interaction [9]; and responsibility [8]. The interrelations of these values as applied are also identified.

A. Privacy

Privacy is protected when a person "determine[s] what information about himself or herself can be communicated to others. [5]" Included are privacy of information, such as personal health data, and privacy of the home environment, where information that is not relevant to the purpose of smart homes may be accessible [10]. Smart homes must develop to minimize capture of "irrelevant" information in the home, and assure that the storage and transmission of it to providers and family is secure [11]. The professional obligation of confidentiality helps to contain privacy concerns. In addition to the home environment, physical privacy includes freedom from unwanted contact with, or surveillance by, other people [12].

The importance of independence in the context of smart homes is described in the literature in terms of avoiding unnecessary dependence. There is potential for residents to become overly reliant on such technologies [8]. A technology may enable a task that is otherwise difficult for a user with functional limitations and become essential to the extent that he or she will not attempt the task without this assistance. Automating everyday tasks may result in making some residents less active, physically and possibly even mentally. Moreover, any negative feelings of dependence will likely be stronger in the home setting, "one's defining place [13]." The challenge for designers of smart homes is to create a system that "adds ability without removing status [14]." Thus, technology should not minimize but rather enhance independence [15].

In summary, the successful diffusion of smart home technologies depends to a great extent on end users' acceptance of both the concept of smart home monitoring and the specific implementation features and how these affect daily living. It is therefore important to explore end users' perceptions and acceptance of the distinct sensing approaches (DDS vs IMS) when discussing the benefits and challenges of each mode.

B. Obtrusiveness

While literature on elder home monitoring technologies recommends that systems be designed to minimize their obtrusiveness [16, 17], this concept is neither explicitly defined nor consistently used. For example, Suzuki *et al.* use "non-intrusive" to emphasize that people do not have to operate a system [18], Lymberis and Olson used the term "non-obtrusive" to refer to miniaturization of monitoring devices in intelligent biomedical clothing [19], Ling *et al.* describe a minimal contact oxygen delivery system as "non-obtrusive" because it does not contact the face and is odorless [20], and Suzuki *et al.* selected sensors for an automatic remote health monitoring system based on their "ease of installation and *unobtrusiveness*" [21]. Conversely, Abascal and Nicolle review similar systems and emphasize that these technologies are "very *intrusive* and must only be used with the permission of the user" [11]. We have in previous work developed a theoretical framework for the assessment of obtrusiveness based on defining obtrusiveness as a summary evaluation by a person based on characteristics or effects associated with the technology that are perceived as undesirable and physically and/or psychologically prominent [10]. Within this definition, there are three underlying assumptions: 1) obtrusiveness is a summary evaluation that may be based on the cumulative obtrusiveness of a number of characteristics or effects associated with the technology or on one characteristic or effect that is especially important or prominent to a person; 2) the obtrusiveness of a given technology is subjectively assigned by each person; 3) this includes not only the elder, but also any other people in the home and family or friends who act as caregivers and may utilize the information generated by a system. Based on a review of the literature, the developed framework proposes twenty-two categories, grouped into eight dimensions, of perceived intrusiveness in home monitoring technology. The categories of obtrusiveness range from what some may consider inconveniences (e.g., minor interference with daily activities) to potentially deeper concerns (e.g., that a system may be perceived as a symbol of an elder's loss of independence). Furthermore, the proposed framework was empirically validated with a series of interviews and focus groups with elders in independent retirement communities and nursing homes, including both settings that utilize assistive technologies and/or "smart home" features and traditional settings that do not. A qualitative analysis confirmed the identified categories and the overall dimensions of obtrusiveness (physical, usability, privacy, function, human interaction, self-concept, routine, and sustainability) [22].

III. Methods

We interviewed community dwelling older adults and their informal caregivers/ family members using this obtrusiveness framework to assess how the distinct features of the two sensing approaches (DDS vs IMS) affect end users' perceptions. Interview sessions were audio-taped and transcribed for qualitative analysis. The content analysis identified themes that will highlight participant evaluations of obtrusiveness and potentially inform the research team of any necessary adjustments in our approach. During the interviews videotapes of smart home projects designed based on these distinct approaches were presented to the participants.

The interview guide instrument pertaining to privacy specifically, was a semi-structured series of questions to guide the interviewer. The questions focused on the subjects' initial impression of the sensing system and the extent to which this monitoring is perceived as in violation of subject's privacy. Furthermore, in order to explore subjects' preferences on system characteristics, we integrated descriptive cues based on the Bellotti and Sellen framework [23] for describing privacy issues in media spaces. This framework includes four dimensions that play a role in privacy perceptions, namely: capture (when and what information gets recorded), construction (what happens to the information once it gets recorded), access (who has access to the information) and purposes (how will the information be used). Capture refers to the data type and how recognizable a person's identity, environment or activity is within a captured image or dataset. Examples of different applications and resulting datasets (including numeric datasets, video sequences, still images) were discussed to examine how this dimension may or may not affect overall privacy concerns.

A content analysis was performed on the interview transcripts and data codes and themes were inductively generated. We used two levels of coding: the individual text line (open coding) and the clustering of ideas or themes (axial coding) [24].

IV. Results

We interviewed 20 older adults and 14 family members, friends, spouses or others who assumed an informal caregiving role. Average age of older adults was 74.5 years and that of caregivers was 47.8 years.

Most older adults stated that the indirectness of using a home's existing utility infrastructure (IMS) provides important benefits with regard to privacy when compared to approaches that propose cameras, sensors or microphones within the living space (DDS) as they seem less obvious to visitors and are not clearly visible as constant reminders of one's own frailty. In this context, participants commented on the issue of *stigma*, namely the fact that many DDS applications, whether installed in the home or even wearable by the residents, may label them as in need of special assistance. As such, DDS systems may indeed introduce more privacy concerns.

On the other hand, several participants felt that DDS applications may be able to provide greater detail in terms of the actual activities or circumstances and would not mind their visibility if they served a needed purpose. This is in accordance with recent work that indicates that older adults are often willing to compromise certain levels of privacy to gain support in remaining independent [25]. This type of conditional reasoning determines in many cases the acceptance of privacy invasive technologies, where a device that may be considered to be intrusive, is likely to be accepted if it is viewed as necessary to support a need [7].

Caregivers seemed to favor DDS applications because of the detailed information it may provide on actual activities in the home. Older adults on the other hand seemed to find greater value in IMS systems where the sensors were part of the residential infrastructure rather than additional entities that were installed for the purposes of monitoring. As one respondent said, an IMS system "would measure things that happen with the utilities, not necessarily focus on me and whether I do things right, this is OK with me, it doesn't feel like big brother at all…." Several respondents felt they would welcome either approach if it were widely installed in independent retirement communities or assisted living facilities.

Overall, both older adults and their caregivers were accepting of sensing technologies and found great value in systems that assist with monitoring and detecting emergencies or allow for early interventions. Specific features such as video, wearable visible sensors and reminder systems were perceived as more intrusive and in most cases were not rated as acceptable.

Access to resulting datasets was also addressed by participants. Older adults stated that they would like their loved ones and their health care providers to have access to information resulting from a sensing system but did emphasize a concern that the data sets may be accessible to unauthorized third parties. Family members saw great value in systems that could provide them with daily information about their loved ones, especially in cases where they were separated by them by large geographic distance and they identified themselves as distant caregivers. In that context, caregivers found that such systems could empower them and allow them to be more actively involved in the care for and life of their loved one.

V. Conclusion

Privacy is the most commonly raised criticism of ubiquitous computing [26]. The concrete definition of "privacy" is a challenge [27], as it is important to recognize that privacy is affected by market, social, legal, and technical forces [28]. As we compare the two distinct approaches to smart home systems (DDS vs IMS) we believe it is important that home activity sensing systems provide appropriate considerations for the privacy of people living in a home where activities are sensed. The design and implementation of smart home approaches need to be informed by the actual needs and concerns of their target audience and after consideration of both its social implications and potential unintended consequences.

References

[1] Davis FD. Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Quarterly 1989;13(3):319-340.
[2] Friedman B, Peter H Kanh J. Human values, ethics, and design. In: Jacko JA, Sears A, editors. The Human-Computer Interaction Handbook.
[3] Bauer KA. Home-based telemedicine: A survey of ethical issues. Cambridge Quarterly of Healthcare Ethics 2001;10:137-146.
[4] Brey P. Freedom and privacy in Ambient Intelligence. Ethics and Information Technology 2005;7:157-166.
[5] Friedman B, Peter H Kanh J, Borning A. Value Sensitive Design and information systems. In: Zhang P, Galletta D, editors. Human-Computer

Interaction and Management Information Systems: Foundations. Armonk, New York: M.E. Sharpe; 2006. p. 348-371.
[6] Magnusson L, Hanson EJ. Ethical issues arising from a research, technology and development project to support frail older people and their family carers at home. Health and Social Care in the Community 2003;11(5):431-439.
[7] Melenhorst A-S, Fisk AD, Mynatt ED, Rogers WA. Potential intrusiveness of aware home technology: Perceptions of older adults. In: Human Factors and Ergonomics Society 48th Annual Meeting; 2004; New Orleans; 2004. p. 266-270.
[8] Stip E, Rialle V. Environmental cognitive remediation in schizophrenia: ethical implications of "smart home" technology. Canadian Journal of Psychiatry 2005;50(5):281-91.
[9] Wylde M, Valins M. The impact of technology. In: Valins M, Salter D, editors. Futurecare: New Directions in Planning Health and Care Environments. Oxford: Blackwell Science; 1996. p. 15-24.
[10] Hensel, B.K., Demiris, G. and Courtney, K.L. (2006). Defining Obtrusiveness in Home Telehealth Technologies: A Conceptual Framework. *Journal of the American Medical Informatics Association* 13(4). 428-431.
[11] Abascal, J. and Nicolle, C. (2005). Moving Towards Inclusive Design Guidelines for Socially and Ethically Aware HCI. *Interacting with Computers* 17(5). 484-505.
[12] Allen AL. Privacy in Healthcare. In: Mitcham C, editor. Encyclopedia of Bioethics. 3rd ed. Farmington Hills, Michigan: Thomson Gale; 2004. p. 2120-2130.
[13] Ruddick W. Transforming homes and hospitals. Hastings Center Report 1994;24(5):S11-S14.
[14] Cowan D, Turner-Smith A. The role of assistive technology in alternative models of care for older people. In: With respect to old age research. London: Age Concern Institute of Gerontology, Kings College; 1999. p. Appendix 4: 325-346.
[15] Korr W, Encandela J, Brieland D. Independence or autonomy: Which is the goal? International Journal of Law and Psychiatry 2005;28:290-299
[16] Miskelly, F.G. (2001). Assistive Technology in Elderly Care. *Age and Aging* 30(6). 455-458.
[17] Rialle, V., Duchene, F., Noury, N., Bajolle, L. and Demonjeot, J. (2002). Health "Smart" Home: Information Technology for Patients at Home. *Telemedicine Journal and e-Health* 8(4). 395-409.
[18] Suzuki, R., Ogawa, M., Tobimatsu, Y. and Iwaya, T. (2001). Time-Course Action Analysis of Daily Life Investigations in the Welfare Techno House in Mizusawa. *Telemedicine Journal and e-Health* 7(3). 249-259.
[19] Lymberis, A. and Olsson, S. (2003). Intelligent Biomedical Clothing for Personal Health and Disease Management: State of the Art and Future Vision. *Telemedicine Journal and e-Health* 9(4). 379-386.
[20] Ling, E., McDonald, L., Dinesen, T.R. and DuVall, D. (2002). The OxyArm: A New Minimal Contact Oxygen Delivery System for Mouth or Nose Breathing. *Canadian Journal of Anesthesia* 49(3). 297-301.
[21] Suzuki, R., Ogawa, M., Otake, S., Izutsu, T., Tobimatsu, Y. and Iwaya, T. (2004). Analysis of Activities of Daily Living in Elderly People Living Alone: Single-Subject Feasibility Study. *Telemedicine Journal and e-Health* 10(2). 260-276.
[22] Courtney, K.L., Demiris, G. and Hensel, B.K. (2007). Obtrusiveness of Information-Based Assistive Technologies as Perceived by Older Adults in Residential Care Facilities: A Secondary Analysis. *Medical Informatics and the Internet in Medicine* 32(3). 241-249.
[23] Bellotti, V. and Sellen, A. (1993). Design for Privacy in Ubiquitous Computing Environments. *Proceedings of the European Conference on Computer Supported Cooperative Work* (ECSCW), 77-92.
[24] Benoliel JW. (1996). Grounded theory and nursing knowledge. *Qual Health Res.,* 6:406-28.
[25] Caine KE, Rogers WA & Fisk AD (2005). Privacy perceptions of an aware home with visual sensing devices. *Proceedings of the Human Factors and Ergonomics Society 49th Annual Meeting.* Santa Monica, CA: Human Factors and Ergonomics Society.
[26] Hong, J.I. and Landay, J.A. (2004). An Architecture for Privacy Sensitive Ubiquitous Computing. *Proceedings of the International Conference on Mobile Systems, Applications, and Services* (MobiSys 2004), 177-189.
[27] Palen, L. and Dourish, P. (2003). Unpacking "Privacy" for a Networked World. *Proceedings of the ACM Conference on Human Factors in Computing Systems* (CHI 2003), 129- 136.
[28] Lessig, L. (1999). *Code and Other Laws of Cyberspace*. New York: Basic Books.