Aging with the Internet of Things

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With capabilities for sensing, analysis, and actuation, the IoT has immense potential to help aging adults maintain health and independence.

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The Internet of Things (IoT) offers a host of new functionalities for sensing both environments (e.g., through motion-activity sensors) and individuals (e.g., through wearable smart watches) and for analyzing sensed data to make them actionable to users via notifications (e.g., through a smart speaker) and to applications via actuators (e.g., through a light switch). Wireless capability facilitates the deployment and use of such devices in every aspect of life and across age groups.

This article explores the potential of the IoT to compensate for age-related changes by helping older individuals achieve and maintain health and independence. We briefly explain the Internet of Things and its relevance to aging, and then illustrate its applicability with a fictional 80-year-old. Although much of the technology exists to support the fictional scenario, there are challenges to the widespread attainment of the IoT's potential. We review these and then focus on the particular challenge of technology acceptance among the elderly, considering particular aspects

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of this barrier, before closing with suggested steps to realize the IoT vision.

Introduction

The Internet of Things is a network of devices that offer both sensing and actuating capabilities related to an environment or user; the devices may have some computing and storage capabilities to process sensed data (e.g., room temperature, user motions); and they require network capabilities to receive and transmit the data (Consel and Kabáč 2017). Advances enable them to provide ever higher-level functionalities (Bahga and Madisetti 2014), making them readily usable via web or mobile applications. In addition, they can be configured by the user (e.g., to set a threshold for a room temperature, a duration of physical inactivity) and send notifications (e.g., alarm, text messages, push notifications) when certain situations are detected. The magnitude of potential impacts is illustrated by the pervasive nature of the IoT, which covers all aspects of people's lives: health, entertainment, home, transportation, communication, and more.

Why would the IoT be of interest or value to aging? The answer lies in one of the fundamental challenges of aging: the trend toward loss of function and potential loss of independence. Among adults over age 65 in the United States, for example, nearly half require assistance with routine daily activities and over 20 percent have mild cognitive impairment or dementia. As the large baby boomer population ages, these numbers will grow substantially during the next decade.

These trends have major implications for society as family caregiving is the major source of support for those who need assistance, yet the number of younger individuals available for this support will decline with the shifting demographic trend toward an older population. Thus, strategies for sustaining well-being and independence with aging are a high priority.

IoT Support for Aging: An Illustrative Scenario

To illustrate how the IoT can support aging, we present a scenario with a fictional individual who aggregates the profiles of participants in studies of assistive technologies. The account is an idealization to frame the discussion. Although the scenario is based entirely on existing technologies, there is much research to be done and it is likely that much of what we describe may be adopted only in part.

Mr. Dubois is 80 years old and lives by himself in an apartment in a small town. His daughter, Yvette, does not visit often because it is a 5-hour drive from where she lives. She used to call almost every day to check on her father, which was not satisfactory for either of them. To address this situation, Mr. Dubois subscribed to an application for monitoring his activities, leveraging WiFi signals from already deployed devices (e.g., router, WiFi speakers). He configured the app with a selection of events that Yvette agreed to help him track. She can now see on her smartphone how her father's day is unfolding.

A longitudinal analysis module indicates his functional status. The data show deviations in daily routines, level of physical activity, medication taking, sleep patterns, and gait. Mr. Dubois allowed this assessment to be communicated to his physician, augmented with medical-related measurements that complement self-reported information, providing useful insights for medical appointments.

Mr. Dubois is comfortable using a computer and smartphone, as long as this use involves applications he is already familiar with, mainly email, weather, a calendar, and a favorite online game. He recognizes his lack of motivation to adopt new applications and complains vehemently about new versions of his usual applications that keep changing their user interfaces.

IoT data can show deviations in daily routines, level of physical activity, medication taking, sleep patterns, and gait.

For example, he had stopped using the photo application on his computer until Yvette, during one of her visits, showed him how to use a new voice-controlled interface. The speech recognition module allowed Mr. Dubois to perform his tasks of interest, giving voice commands to the built-in microphone of his computer or a smart speaker within range (he has several to listen to music). He now receives an audio notification when new photos are posted by his family and friends. He can activate voice-driven dialogues to perform tasks in the photo application such as displaying recent photos on any connected screen, managing pictures, and posting his own. A module of the application adapts to his usage patterns and optimizes the steps proposed in the dialogues to improve efficiency and his user experience.

Although Mr. Dubois remains independent, recent minor events have shown that he could use some help. He and his daughter decided to subscribe to a couple of services that address the situations of concern. One service monitors the stove to ensure that someone is at least periodically present in the kitchen when the stove is on. If the stove is left unsupervised, an audio alert is sent to Mr. Dubois via the home speakers. If he does not promptly respond to the alert, the stove turns itself off automatically. Another service involves Mr. Dubois's financial transactions. A secure online transaction monitoring service flags unusual financial activity and, with his permission, shares this information with his daughter.

An IoT service monitors the stove to ensure that someone is at least periodically present in the kitchen when the stove is on.

Finally, since his last medical examination, Mr. Dubois has set himself a daily goal of increasing his physical activity. He acquired a new watch with a built-in activity tracker and he and his doctor configured it with his profile and appropriate goals. The device takes a variety of reliable measurements (heart rate, steps, body temperature, GPS tracking, gait) and compiles them into actionable information, delivered to Mr. Dubois by a virtual coach that interacts with him via voice interface, allowing him to rapidly become proficient in using the system. Mr. Dubois's activities are recorded and both inter- and intraindividual analyses continuously assess his activities with respect to his goals. The virtual coach is understandable and pragmatic for Mr. Dubois, and its sophisticated analyses are useful to his physician.

As illustrated in the scenario above, IoT devices can provide aging individuals with support in their daily life, stimulating, assisting, and/or compensating to address age-related changes and in the process both reinforcing the user's self-determination and reducing caregiver burden (Dupuy et al. 2016). And because IoT services address the specific user's needs and preferences, they leverage the individual's motivation.

IoT Potential and Challenges

Innovation tends to effectively transfer among user populations when it leverages mainstream technologies, and the rich potential functionalities and ubiquity of IoT devices enable older users to use mainstream technologies as opposed to special-purpose, expensive, stigmatizing "senior" devices. A touch-screen tablet, for example, can provide application-level user interfaces of value and immediate usability to older adults (e.g., display of a remote control with large buttons and familiar symbols).

Connectivity and Interoperability

Despite the potential for connectivity, most devices tend to be narrowly focused on a specific purpose (e.g., room temperature) or task (activity tracking), providing limited interoperability. But their potential connectedness is already supported by a pervasive network infrastructure. Devices can send/receive data and interact across area-specific networks (e.g., home, health, security) thanks to dedicated gateways; Bluetooth, for example, is used for both wearable devices and entertainment devices.

The IoT can promote full interoperability of devices and realize *services* as the data produced are combined and cross-checked to improve the accuracy of analysis and refine the delivery of assistance. Achieving this goal requires that services depart from specialized tasks (e.g., inactivity alert based on a timer and an activity sensor) and target higher-level activities (e.g., detection of individual deviations in personalized daily routines).

Trends in IoT Innovation

The IoT gathers and processes data for applications that are customized for user needs and preferences, with data storage and analysis increasingly done by online applications (apps) promoted by smartphones. Mobile apps that provide computing support for the aging population can create opportunities to introduce or adapt device use for older users. Mainstream devices (such as the tablet) can thus become relevant to older adults. For example, activity-tracking wristbands that monitor sleep, heart rate, number of steps, and a variety of activity-related movements were originally intended to support physical exercise such as walking, running, or cycling, but some vendors of such devices now team up with third-party companies that provide advanced coaching based on user data.

If vendors appreciate the size and needs of the aging population, age-supporting apps could provide feedback and be used to suggest and coach physical activities or exercises adapted by professionals. More advanced applications and devices could monitor dimensions such as stress levels with respect to physiological signs and mobility with respect to gait and posture information (Kaye et al. 2012) and help address challenges such as fall risks and mood disorders.

Such applications must be customizable for each user and trustworthy in the services they deliver. Furthermore, they must avoid false alarms and irrelevant or, worse, erroneous user advice. The providers of these services must be dedicated to capturing large amounts of relevant data to ensure that their inference algorithms and advice are actionable and reliable.

As can be expected, making user data available for analysis (e.g., by opening up vendor platforms to unaffiliated programmers and third parties) may raise security and privacy issues. This could create a conflict between fostering application innovation by giving access to as much data as possible, at the cost of risking privacy breaches, and protecting the user's data by imposing stringent and restrictive rules, at the cost of discouraging programmers.

The development of IoT applications should leverage cloud computing, which covers all the functionalities needed to build innovative applications, including authentication services, storage and database facilities, data processing, machine learning, and speech recognition. As shown for mobile platforms, this approach dramatically improves software productivity. Additionally, cloud computing should achieve IoT interoperability by providing support to aggregate and cross-check information with other devices.

Trends in programming and platforms should enable computing support for aging to keep pace with mainstream technology innovation. Indeed, developers for this population can integrate readily available, advanced building blocks to deliver functionality-rich applications and thus reduce the gap between mainstream technologies and those dedicated solely to older adults.

Evaluation

There are significant standardization gaps, such as high variability in the devices or technologies (both hardware and software) and no common ontology or schema for specification of the systems deployed and the analytic algorithms applied. To ensure that the systems are truly individualized, more research is needed on usability across the multiple stakeholders involved, from the older individual to family members, clinicians, and other service providers.

Mobile apps will need to undergo evaluation to ensure their usability and efficacy. Evaluation procedures should be more stringent for applications that target security or health and should include an evidence-based analysis of efficacy.

IoT applications and devices could monitor physiological signs and mobility to help address challenges such as fall risks and mood disorders.

Recognizing when an application crosses the line between tracking a user's general well-being and identifying specific medical issues can be challenging as innovation brings unforeseen functionalities and usage contexts of technologies. The more medically oriented an application, the higher the degree of evaluation needed to ensure its safety and reliability. This is likely to slow the development and adoption of such applications.

App Navigation

Finally, an important practical issue to address is the navigation of an online app catalogue, which becomes increasingly challenging as it grows. This navigation could be assisted by a recommendation system based on information from deployed applications and the needs and preferences of users and their care partners. This recommendation system would integrate domains such as medicine, psychology, and ergonomics.

While rates vary from one individual to the next, in general older adults increasingly need assistance in managing their computing environment because of declines in sensory (e.g., hearing, vision, touch) and cognitive function (e.g., slower reaction times, processing speeds, memory), affecting their ability to fully benefit from applications for their daily activities. This need should give rise to new types of professional service workers with expertise in computing support for older adults (e.g., training users, configuring devices, maintaining assistive support, and prescribing new services).

Factors That Affect Technology Acceptance

Virtually any device can be proposed to older adults as long as adoption is seamless and meaningful uses can be identified, programmed, and disseminated. For example, mobile apps offer a variety of ways to assist a user in performing a task or activity; each variation is in principle meaningful and customized to individuals with shared characteristics and preferences. This customizable usefulness can address virtually every aspect of daily life and contributes to successful adoption (Dupuy et al. 2016). Nonetheless, technology acceptance remains a challenge. We briefly review commonly cited issues relating to technology acceptance (Czaja et al. 2009; Kaye 2017).

Needs analysis should target both individual users and their care or life partners.

Addressing Needs

To be accepted, a new technology must address the user's needs. A proper needs analysis must be conducted before any technology deployment. It can involve a variety of methods, such as questionnaires and task analyses. Because studies have revealed differences in perceived needs, it should target both the user and their care or life partners (e.g., Gold 2012; Wild et al. 2008). Matching needs with applications can be challenging, especially when a catalogue with a plethora of applications must be navigated. Classification approaches should be used to group applications for aging according to dimensions such as health conditions (Pollack 2005) and activity types (Gillespie et al. 2012).

Leveraging Motivation

Identifying needs is not sufficient if the user is not motivated to use the technology. Recent work has shown a relationship between motivation and technology acceptance in both younger and older adults (Dupuy et al. 2016; Lee et al. 2015). The IoT can facilitate motivation because it is not a one-size-fits-all model served by a monolithic computing system. Instead, it should support the emergence of rich online catalogues of applications that can assist specific activities that are meaningful to the user and tailored to their needs. This approach is illustrated by the HomeAssist platform for independent living (Consel et al. 2017). A field study showed that the granularity of its applications matched meaningful support needs of users, motivating them to use the apps and thus bringing them satisfaction and improving their well-being (Dupuy et al. 2016).

Promoting Inclusive Design

Applications can be ill designed and stereotyped or biased when targeting older users, resulting in challenges to age-related sensory, motor, and cognitive changes and exhibiting poor usability in terms of efficiency, efficacy, learnability, and other dimensions. Developers must leverage, on the one hand, user-centered design principles and experience that account for the specificities of older adults (Czaja et al. 2009) and, on the other hand, software development approaches that integrate human-related dimensions (Consel 2018).

Lowering Cost

Acquiring IoT devices to support aging can be costly. Fortunately, the IoT promotes the adaptation and use of mainstream devices and technologies to support aging, delivering more affordable products than those developed specifically for older users.

Ensuring Privacy

The IoT raises important privacy issues both because it is pervasive and because devices rely on greater amounts of data about users' environment and users themselves, a risk that may be even more pronounced for older adults as they age and their needs for monitoring and assistance increase. This situation is further complicated by the growing number of platforms sharing user data with third-party developers to boost their catalogue of applications. All these factors make privacy a major challenge for the IoT to support aging.

It is common to read of privacy breaches in widely used applications (e.g., social networks, health system databases). The Health Insurance Portability and Accountability Act of 1996 (HIPAA; DHHS 2003) protects the privacy of health information, but does not cover private online applications. In May 2018 the European Union passed a regulation on personal data that applies to any business regardless of location and area of service. The General Data Protection Regulation (GDPR) protects the data and privacy of all individuals in the European Union (EPC 2016) and introduces a major requirement on business processes: "data protection by design *and by default*" (emphasis added). Thus a processor of personal data is required to be designed and built using principles and safeguards to protect the data using the highest possible privacy settings by default.

What Is Needed to Realize the IoT Vision

The IoT can bring needed information and services into everyday life for older adults. Applications that are increasingly device agnostic should enhance interest among the growing population of aging users by accounting for their specific attitudes, beliefs, and needs. Online app catalogues may eventually create a continuum of services covering the needs and preferences of all age groups.

Over the past decade, many prototypes of "senior smart apartments" and some larger, end-to-end systems have been deployed (e.g., Consel et al. 2017; Cook et al. 2013; Kaye et al. 2011) to explore their feasibility and efficacy. But there remain few studies in other areas such as medicine, psychology, and human factors. Studies suggest value but have been limited by small sample sizes, short study periods, biased designs, and the involvement of nondiverse populations (Liu et al. 2016; Madara Marasinghe 2016).

Barriers to technology deployment include lack of usability, inadequate research expertise, costs, and lack of evidence of efficacy or effectiveness. Aside from ongoing technological improvements, what is missing is a larger research ecosystem to design, develop, deploy, and critically evaluate the services in order to create the evidence to move users, as well as governments, toward adoption.

We suggest the following steps to put this vision into practice:

- Much research is needed to conduct field studies to assess computing systems and protocols that support aging with respect to three dimensions: clinical, ergonomic, and acceptability.
- To address the major societal challenge of independent living, the home should be a primary area of focus. Real-world experiments of IoT-based platforms supporting independent living—such as Collaborative Aging Research Using Technology (CART; www.carthome.org; Kaye et al. 2011), the Center for Advanced Studies in Adaptive Systems at Washington State University (CASAS, casas.wsu.edu; Cook et al. 2013), and HomeAssist[1] (Consel et al. 2017)—should be encouraged, fostering a collaborative approach in this research area.
- Public-private partnerships and government support will be needed to create precompetitive spaces for development.
- To address online privacy breaches the computing industry and user communities should actively engage in developing regulations to minimize such risks. Different privacy levels could be offered, depending on the sensitive nature of user data.
- Larger scale, as seen in other areas of research that inherently utilize big data (e.g., genomics), is needed to build evidence that can be relied upon across communities.

A research ecosystem is needed for the design, development, deployment, and evaluation of services, to create evidence and promote adoption.

- Models should be developed to enable comparison of platforms with respect to dimensions such as measurement accuracy, effectiveness in supporting aging, and learning cost for users.
- Research groups studying IoT-based support for aging should collaborate to accelerate progress, to make this research area more mature, and to develop more effective and sustainable approaches.

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[1] phoenix.inria.fr/research-projects/homeassist

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References

Alzheimer's Association. 2019. Mild Cognitive Impairment. Online at https://www.alz.org/alzheimers-dementia/what-is-dementia/related_conditions/mild-cognitive-impairment.

Bahga A, Madisetti V. 2014. Internet of Things: A Hands-On Approach. Online at www.hands-on-books-series.com.

Consel C. 2018. Assistive computing: A human-centered approach to developing computing support for cognition. Proceedings of the IEEE/ACM 40th International Conference on Software Engineering: Software Engineering in Society (ICSE-SEIS), May 27–Jun 3, Gothenburg, Sweden (pp 23–32).

Consel C, Kabáč M. 2017. Internet of Things: From small- to large-scale orchestration. Proceedings of the 2017 IEEE 37th International Conference on Distributed Computing Systems (ICDCS), Jun 5–8, Atlanta (pp 1748–1755).

Consel C, Dupuy L, Sauzéon H. 2017. HomeAssist: An assisted living platform for aging in place based on an interdisciplinary approach. Proceedings of the International Conference on Applied Human Factors and Ergonomics, Jul 17–21, Los Angeles (pp 129–140).

Cook DJ, Crandall AS, Thomas BL, Krishnan NC. 2013. CASAS: A smart home in a box. Computer 46(7):62–69.

Czaja SJ, Rogers WA, Fisk AD, Charness N, Sharit J. 2009. Designing for Older Adults: Principles and Creative Human Factors Approaches. Boca Raton FL: CRC Press.

DHHS [US Department of Health and Human Services]. 2003. Summary of the HIPAA privacy rule. Washington. Online at https://www.hhs.gov/hipaa/for-professionals/privacy/laws-regulations/index.html.

Dupuy L, Consel C, Sauzéon H. 2016. Self determination-based design to achieve acceptance of assisted living technologies for older adults. Computers in Human Behavior 65:508–521.

EPC [European Parliament and Council]. 2016. Regulation on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation). EUR-Lex, Apr 27. Online at https://eur-lex.europa.eu/eli/reg/2016/679/oj.

Gillespie A, Best C, O'Neill B. 2012. Cognitive function and assistive technology for cognition: A systematic review. Journal of the International Neuropsychological Society 18(1):1–9.

Gold DA. 2012. An examination of instrumental activities of daily living assessment in older adults and mild cognitive impairment. Journal of Clinical and Experimental Neuropsychology 34(1):11–34.

Kaye J. 2017. Making pervasive computing technology pervasive for health and wellness in aging. Public Policy & Aging Report 27(2):53–61.

Kaye JA, Maxwell SA, Mattek N, Hayes TL, Dodge H, Pavel M, Jimison HB, Wild K, Boise L, Zitzelberger TA. 2011. Intelligent systems for assessing aging changes: Home-based, unobtrusive, and continuous assessment of aging. Journals of Gerontology Series B: Psychological Sciences and Social Sciences 66(Suppl 1):i180–i190.

Kaye J, Mattek N, Dodge H, Buracchio T, Austin D, Hagler S, Pavel M, Hayes T. 2012. One walk a year to 1000 within a year: Continuous in-home unobtrusive gait assessment of older adults. Gait & Posture 35(2):197–202.

Lee Y, Lee J, Hwang Y. 2015. Relating motivation to information and communication technology acceptance: Self-determination theory perspective. Computers in Human Behavior 51:418–428.

Liu L, Stroulia E, Nikolaidis I, Miguel-Cruz A, Rios Rincon A. 2016. Smart homes and home health monitoring technologies for older adults: A systematic review. International Journal of Medical Informatics 91:44–49.

Madara Marasinghe K. 2016. Assistive technologies in reducing caregiver burden among informal caregivers of older adults: A systematic review. Disability and Rehabilitation: Assistive Technology 11(5):353–360.

Pollack ME. 2005. Intelligent technology for an aging population: The use of AI to assist elders with cognitive impairment. AI Magazine 26(2):9.

Wild K, Boise L, Lundell J, Foucek A. 2008. Unobtrusive in-home monitoring of cognitive and physical health: Reactions and perceptions of older adults. Journal of Applied Gerontology 27(2):181–200.