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Smart Home for Seniors: Opportunities and Challenges for AI

(Preprint version)

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Abstract: The world's population is aging. This raises crucial questions regarding the health care and well-being of these people. Technological solutions such as Smart homes for the elderly is one of the possible solutions. Smart homes are designed to help their residents perform their daily activities and improve their quality of life while preserving their privacy. These solutions are usually equipped with a set of software and hardware components such as sensors to monitor the living space and recognize the behaviors and activities of the resident. This makes it possible to detect anomalies, to inform about risk situations and to take appropriate measures. For the elderly, often living alone, this can improve their safety, monitor their health and inform their relatives, for example. The purpose of this paper is to present a quick and concise overview of Smart home solutions and a focus on opportunities and challenges for AI. In terms of current solutions, the focus will be on the functionalities that can be provided by this type of solutions and the technical challenges and limitations encountered in practice for the use and large scale deployment of these solutions. We will try to focus on a variety of tasks and issues that require the use of artificial intelligence for a truly intelligent Smart home. This position paper aims to first clarify the opportunities that these Smart home solutions represent for artificial intelligence, but also highlight the challenges and the technical limits. We also present the main results of a survey that we recently conducted with elderly people in Hauts-de-France in France. In doing so, we give some recommendations for the design and the deployment of Smart home on a large scale.

1 INTRODUCTION

The finding is well established: the world's population is aging. Indeed, most countries in the world are experiencing a growth in the number and proportion of older people in their population. According to data from World Population Prospects: Revision 2019¹, by 2050, 16% of the world's population will be over 65, while in 2019 this proportion is 9%. By 2050, one in four people living in Europe and North America could be 65 years of age or older. In some countries, such as Japan, the United States of America or European countries, this phenomenon is mainly due to the arrival of the baby boomer generation at retirement age. In France, with the extension of the life span, the aging of the French population continues. People aged 65 and over represent 20% of the population. INSEE²'s demographic forecasts predict that the proportion of people over 60 years old will

increase strongly until 2035 (their share should continue to increase, but more modestly afterwards). INSEE estimates that 4 million seniors would be in loss of autonomy in 2050. This problem affects all of the countries, but it has certain specificities in some regions, such as the fact that seniors are more vulnerable to poverty and health issues. There is then a real question of society regarding the care of this segment of the population.

Obviously, the needs in terms of health care and well-being of the elderly is a real challenge. It is also interesting economic opportunities, especially for AI. One of the solutions is of a technological nature and concerns Smart homes specially designed for the elderly. Indeed, the "industry" of Smart homes dedicated to the elderly has greatly developed in recent years to meet these needs still rising. Smart home technologies can bring real health and wellness benefits in addition to energy savings, comfort and safety. Solutions adapted to the needs of the elderly impose several constraints because of their state of health and, possibly, their loss of autonomy, loneliness for some of them and their relationship to technology. The ex-

¹<https://population.un.org/wpp/>

²<https://www.insee.fr/en/metadonnees/source/serie/s1316>

isting Smart home technologies mainly concern home automation in the broad sense and is hardly adapted to the needs of the elderly. In addition, most existing solutions are expensive, complex to deploy and often require controlled and constrained environments. It is clear that lightweight, resource-efficient, inexpensive and scalable solutions are needed, which requires minimal effort of installation, configuration and control by users.

In general, a Smart home solution consists of a set of hardware components, communication systems and a set of application components (software) to control these solutions, set them up and possibly benefit from certain services that can be insured by service providers. They are still very basic functionalities and which only allow to centralize the control of certain connected devices and objects, and to make their use easier and achievable remotely. In the context of a Smart home for the elderly, at a minimum there must be intelligent functionalities to detect abnormal or at-risk situations, and possibly functionalities or services provided by health professionals or assistance. It is clear that the existing solutions are very limited at the technical level and several brakes must be lifted so that these solutions can be deployed and used in practice. For example, data security and interoperability of solutions are among the urgent challenges. Like any emerging field, we are witnessing a proliferation of supply in terms of more or less complete solutions. Hence the need for standardization and supervision of these solutions, particularly in the field of Smart homes for the elderly.

The aim of this position paper is to first highlight the opportunities that these Smart home solutions represent for artificial intelligence, but also highlight the challenges and the technical limits. We also present the main results of a survey that we recently conducted with elderly people in Hauts-de-France in France. The paper mainly addresses the technical aspects of Smart home solutions and does not claim that these solutions can address all the problems of home care for the elderly. In doing so, we give some recommendations for the design and the deployment of Smart homes on a large scale. This paper also does not really address the ethical and some societal aspects that are as important as the other aspects (technical, cost, efficiency, etc.) for the success of such technology.

2 HARDWARE AND SOFTWARE COMPONENTS

Smart home solutions have origins in several fields, mainly in computer science, robotics and electronics such as home automation, ubiquitous computing, embedded computing, telemedicine, gerontechnology, assistive robots and what is called "assistive living". Without being exhaustive, we find a whole range of components that can be classified into two categories.

2.1 Hardware Components

This category includes all acquisition devices (sensors), control devices (actuators) and data transmission devices.

- **Sensors.** These are components that measure certain parameters of interest such as temperature, presence, motion, pressure, humidity, brightness, sleep, heart rate, stress, etc. Some sensors such as heart rate sensors are worn or implanted directly into the body (Pantelopoulos and Bourbakis, 2009) while other sensors are generally placed, according to their nature, in certain areas of the living space. It should be noted at this level that some data may come from external sources, particularly when it comes to supplementing the data of the Smart home with ambient data such as the level of air pollution or the presence of air allergens.
- **Actuators.** These components allow to act on certain connected objects or devices for example to control the light, the heating or the shutters. These are usually switches, valves or motors that can be operated automatically or remotely.
- **Means of Communication, Storage and Processing.** These are all components or parts of components for temporarily storing certain data after acquisition, to transmit them to other components for long-term storage, to be processed or aggregated. Gateways and access points are used here to route data from the sensors to local units or servers that store and process such data. To communicate with a wide range of sensors, wireless and low-power technologies are generally used. Thus, we find Zigbee technology (IEEE 802.15.4 standard), WiFi (IEEE 802.11 standard) and Bluetooth (IEEE 802.15.1 standard or its variants).

2.2 Software Components

The hardware part is used to collect data of interest and serves as a medium for communication, storage and data processing. The application part serves, in turn, the processing of these data, their display to the user and the control of the solution. There are two main categories of applications: First, there are applications intended for the user, in this case the occupant of the Smart home, to give him certain information and enable him to control this solution. These are, in general, very basic features of data retrieval and management of devices and connected objects (for example, simple display of activity data). Some applications provide intelligent features such as fall detection or anomaly detection.

Some solutions adopt a centralized architecture in the sense that the data is stored and processed locally on a dedicated server. Other solutions adopt a distributed architecture using remote services on the cloud, for example (Li et al., 2018). The reader interested in hardware aspects can find further details in (Majumder et al., 2017)

3 SMART FEATURES

While connected objects are able to collect many types of data with their sensors and possibly acquire additional data from other sources (such as data on air pollution or the presence of allergens that may be provided in real time by certain websites), the collected data are often neither correlated nor used to infer relevant information or knowledge in order to carry out intelligent tasks or to offer relevant recommendations to the user (Tabia et al., 2018; Vallée et al., 2016; Le et al., 2012). For example, sleep quality is affected by a number of factors such as physical activity, stress, eating habits (such as drinking alcohol or caffeinated beverages and smoking) and environmental factors. It is then possible to analyze and correlate the data collected on these parameters in order to highlight the factors that have a positive or negative impact on the quality of the user's sleep (Babaie et al., 2014; Tabia et al., 2018). Of course, this requires the use of data analysis, data mining and artificial intelligence techniques to extract useful knowledge from the large amounts of data collected. We highlight in the following some smart features particularly relevant for the elderly.

3.1 Activity Recognition

The goal here is to recognize the current activity of the person occupying the Smart home. In general, this involves associating a flow of data from sensors (such as motion sensor data, presence data or video data) with a class or subset of predefined classes such as Sleeping, Cooking, Eating, Reading, Telephoning, etc. Activity recognition results can be used to keep the elderly family or carers informed, for example, or to detect abnormalities or situations that are dangerous and that may require intervention. At the level of activity recognition systems, we find essentially rule-based systems, probabilistic models (Lu et al., 2017), classifiers and techniques of machine learning and computer vision (Skocir et al., 2016; Kim et al., 2010; Chen and Khalil, 2011).

3.2 Anomaly Detection

The goal here is to analyze activity data (such as physical activity, sleep data, or physiological data) to detect abnormalities. By anomaly, we mean a significant deviation from the norm or the habits of the user. Simply put, an analysis of a person's history of sleep schedules and durations may reveal patterns and sometimes abnormal or unusual behaviors. Often, statistical and machine learning models are used to associate a degree of "normality" with a data flow. Once an anomaly is detected, an alert can be raised to deal with this situation. By way of illustration, several approaches are based on the analysis of time series of sleep data to detect anomalies that may be due to stress or illness (Babaie et al., 2014; Sfar et al., 2017; Li Ye et al., 2010).

3.3 Detection of Risk Situations

This type of functionality is essential for people living alone and it aims to detect falls, depressive states, dehydration, taking abnormal medication to name a few examples. Several technologies are needed to quickly detect such situations as the analysis of sounds or videos, computer vision, sensors and dedicated portable devices as well as ground vibration sensors.

3.4 Virtual Assistants

Smart or virtual assistants are particularly useful in the context of the Smart home for the elderly who have several needs that can be met by these assistants. These include searching for information on the Internet, calendaring features, or notepad. A Smart

assistant can also take care of performing some basic tasks such as making a phone call, sending an email or SMS. It can also be used as a voice interface for home automation or to locate certain objects in the house. Regarding the solutions and projects specifically dedicated to the elderly, we can mention the European project Alfred whose objective is to design and develop an interactive assistant for independent living and active aging, or the project DALIA aiming to be an integrated and personalized solution, based on a personal virtual assistant, which helps older adults to live at home independently.

3.5 Alert Management

Alert management is a problem that does not directly concern the user but rather the structures and service providers that are supposed to intervene to support the alerts raised. Effective alert management requires prioritization, filtering, false alarm detection and alert correlation mechanisms.

3.6 Recommendation

Several other smart features can be added and integrated into a Smart home solution. Recommendation features may be considered (Mshali et al., 2018; Vallée et al., 2016) (for example, recommending physical activity if the system experiences a lack of activity for a period of time or recommending a reduction in heating for a certain period of time for a better sleep). Moreover, a virtual assistant can offer games to maintain better cognitive abilities (Hao and Miao, 2017). This type of functionality will eventually require additional data and other tools and will impact the costs and reliability of these solutions. Among the most successful projects in terms of intelligent features, there is the American project CASAS (Cook et al., 2013) where sensor data is collected via a computer network and stored in a database that a smart program uses to learn and infer useful knowledge about habitual behaviors and activities. Such models are subsequently used for anomaly detection or provide recommendations. Based on this information, a Smart home can select and automate actions that meet the goals of the Smart home application. In addition, the CASAS architecture facilitates the development and implementation of future smart home technologies by providing a lightweight, easy-to-install design that delivers smart, out-of-the-box functionality requiring minimal installation and configuration efforts.

4 MAIN TECHNICAL CHALLENGES

This section focuses on the current challenges that need to be addressed for the use and adoption of Smart home solutions in practice. There are, in fact, four big issues now:

4.1 Data Security

Given the nature of the data collected, it is clear that privacy considerations and sensitive data in general are critical to the success of a Smart home solution. In this context, security is to be taken broadly, including the security of collection, storage, the processing chain, the communication of information and the security of the devices themselves (Jacobsson et al., 2016).

4.2 Interoperability

This aspect concerns the lack of interoperability in order to share, for example, some data provided by different vendors or solution vendors. This allows, among other things, to build a solution by integrating components from different suppliers. At present, interoperability in Smart home technologies and associated applications is unsatisfactory due to the use of different technologies, incompatible communication protocols, conflicts of interest, types and heterogeneous data formats (Asad and Taj, 2018). Improving interoperability requires the use of standardization, the development of data exchange and encoding protocols.

4.3 Industrialization

This aspect concerns the transition from the prototype stage to reliable solutions that can be used in practice. This involves mastering several criteria such as low costs, low maintenance, non-intrusiveness and security of solutions, their energy savings and the care of the real needs of the elderly. It is necessary to find a good compromise between all the conflicting criteria (security, cost, ease of use and installation/configuration, Smart features, etc.).

4.4 Personalization

One of the challenges facing the use of Smart home solutions and more generally IoT is personalization (Vallée et al., 2016). This latter aims to provide services tailored specifically for the user needs and preferences. However, user effort are often needed to pro-

vide some information that cannot be automatically sensed. For example, if the food intake is provided directly by the user, then because it is time-consuming and perhaps boring, this information will not be provided appropriately by the user. Same problems hold for taking into account user's preferences and constraints.

In addition to the challenges mentioned above, every aspect of Smart home solutions has its own challenges. In particular, the main weaknesses in the detection of anomalies concern the difficulty of distinguishing between abnormalities and normal changes, false positive rates that are too high, lack of diagnosis and cold start problem (period preceding data collection representing the normal and usual habits and behaviors of the user). Indeed, the detection of anomalies can be based either on a specification or definition of normal behaviors, or based on the data of normal behaviors and situations. The problem is that it is very difficult to define normal behavior. The difference between what is considered normal and abnormal behavior is often very vague. In the case of anomaly detection in a Smart home solution, the human behavior is not regular and changes over time. On the other hand, what is abnormal for one person may be quite normal for another.

In activity recognition, there are first limitations related to the low level of reliability of the tools used (for example, the recall and accuracy of prediction techniques are still too weak), the low account of the context, history and also the difficulty of distinguishing between the activities of several people in the same living space. For Smart assistants, the main challenges are, of course, privacy and confidentiality of data, personalization (Vallée et al., 2016) and taking into account the context and specificities and particularities of each user, and finally, the interaction and so-called senior-friendly features.

5 WHAT ABOUT THE ELDERLY, THEIR NEEDS AND THEIR EXPECTATIONS?

If the finding concerning the aging of the population worldwide is shared and confirmed statistically from year to year, there is not really any case study or surveys concerning the sociology of the elderly and their relationship to technology, nor their perceptions and needs for Smart homes or connected objects. As part of a project, we conducted a survey with elderly people in the Hauts-de-France region in France. Here are the main elements concerning this survey.

The study has the following objectives :

- know about the practices that seniors have of the new technologies of information and communication;
- understand the knowledge and use, if any, that they have connected objects that contribute to the quality of life in the home; and
- collect their expectations on this issue.

These three objectives should make it possible to characterize the relationship of seniors with ICTs and connected objects and to bring out useful analysis for the question of the acceptability and usability of connected home technologies. Data were collected in 2019 by questionnaires, completed face-to-face and at home (with some exceptions). 96 questionnaires were exploited and processed using Sphinx Campus³. Respondents have the following characteristics: 53.8% in the age group 65 - 74 and 46.2% over 75; 63.4% women and 36.6% men; 81.7% retired, having been mostly employed or workers; 60.2% having a monthly income between 800 and 1500 euros, 33.3% having an income of more than 1500 euros and 6.5% having less than 800 euros. The household consists of an average of 1.7 persons and 2.4 children. 75.3% of the respondents are tenants of their home.

5.1 ICT Equipment and Uses

In more than 59% of cases, the household has two or more equipments (Internet, computer, Smartphone or tablet) but more than 29% of respondents say they have none. They are 42.6% to use Internet daily, 27.2% to connect once or twice a week, and 29.4% to connect more rarely or never. The most common uses of the Internet in the last 12 months are in order of importance: searches on the Internet (49%), the exchange of short text messages or photos (45%), exchange e-mails (42%).

The three main obstacles for respondents are (in order of importance): the difficulty of using the Internet (67.7%), the insufficient protection of personal data on the Internet (51%), the uselessness of Internet for everyday life (42.7%).

5.2 Connected Objects Contributing to the Quality of Life in the Home, Knowledge and Uses

49% of respondents say rather know what can serve connected objects against 20.8% saying rather do not

³Software solution for surveys and data analysis.

know and 21.9%, do not know at all. 20.8% of respondents say they have at least one connected object. It is essentially (in order of importance): tensiometers, scales, bracelets or watches measuring physical activity and surveillance cameras. Their use is daily for 47.6% of respondents with connected objects; 33.3% report using them occasionally and 19% rarely or never. The reasons given for non-use refer first of all to the feeling that they did not constitute an aid in everyday life and that these objects were too restrictive. The two main reasons that led respondents to use a connected object the first time are in order of importance, a health problem (47.6%) and then the search for comfort (28.6%). The recommendation to buy a connected object comes first and foremost from the family (71.4%), then from the doctor (42.9%) and finally friends (19%).

5.3 Needs and Expectations

The three main types of expectations for connected objects that emerge are, in order of importance: improve daily life (79.2%); prevent accidents in life (79.2%); motivate to do physical activities to stay healthy (38.5%). The three main types of advice expected to equip with a connected object are in order of importance : its use (83.3%), its functionalities (75%), its health (71.9%). The family for 55.2% of the respondents, the professionals of the connected objects for 54.2%, then, further the health professionals represent the people perceived as the best able to give advices for the choice of a connected object. The communication of measurements made by connected objects would be more natural to his doctor for 85.4% of respondents, then to the family (49%). In the case where respondents could benefit from a Smart home, 69.8% say they would be very embarrassed to be filmed or recorded continuously. The three main barriers to the purchase or use of new products or services are in order of importance: the fear of not knowing how to use them (66.7%); the price / remainder too high (66.7%); and far behind, the possible malfunctions (37.5%). The following is the cost / utility ratio, the confidentiality of the data and the lack of information on the product or the service.

5.4 A Differentiated Relationship to ICTs and Connected Objects

The sex of the respondents, and even more so their age, the socio-professional category, and just as much the use of the computer tool and the Internet as part of a professional activity, play a significant role in the equipment, use and vigilance concerning the protec-

tion of digital personal data. The 65-74 year olds, the men, the highest socio-professional situation, the professional use of ICT lead to a higher rate in terms of equipment, use and acceptability. There is a concern about the protection of personal data on the . It is most likely this population that will experiment first Smart home solutions, provided that the issue of protection of personal data finds a satisfactory answer. Overall, 47.9% of respondents believe that the development of connected objects will allow better monitoring of the health of each. For 25%, it will rather represent an additional constraint that will not change the health of everyone. The remaining 25% say they do not know. These last results show, following those that have been mentioned above, that, on the one hand, the usefulness of connected objects in the quality of life at home remains to be demonstrated, and that, on the other hand, the usability must be a priority issue to allow for their dissemination. Nearly half of the respondents, however, are already convinced of their interest in their health. But the problem of data security is to be addressed, which will help, in part, to promote the acceptability of connected home technologies. It will still be necessary to overcome the feeling of intrusion and intrusiveness associated with the data collection on which the operation of Smart homes rests.

6 CONCLUSIONS

Smart home solutions are still an emerging market where there is a lot of innovation and it will take time to get enough perspective to identify the real needs, develop effective solutions and advance on the field of standardization, interoperability and security of the solutions. In addition, a range of services from certain players and operators must be developed so that Smart home solutions really meet the needs of the elderly. Currently, there is low acceptance of users of Smart home solutions (Portet et al., 2013) in general. The majority of the solutions are complex and still at the stage of proof-of-concept or prototype. This is, in part, due to the fact that no application or service is really "essential", their costs are high, the offer from partners, installers and service providers is very limited. To this can be added the shortage of skills (for example, installers), lack of standards or their divergence and the fact that there is still no real cross-application integration provider today. In the future, it is likely that there will be a change in lifestyles and the relationship to technology will change in the direction of gradual adoption and according to the needs and contexts of these technological solutions. Indeed, on the one hand the Internet is more and more in-

dispensable and we are witnessing the ever-growing importance of entertainment and security needs (as for video surveillance). On the other hand, there is a lot of progress in the convergence and connectivity of everyday objects (such as the telephone, Internet, television, household appliances, remote monitoring ...). The decreasing costs of technology and technological improvements and availability (due to the rise of wireless solutions and the improvement of broadband penetration) will no doubt end up attracting many users. Finally, the increased cooperation of companies and consortia for better interoperability is likely to encourage the integration of different Smart home technologies.

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