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Health Smart Homes: New Challenges

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Abstract

Health Smart Homes provide various forms of assisted living support, by monitoring the activities and health status of their occupants to generate flows of information and sometimes interventions involving the occupants and their careers. Technologies of varying complexity must be combined to produce the underlying Health Smart Home system, and processing of the resulting data may require methods of varying sophistication. These aspects have been well studied, but no widely-adopted approaches for practical implementation of systems or systematic processing of data have been developed. Also, the integration of Health Smart Home services with the overall health care system has not been regularized. This paper identifies and categorizes the emerging high-level challenges beyond those in the basic technical and algorithmic spaces. These challenges will influence future directions for Health Smart Homes and their wider adoption and integration with health systems.

Keywords:

Assisted Living Facilities; Computing Methodologies.

Introduction

Contemporary Smart Home concepts have been developed over the last two decades. A Smart Home consists of a living space equipped with electronic devices and communications infrastructure to enable monitoring and control of the immediate physical environment, coupled with a system with sufficient computational power, data storage and decision making capabilities to provide customization and efficiency of operation [1]. The emergence of Wireless Sensor Networks [2] and more recently, the Internet of Things (IoT) [3] and Cloud Computing [4] services, have provided the ideal technical fabric for constructing Smart Homes. Integration approaches relying on middleware and open source conversion platforms for various device and communications standards are now being supplanted by evolving Cloud-IoT synergies [5].

Health Smart Homes have been popularized alongside the mainstream Smart Home movement [6], with additional distinctive characteristics. Their purpose is more critical, in that they must measure, understand, and manage the health status of their occupants [7]. Early technical challenges identified for Health Smart Homes included the lack of appropriate sensor availability and performance [8], and difficulty in coordination of subsystems to provide component functions targeted to health needs [9]. The importance of social and ethical considerations for home occupants and subjects of care were also identified [10], and the need for multidisciplinary collaboration in the development of more comprehensive health solutions [11]. Examination of Health Smart Home experimental implementations has revealed a wide spread of technology choices across numerous contexts [12], but little evaluation of their clinical effectiveness has been performed [13]. Despite attempts to standardize health sensor device protocols, such as the Continua framework [14], the lack of integration at a systems level remains a major limitation [15].

More recently, emphasis is being placed within health systems in the development of new models of care where consumers can receive a range of health services in new settings including their homes [16]. There is a clear consumer- supported move towards the widespread use of personal monitoring devices [17] that will need to be integrated into this emerging care environment. There is also a more general societal move towards wider access and use of personal electronic health records, and the implied connectivity of information systems, which will be required to achieve this [18]. Increasingly, interoperability and standardization are becoming aspirations for health systems that will ultimately rely on universal electronic data exchange and rich information environments supporting personalized "precision" patient care [19]. Health Smart Homes will need to harmonize with developments in these areas and, importantly, become part of a health services continuum, rather than isolated entities.

Methods

Given this broader perspective, we can readily distinguish two major challenge areas, Systems and Data, that will need to be addressed in the Health Smart Home of the future. In the following sections, we identify aspects within these two areas that are currently open issues and for which substantial work is needed to make further progress.

Systems Challenges

In the context of whole-of-systems concepts for Health Smart Homes, we comment on three new challenge areas: Architecture issues, including overall design considerations; Integration issues, such as interfacing and interoperability; and Safety issues, involving protection of users and the systems themselves.

Architecture Issues: The computing-based components consisting of: (i) hardware units; (ii) connecting networks; and (iii) intelligent software modules, which make up a Health Smart Home, can be viewed as a Critical System, in the same sense as large scale physical infrastructure systems (e.g., power grid) or complex machinery control systems (e.g., passenger aircraft). Such systems need mechanisms to allow update and replacement of components without disrupting system function, and addition or deletion of components without compromising the integrity and performance of the system. This would imply an ability to assure the effects of any such changes, and to predict their impact, on other components should be embedded in the system development methodology [20]. Consistency of protocols for managing data and control within critical systems, including movement towards self-validation to provide error resilience to changes [21] along with convergence of Wireless Sensor Networks with IoT and Cloud Computing technologies [22], will help advance this cause.

Integration Issues: To achieve fuller knowledge of past health history and to conduct longer time frame modeling of occupants' complex health circumstances (e.g., when monitoring a subject with multiple chronic diseases), it may be necessary to connect with external sources of health information on the individual and leverage sophisticated external health decision making and services delivery systems. This implies interoperation of the Health Smart Home with other health services will be necessary, which in turn will have associated impacts on workflows and care models. Some reconceptualization of the Health Smart Home as one of the essential components in the overall health system would help to address this matter. This would include differentiating between the role of supporting healthy living (e.g., preventive health coaching and lifestyle monitoring) [23] and that of supporting existing acute health care delivery (e.g., the numerous "hospital in the home" initiatives) [24]. Monitoring to support acute care at home is currently arguably more socially acceptable and the intrusiveness of the required technology tolerated if not accepted. However, in designing for non-acute care and supporting everyday wellbeing, this level of acceptance and related engagement diminishes [25].

Safety Issues: As wireless connectivity becomes ubiquitous individuals are placed at higher risk of accidental or malicious interference with electronically managed data streams and control functions. This security vulnerability is amplified in high density Wireless Sensor Networks and IoT settings [26] such as Smart Homes, and where the sensitivity of health data to breach must be considered. Protection against such situations necessitates rigorous enforcement of failure detection and recovery, audits and monitoring to determine misuse, and system risk management processes to mitigate against failures. Robustness and resilience components in the system design cycle need to be developed, and operational surveillance protocols need to be established so that warnings can be generated and fail-safe defaults adopted. Whether it is in the pre-determined sensor networks or the healthcare IoT environment, the fail-safe modes of devices, such as power failure incidents, must be carefully considered. The fail modes - default on or default off – need to be contextually considered. For example, under some conditions in falls monitoring, a false negative (e.g.. from a slow fall) may be more damaging than a false positive (e.g., bending down to reach the floor). Further, the device susceptibility to attacks and the challenge of applying traditional security models with delineated network boundaries to dynamic Smart Home and Healthcare IoT networks, pose significant problems which demand more attention in system standards development [27].

Data Challenges

Extracting more value from health data is currently a major emphasis in formulating major electronic health record and Clinical Decision Support strategies. This is beginning to extend to the use of data from sources such as Health Smart Homes monitoring. Three aspects of this trend contribute to the emergence of new issues here: Management of the related datasets including content and custodial issues; Recognition of relevant patterns in the data to allow accurate continuous classification of an individual's activities; and Personalization of decision making concerning health events or status, relative to the individual's aggregated data.

Data Management Issues: As in hospital-based patient record systems, strict establishment and adherence to standards for Health Smart Home datasets will be necessary, and equally, the interpretation of externally sourced health data on individuals will need to be informed by knowledge of those standards. Little existing standards work has been reported for Health Smart Home settings and this inhibits wider use and sharing of datasets with other elements in established health systems. If this was addressed it would become easier to provide reference sets of experimental data for algorithm tuning and benchmark data for performance analysis. In the same way as standards were adopted in the research community for sharing physiological datasets via PhysioNet [28], a similar practice would be desirable for Health Smart Homes where sharing is much less common [29]. Another related matter is that of the processing of the data in a Health Smart Home to ensure clinical usefulness as well as appropriate detection and response to potential health indicators. The healthcare workflow and the integration of data from sensors with clinical knowledge is of vital importance to assure improved health outcomes [30].

Pattern Recognition Issues: Characterization and reliably detecting patterns associated with health conditions (e.g., using physiological signals) or behavioral manifestations (e.g., mobility tracking) remains an open problem. Much effort has been invested in attempts to create robust algorithms for such pattern extraction using machine learning and artificial intelligence methods on data which may be sparser than desired due to physical limitations in the collecting infrastructure [31]. The highly variable nature of repeated situations and activities, both between and within subject, and allowing for "drift" in patterns over time and in different contexts can confound the success of these approaches [32]. Statistical detection of anomalies and structuring patterns into a hierarchy of macro to micro pattern characterizations offer some positive directions for longer term adaptation within activity algorithms, leading to greater consistency of results [33]. The enormity of the range and tolerance issues associated with achieving high sensitivity and specificity performance for detecting and classifying daily living activities, will likely maintain this challenge for research into the foreseeable future.

Subject Personalization Issues: Personalized application of algorithms in a Health Smart Home is an essential feature of its operation: if real health benefits are to be gained then it is necessary to tune the system as well as possible to fit the characteristics of the occupying individuals. This may require considerable sophistication in classifier decision-making logic, as well as dealing with multilayer redundancy through the existence of overlapping data sources (e.g., wearables vs ambient) in the data collection and processing stages [34]. Interference from interactions with other people and from externally imposed events which affect the individual, can degrade performance considerably. The more factual data that can be collected on an individual, and the more information that captures the influence of context and current situation, the more opportunity there is to create a fuller personalized picture [35]. Incorporating knowledge of phenotypical habits such as a weekly cycle of behavioral interactions and incorporation of indirectly measurable affective parameters such as mood and stress, may also contribute to overcoming these limitations [36].

Discussion

The simplicity of typical Health Smart Home solutions and the lack of compelling evidence for their clinical effectiveness has been identified as a major limitation in their adoption [37]. On the other hand, the increasing importance of home-based healthcare delivery and the consequent acceleration in the need for Health Smart Homes has been noted [38]. The clinical evidence for keeping people at home and avoiding unnecessary hospital admissions is plentiful [39]. Integrating social and health care, patient self-management, socio- economic status as well as coordination with primary care providers are some of the factors that can impact this [40]. The use of Health Smart Homes could be a vital component for improvement in keeping people at home longer.

It is probably unreasonable to expect that any of the new challenges identified above will be resolved by incremental progress, or by awaiting an unforeseen breakthrough followed by widespread adoption. The history of Smart Home development has been marked by independent engineering contributions and implementation models driven in a bottom-up manner [41]. A much broader, overarching approach will be needed to catalyze progress in these areas, as they will affect other aspects of the technology. For example, if a standard were to be agreed for data captured by sensors in a Health Smart Home, which prescribed that side information on precision and reliability must be included, then much previous work would be rendered obsolete.

Conclusions

The evolution of Health Smart Homes to achieve widespread presence requires more than technology advancement. The challenges identified above are subtle and complex consequences of the broader environment for health care within which the Health Smart Home functions. However, it seems likely that these challenges will influence future directions in Health Smart Homes, their wider adoption, and their integration with existing health systems. We advocate that more attention should be paid to these broader issues and that related research questions must be explored, alongside the current proliferation of underpinning engineering and implementation work.

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References

[1] S.S. Intille, Designing a home of the future, *IEEE Pervas Comput* **1** (2002), 76-82.
[2] G.J. Pottie and W.J. Kaiser, Wireless integrated network sensors, *Commun ACM* **43** (2000), 51-58.
[3] N. Gershenfeld, R. Krikorian and D. Cohen, Internet of Things, *Sci Am* **291** (2004), 76-81.
[4] R. Buyya, C.S. Yeo, S. Venugopal, J. Broberg and I. Brandic, Cloud computing and emerging IT platforms: Vi- sion, hype, and reality for delivering computing as the 5th utility, *Future Gener Comp Sy* **25** (2009), 599-616.
[5] A. Botta, W. De Donato, V. Persico and A. Pescapé, Inte- gration of cloud computing and internet of things: a sur- vey. *Future Gener Comp Sy* **56** (2016), 684-700.
[6] V. Rialle, F. Duchene, N. Noury, L. Bajolle and J. De- mongeot, Health smart home: information technology for patients at home, *J Telemed e-Health* **8** (2002), 395-409.
[7] I. Korhonen, J. Parkka and M. Van Gils, Health monitor- ing in the home of the future, *IEEE Eng Med Biol* **22** (2003), 66-73.
[8] M. Chan, D. Estève, C. Escriba and E. Campo, A review of smart homes—Present state and future challenges, *Comput Meth and Prog Bio* **91** (2008), 55-81.
[9] D. H. Stefanov, Z. Bien and W.C. Bang, The smart house for older persons and persons with physical disabilities: structure, technology arrangements, and perspectives, *IEEE T Neural Sys Reh* **12** (2004), 228-250.
[10] G. Demiris, M. J. Rantz, M.A. Aud, K.D. Marek, H.W. Tyrer, M. Skubic and A.A. Hussam, Older adults' attitudes towards and perceptions of 'smart home' technologies: a pilot study, *Med Inform Internet* **29** (2004), 87-94.
[11] S. Koch, Healthy ageing supported by technology–a cross-disciplinary research challenge, *Inform Health Soc Ca* **35** (2010), 81-91.
[12] S. Koch, M. Marschollek, K.H. Wolf, M. Plischke and R. Haux, On health-enabling and ambient-assistive technolo- gies, *Meth Inf Med* **48** (2009), 29-37.
[13] G. Demiris and B.K. Hensel, Technologies for an aging society: a systematic review of "smart home" applications. *Yearbook of Medical Informatics* **3** (2008) 33-40.
[14] R. Carroll, R. Cnossen, M. Schnell and D. Simons, Con- tinua: An interoperable personal healthcare ecosystem, *IEEE Pervas Comput* **6** (2007).
[15] M. Memon, S.R. Wagner, C.F. Pedersen, F.H. Beevi and F.O. Hansen, Ambient assisted living healthcare frameworks, platforms, standards, and quality attributes, *Sensors* **14** (2014), 4312-4341.
[16] M. Chan, D. Estève, J.Y. Fourniols, C. Escriba and E. Campo, Smart wearable systems: Current status and future challenges, *Artif Int Me* **56** (2012), 137-156.
[17] J. F. Coughlin and J. Pope, Innovations in health, well- ness, and aging-in-place, *IEEE Eng Med Biol* **27** (2008).
[18] N. Archer, U. Fevrier-Thomas, C. Lokker, K.A. McKibbon and S. E. Straus, Personal health records: a scoping re- view, *J Am Med Inform Assoc* **18** (2011), 515-522.
[19] W. E. Hammond, C. Bailey, P. Boucher, M. Spohr and P. Whitaker, Connecting information to improve health, *Health Affair* **29** (2010), 284-288.
[20] K. Benghazi, M.V. Hurtado, M.J. Hornos, M.L. Rodríguez, C. Rodríguez-Domínguez, A.B. Pelegrina and M.J. Rodríguez-Fórtiz, Enabling correct design and formal analysis of Ambient Assisted Living systems, *J Syst Software* **85** (2012), 498-510.
[21] M. Chen, J. Wan, S. González, X. Liao and V.C. Leung, A survey of recent developments in home M2M networks. *IEEE Commun Surv Tut* **16** (2014), 98-114.
[22] J. Gubbi, R. Buyya, S. Marusic and M. Palaniswami, In- ternet of Things (IoT): A vision, architectural elements, and future directions. *Future Gener Comput Sys* **29**(7) (2013), 1645-1660.
[23] J.A. Botia, A. Villa and J. Palma, Ambient assisted liv- ing system for in-home monitoring of healthy independent elders, *Expert Syst Appl* **39** (2012), 8136-8148.
[24] G. Caplan, N. S. Sulaiman, D.A. Mangin, N. Aimonino Ricauda, A.D. Wilson and L. Barclay, A meta-analysis of "hospital in the home", *Med J Australia* **197** (2012), 512-519.
[25] T. Irizarry, A.D. Dabbs and C.R. Curran, Patient portals and patient engagement: a state of the science review, *J Med Internet Res* **17** (2015).
[26] R.H. Weber, Internet of Things–New security and priva- cy challenges, *Comput Law Secur Rev* **26** (2010), 23-30.
[27] P.A.H. Williams and V. McCauley, Always Connected: The Security Challenges of the Healthcare Internet of Things, *Proceedings of the IEEE World Forum in Internet of Things* (2016), 30-35.
[28] G.B. Moody, R.G. Mark and A.L. Goldberger, Physio- Net: a web-based resource for the study of physiologic sig- nals, *IEEE Eng Med Bio* **20** (2001), 70-75.
[29] A. Fleury, M. Vacher, F. Portet, P. Chahuara and N. Noury, A multimodal corpus recorded in a health smart home. *Proceedings of the International Conference on Language Resources and Evaluation LREC 2010* (2010), 99-105.
[30] P.A.H. Williams and A.J. Maeder, A conceptual framework for secure use of mobile health. *J Int Soc Telemed eHealth* **1** (2013), 44-51
[31] J. Ko, C. Lu, M. B. Srivastava, J.A. Stankovic, A. Terzis and M. Welsh, Wireless sensor networks for healthcare. *Proceedings of the IEEE* **98** (2010), 1947-1960.
[32] L. Chen, J. Hoey, C.D. Nugent, D.J. Cook and Z. Yu, Sensor-based activity recognition. *IEEE T Syst Man Cy C* **42** (2012), 790-808.
[33] P. Rashidi, D.J. Cook, L.B. Holder and M. Schmitter- Edgecombe, Discovering activities to recognize and track in a smart environment, *IEEE T Knowl Data En,* **23** (2011), 527-539.
[34] S. Okour, A. Maeder and J. Basilakis, Multi-layered sys- tem design for classifying activities of daily living, *St Heal T* ***178*** (2012), 157- 162.
[35] A. Harvey, A. Brand, S.T. Holgate, L.V. Kristiansen, H. Lehrach, A. Palotie and B. Prainsack, The future of tech- nologies for personalised medicine, *New Biotechnol* **29** (2012), 625-633.
[36] R.A. Calvo and S. D'Mello, Affect detection: An inter- disciplinary review of models, methods, and their applications. *IEEE T Affect Comput* **1** (2010), 18-37.

[37] L. Liu, E. Stroulia, I. Nikolaidis, A. Miguel-Cruz and A. R. Rincon, Smart homes and home health monitoring tech- nologies for older adults: A systematic review. *International J Med Inform* **91**(2016), 44-59.
[38] R. Haux, S. Koch, N.H. Lovell, M. Marschollek, N. Nakashima and K.H. Wolf, Health-Enabling and Ambient Assistive Technologies: Past, Present, Future. *IMIA Year- book of Medical Informatics* **11** (2016), S1-S16.
[39] M.V. Williams, A requirement to reduce readmissions: take care of the patient, not just the disease, *J Am Med Inform Assoc* **309** (2013), 394-396.
[40] S. Purdy, Avoiding hospital admissions: What does the research evidence say? *The King's Fund* (2010), Available from https://www.kingsfund.org.uk/sites/files/kf/Avoiding-Hospital-Admissions-Sarah-Purdy-December2010.pdf
[41] M.R. Alam, M.B. Reaz and M.A. M Ali, A review of smart homes—past, present, and future, *IEEE T Syst Man Cy C* **42** (2012), 1190-1203.

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