Information Systems Frontiers (2020) 22:23–27
https://doi.org/10.1007/s10796-019-09965-3

Emerging Frontiers in Smart Environment and Healthcare – A Vision

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Published online: 10 December 2019

Abstract
The second half of the twentieth century has witnessed unprecedented development and growth in information technology. What began as a foundational technology in exploring science and engineering has evolved into ground-breaking tools in most fields of endeavor. Today, rapidly expanding applications of informatics are being developed in diverse fields such as business management, transportation, environmental monitoring, building management, various aspects of healthcare, and even in fine arts. Driven by new developments in data analytics, Big Data, Artificial Intelligence and Deep Learning neural networks, enormous opportunities are opening up in therapeutic application of IT well beyond clinical diagnostic aids and computational biology. Augmentation of human mental faculties particularly with respect to multivariate analysis will drive major areas of research in the coming years. A number of potential research areas are presented in the paper.

Keywords Ambient Intelligence · Artificial Intelligence · Big Data · Personalized Healthcare · Deep Learning · Smart City · Smart Buildings · Lighting controls · IT · PTSD · Autism

1 Introduction

As we move further into the spectacular advances made in the Information Technologies in the past two decades, applications are spreading into new areas, beyond the traditional world of science and engineering. Of all these areas, two important ones to be considered in this paper are the environment and individual health, which are, in many ways, related. Due to rapid urbanization, cities are getting overcrowded and pollution is increasing at an unprecedented rate in some regions of the world. Inefficiency in energy usage, uncontrolled emission of greenhouse gases, and discharge of harmful chemicals in the water supply chain are major concerns in many parts of the world. Simultaneously, new diseases are emerging and the effects of conventional medicines such as antibiotics are proving ineffective due to over and improper use.

Initiatives in smart environments, including smart cities and regions, are seen as possible solutions that are driven by advances in IT. Similarly, application of AI, Big Data, bioinformatics and genomics on healthcare is expected to bring about much needed improvement in overall quality of life. Furthermore, they open up practical possibilities hereto unexplored due to the enormity and complexity of data involved.

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2 Smart Environment and Smart City

What initially began as a drive for conservation and clean environment, has grown to include aspects of convenience, aesthetics and the overall sustainability of the planet. Faced with acute shortages of clean water and air in many parts of the world, as well as growing population densities in cities, the world population is expected to reach 9.8 billion by 2050, with 70% being located (6.7 billion people) in urban areas. This calls for renewed thinking about the design of the cities of the future that will need to address ecology, water, energy, waste management, food supply, and mobility while preserving culture and heredity.

Net-zero carbon emissions and energy are among the goals set for many of these initiatives.

Approaches to structured smart-city designs (https://www.nationalgeographic.com/magazine/2019/04/ n.d.) include scalable modular approaches involving what are termed as Urban Hubs. Each Hub consists of certain basic functionalities such as:

- Contamination clean up instead of burial in hazardous sites
- Sponge city where water percolates through soil to recharge water table
- Green roofs
- Automated recycling

- Rainwater cleansing
- Smart water where sensing and remote-controlled technologies maximize water usage efficiency in urban farms
- Backyard Gardens
- Urban farms and gardens
- Social transit to enable high speed rail hubs as business and social centers
- Compact neighborhoods with all services within walking distance from homes and workplace
- Family life enabled by parks and recreation areas allowing for socializing among families
- Mixed density housing allowing for diversity in the workforce while minimizing crowding
- Drone based transportation of people as well as goods

Buildings, both commercial and residential will be required to meet a number of basic requirements, such as:

- Net-Zero Energy via deployment and sharing of renewable energy sources
- Natural lighting
- Solar walls, windows and roofs
- Wind turbines for tall buildings
- Ecological sustainability of neighborhoods by inclusion of effective greenery
- Safety and security at multiple levels
- Living spaces with Ambient intelligence to seamlessly cater to the personalized needs of the individuals
- Connectivity within the city, as well as with the outside world

The power distribution in cities and regions is an area undergoing significant reconsideration due to the advent of renewable energy sources, reliability considerations and increased loads due to the charging of electric vehicles, among many. Distributed power, such as micro grids and including storage technologies, are being designed and tested and will continue to be significant in the years to come (Eisen 2012). Off-grid energy harvesting power sources are already finding increasing in IOT applications (Op Veld et al. 2009).

The overall architecture for the implementation of the features and functionality of the smart buildings/homes is evolving. A combination of centralized hub concepts, in the form of some devices as well as distributed intelligence (O'Grady et al. 2009) in the ambient via smart sensors and actuators (with open architecture both on the hardware and software aspects) seems to be the trend. Over time, these will be driven by specific application needs. One of the driver applications is expected to be in the space of personal health and well-being. Other drivers will include the Internet of Things, safety and security.

On the device end, the mobile phone has played a flagship role at the individual level.

It began as a verbal communication device and has evolved into the smart phone of today, which serves a myriad of functions such as image capturing and processing, video communication, social media interface, mobile financial assistant, including banking, health monitoring, remote controller and, ironically, even voice communication. Computation and storage capabilities of the mobile phone continue to grow, making it a suitable device to act as a personalized information hub and interface with the functional world of 4G, 5G and beyond. With increasing functionality in the smart homes and buildings of the future, this device is poised to continue broadening its role as the mobile controller and monitor via Apps as well as dedicated configuration software.

Granular and flexible connectivity between smart sensors and actuators in building spaces, as well as outdoor environments, will be critical to the effectiveness of the management systems. Existing power grids and distribution networks offer a solution. Relying on lighting networks in buildings, as well as outdoors in cities, is suitable for this, and is already being exploited in both commercial and residential buildings (https://www.lighting.philips.com/main/systems/system-areas/office-and industry/offices/futureoffice n.d.).

It is likely that in the years to come, smart environments (Mukherjee and et.al. 2006; Aarts and Doyle 2009) will include cognitive functions via devices such as robots and stationary smart sensors, thereby taking over more and more of the routine and not so routine functions of individuals. Communication with individuals will become seamless, including even thought-based interactions (http://news.mit.edu/2018/computer-system-transcribes-words-users-speak-silently-0404 n.d.) with devices and networks, even beyond speech and gestures. One area that will experience these changes will be individual health, or personalized healthcare.

The desired application of smart environments, smart cities, smart buildings and smart homes is to enable people to lead more carefree lives, where certain aspects of the struggle for survival are handled by the smart environment, thereby enabling the individuals to lead a life of creativity. So people move from the survival mode to a more creative mode. Broadly speaking, historically, science and technology has enabled this for humankind. In the present age, Information Technology is a flag bearer in this process.

3 Individual Health in the Home Environment

Much progress has been made in the healthcare space in the last century, when knowledge of the human body and diseases grew rapidly. Introduction of imaging modalities, such as the CT and MRI in diagnostics, have created remarkable insights. Those technologies, along with the development of antibiotics to tackle bacterial diseases, and anti-viral drugs have all but eliminated deadly diseases such as smallpox, diphtheria and polio. Immunotherapy, organ transplants, medical implants and such advances have helped prolong life expectancy from under 50 to over 80 in some regions.

While these advances have taken place, new and chronic diseases have kept mounting, including diabetes, dementia, arthritis, cancer and heart disease. New strains of bacteria have grown immune to antibiotics due to overuse and/or improper use.

New advances in information technologies are opening up many possibilities in preventing disease by determining genomic sequences and propensity to different diseases as well as suggesting lifestyle changes to circumvent such occurrences. Wearable sensors that couple with data analytics are being evaluated in many areas. Electronic health records, coupled with big data and analytics, are allowing for new developments in personalized healthcare. AI tools are being deployed in clinical decision support systems, bio-informatics are being increasingly deployed in drug discovery in a variety of ways, and clinical trials, which typically take a substantial amount of time and expense, can be conceptually reduced by enhanced data-analytics with AI.

The home environment provides some of the most striking, as well as challenging, opportunities from the healthcare perspective. Different areas of the home provide different possibilities. For instance the bathroom is uniquely suited for seamless collection of bodily samples for automated pathological analysis. Examples of Ambient intelligence using mirrors to aid enhanced effectiveness in oral hygiene have been explored. The kitchen is especially suited for guidance and control of proper nutrition for the household. The bedroom is already being explored for its usage in aiding individuals' sleep health by monitoring sleep and even providing therapeutic support.

Currently, an increasing trend is seen in what is being called home healthcare, particularly for the elderly (Landers et al. 2016). Instead of treating them in hospital settings, as is commonly done, the trend is to provide the same level of care in the patient's home. There are many advantages, namely, better chance of recovery due to stress free setting for the patients, less chance of hospital induced sepsis type infection, lower cost and less strain on already stretched hospital bed availability. This requires sophistication in smart home technologies analogous to those available in hospital ICUs with the IT infrastructure and devices for seamless interface in the home setting. This is clearly a growing area of research all around the globe.

An area of exploration largely unaddressed due to its complexity in terms of data analysis, is the use of voice characteristics in the diagnosis of diseases (Mulin 2017; Robbins 2016; Sanchez et al. 2018). Certain types of diseases or ailments are hard to detect by conventional pathological tests but are reflected in one's voice and behavior. An example is PTSD. By using machine-learning and data-mining for detecting characteristic voice patterns and comparing the patterns with those of healthy individuals, clinical decisions can be made quickly, and more effectively. The use of smart phones or other devices embedded in the home environment can offer relevant data for these explorations.

Stretching these trends and extending them to therapeutics in the home settings, several possibilities can be envisioned.

It has been studied and reported that both music and light, when properly exposed to individuals, both psychological and physiological changes take place (Sleegers and et.al. 2013; Samani and Samani 2012; Gordon and et al. 2009; https://www.chronobiology.com/effect-lighting-students-performance/ n.d.; https://www.health.harvard.edu/staying-healthy/music-and-health n.d.; Holden 2019; Routhieaux and Tansik 1997). Circadian rhythms can induce physiological changes when synchronized properly with external stimuli of light and sound, both of which can be used beneficially in certain cases. Patients in hospital ICUs have been reported to be cured faster when provided with proper daylight in the rooms. Similar claims exist with musical sounds. When applied concurrently (both light and sound), new curative effects are conceivable. This will require multivariate control solutions.

Present day technologies make such studies feasible and with big-data analytics and AI, many opportunities can be envisioned in this space.

Imagine a home setting where rooms are designed with hi resolution video/audio, lighting systems that detect the individuals present, and with AI software that determines certain pathological conditions, such as depression, by facial expression, gait etc., and then administer therapeutically designed light and musical sound automatically.

A similar case could be envisioned for autism cases where Ambient Intelligent (AmI) equipped environments in homes can serve to study, in detail, the symptoms and peculiarities of potential patients and come up with innovative cures. Such approaches become increasingly practical with the advancements in IT and can be particularly attractive when compared to therapies that take long periods of time and require close observations, rendering them unfeasible, as well as prohibitively expensive with direct and continuous human involvement. Furthermore, automated data acquisition and analysis of large population using big data and deep learning techniques can lead to rapid solutions for some of these challenging ailments. In fact, studies with lighting in schools have shown enhanced learning ability among school children and this can be extended to work environments for enhancing creativity and productivity across the board. Such applications are foreseen in the coming years.

As with most technical advances, one has to be careful to design systems and experiments upfront to safeguard privacy as well as safety and security such that misuse of such powerful tools and techniques are prevented. Encryption techniques and tools will need to be developed and deployed early on in the process. With proper deployment, the privacy and effectiveness of these techniques can be significantly augmented for patients with depression, PTSD and such stigma-associated ailments.

4 Research Rationale and Possible Approach

There are numerous publications in refereed journals and informal postings claiming the benefits of music and lighting environment on general health as well as for specific ailments. Many of these claims are unsubstantiated and do not meet the rigors of scientific methodology to be dependable. This is not surprising as it can be very complex and expensive to carry out large scale clinical trials or double-blind tests for many of these claims with appreciable sample sizes.

Hence skepticism is understandable among physicians and other professionals. To circumvent this challenge, an approach to start with could be to identify a few significant health effects (or common ailments) and document the published claims in an order of priority based on credibility of the source and the claim. This can be followed up with setting up controlled environments, first in labs, followed by residential settings such as university dorms or public housing (such as military barracks etc.). These living environments would deploy sensors and actuators to sense a few of the health aspects and apply appropriate lighting and sound (musical) stimuli while sensing the effects over extended periods of time. By employing machine learning, AI and Big data methodologies, large scale data collection and analysis could result in more reliable validation (or otherwise) of the claims thereby establishing a data base for further experimentation in extended settings.

Such studies will be resource intensive and could best be carried out in university settings where multiple disciplinary capabilities are available. Government agencies and industrial resources can be brought together to help with these types of initiatives through private public partnerships as health and quality of life are critical to all.

5 Concluding Remarks

Smart environments, including smart cities, smart homes and outdoor areas were initially driven by sustainability and conservation requirements, leading to net-zero energy and net-zero carbon concepts. These were further broadened to include economically competitive and secure environments in communities and cities.

Building informatics are being developed for optimal resource utilization and convenience with the integration of all equipment for optimized control.

Model cities are being planned and implemented around the globe and information technologies are playing a vital role in many fields, from analytics to management and seamless control.

While the environment is vital to sustainability of life, more meaningful drivers of these technologies and solutions turns out to be the health of the individuals and, broadly, all living entities. In the case of humans, much attention has been focused on genomics-based, personalized and preventive healthcare.

Smart environments in homes and work areas are being explored to provide optimal comfort and healthy atmospheres. These can be stretched to seamlessly detect specific health conditions as well as provide therapeutically conducive solutions, even beyond the hospital setting. These include research topics such as:

- Combined light and music therapy for treating many ailments such as insomnia, autism, PTSD, as well as enhanced healing in homes and hospital ICUs.
- Personalized healthcare: connected with on body sensors and monitoring vital signs and other parameters for continuous health management.
- Home healthcare for the elderly combining logistics, diagnostic aids and urgent care. Resource-limited urban settings in emerging nations and competition for quality healthcare driven by mobile-connectivity infrastructure and AI.
- Indoor video surveillance coupled with image recognition and analytics are being explored for elderly as well as child healthcare.

Multivariate controls in optimizing output functions will be increasingly important as better understanding develops in the life sciences. Living systems involving multiple functions and controlling parameters are complex due to the large number of variables of importance.

Currently, and more so in the coming periods, smart surroundings involving smart homes, buildings, cities and regions will be coupled with the quality of life of the individuals inhabiting them. This in turn will involve both physical and mental health, as well as creativity. Deep learning, Artificial Intelligence and associated technologies will find increasing applications. Simplification of life will be an important element in this area as opposed to complexity in the management of day-to-day affairs for the ordinary person trying to integrate with the so-called digital society.

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