# Well-being Technology for Healthcare

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**Abstract**

*As the first ever World Happiness Report has been published by the United Nations, research on well-being has gained much attention in recent years. Well-being research is an interdisciplinary subject that covers both social science and engineering technology. Although a great number of studies have been conducted in social science, related research in engineering technology was limited to biomedicine. In view of such a phenomenon, this survey provides a comprehensive overview and examines recent updates in the Information and Communications Technology (ICT) domain. More specifically, this survey highlights the applications and future development in healthcare technology. Three topics, including biomedical signal processing, affective computing, human-machine interaction, and smart ambient technology, are introduced and discussed in this article.*

***Keywords***: *Well-being technology, happiness, healthcare, human-machine, smart ambient*

## 1. Introduction

The Internet of Things (IoT) in the broad sense refers to a system of uniquely identifiable objects and their virtual representations in an Internet-like structure—that is, a distributed network of smart objects that can be used standalone, or integrated into complex distributed applications. The term was first coined by Kevin Ashton in 1999 [1] and since then the concept has grown rapidly in popularity and given rise to a number of research initiatives. IoT was first implemented in applications for market analysis and in those early days radio-frequency identification (RFID) was seen as the foundational enabling technology. In the past, the idea was mainly to see how machines (or devices) could be connected and enabled to communicate with each other. Today, the term IoT has a slightly different and broader connotation, and denotes advanced connectivity of devices, systems, and services that goes beyond simply machine-to-machine interoperability. To achieve its current purpose, IoT will need to cover a variety of communication protocols, domains, and applications [2].

Well-being is a philosophical term that has been widely used to describe "*what is non-instrumentally or ultimately good for a person*" [1]. Well-being is often related to, but actually covers more than, welfare. Well-being study is a popular subject in social science, particularly in psychology. The research is typically categorized into two types — Subjective well-being and objective well-being. The former examines how people experience the quality of their lives [2]. Subjective well-being is usually associated with nonnegative feelings, satisfaction, or happiness of a person [3]. Unlike subjective well-being that involves personal experiences, objective well-being focuses on measurement based on objective facets, such as education, environment, governance, and social connections according to the "Commission on the

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Measurement of Economic Performance and Social Progress (i.e., the Stiglitz-Sen-Fitoussi Report)." Although the measurement of both theories differs, the pursuit for happiness is the same.

Those ideas have gradually affected academia and leads to a new subject of science. Recently, psychologists established a new branch "positive psychology" to highlight positive experiences as the positive of humans thrives individuals, families, and communities. Positive psychology draws attentions from researchers and becomes a hot spot. A famous case of positive psychology is the course lectured by Dr. Tal Ben-Shahar at Harvard University. According to its syllabus, the course focuses on "*the psychological aspects of a fulfilling and flourishing life. Topics include happiness, self-esteem, empathy, friendship, love, achievement, creativity, music, spirituality, and humor*." Obviously, the idea of positive psychology corresponds with that of well-being study. Additionally, they both pursue the origin of happiness. Although psychological research on happiness and well-being emerged quite early, worldwide studies that stretched from academia to politics were carried out not long ago.

During 2011–2012, the Organization for Economic Co-operation and Development (OECD) and the United Nations respectively published reports on Your Better Life Index [4] and the Worldwide Happiness Index [5]. Such publication has subsequently stimulated academia and aroused the awareness of governments. In response to such a change, many countries correspondingly made national policies one after another to ensure living quality of people. Although such a trend appeared to be initiated by those world organizations, however, in 1972 the king of Bhutan already proposed using "Gross National Happiness (GNH)" to replace "Gross Domestic Product (GDP)." Unlike traditional indicators, GHN focuses on the standard of living of a country instead of economic activities. It reflects the welfare of a country compared with GDP. To promote this indicator, Bhutan even established a national institute to study such a topic.

The GNH has attracted considerable attentions because it measured the mental health of people. The pursuit of well-being happiness gradually initiates the formation of new indicators, for example, Satisfaction with Life Index [6], Quality-of-life Index [7], and Happy Planet Index [8]. Likewise, similar ideas can also be found in many works. For example, Andrew Oswald advocated Happiness Economics [9] by combining economics with other research fields, such as psychology and sociology. A British distinguished economist, Richard Layard, wrote a book entitled "Happiness: Lessons from a New Science," [10]. In this book, Dr. Layard mentioned that the happiness of society did not have to rely on incomes. The book also pointed out seven essential factors of happiness. The research by Dr. Layard integrated not only psychology but also neuroscience, applied economics, sociology, and philosophy. The book provided a review of the research involving happiness. Another book entitled "Well-Being: Foundations of Hedonic Psychology" [11], which was edited by Daniel Kahneman, a Nobel Prize winner in Economic Sciences in 2002, was a comprehensive review that covered the fundamentals of happiness from the perspective of psychology. As a psychologist, Dr. Kahneman published many articles [12, 13] on subjective well-being. As a whole, the common objective of the aforementioned examples is to upgrade the living quality of humans, and to bring more happiness into daily lives. To reach welfare, either personal or societal decisions should be based on the creation of the greatest happiness for the greatest number of people [14].

Despite the focus from the academia and the advocacy from politics, it is still difficult for a society to maintain welfare in practice, for it involves too many facets. Therefore, how to realize well-being becomes a primary topic in social development, and healthcare is the preliminary step towards well-being although healthcare is typically the weakest part during development.

To call upon related research in this field, this survey reviews practical healthcare technologies by examining the technical research and the challenges for future developments. The technical aspect of this article emphasizes the current key research in the domain of Information Communication Technology (ICT), for healthcare technology is an interdisciplinary subject that covers computer science, electrical engineering, psychology, medicine, mechanical engineering, architecture, and so on. Topics outside ICT are beyond the scope of this article.

The remainder of this paper is organized as follows. Section 2 introduces the research on biomedical signal processing. Section 3 presents a recent update of affective computing. Review of human-machine interaction is described in Section 4. Smart ambient technology is reviewed in Section 5. Lastly, Section 6 offers conclusions.

## 2. Biomedical signal processing

Biosignal processing, or biomedical signal processing [15], is a common technique in the research of healthcare technology. It is widely used in measuring various physical signals, such as blood pressure, heartbeat rates, body temperature, and brain waves. Biosignal detection often relies on contact sensors or invasive probes, either in physical or chemical ways. For example, an electroencephalograph (EEG) can capture ionic current flows of neurons by using multiple electrodes placed on the scalp [16]; the brain activity is subsequently recorded in an electroencephalogram for further diagnosis. An electrocardiograph (ECG) is used to measure the electrical activity of hearts [17]. Other electrodiagnosis [18] and chemodiagnosis, such as electrooculograph (EOG) [19], electromyograph (EMG) [20], functional magnetic resonance imaging (fMRI) [21], glucometers [22], and respirometers [23], can also provide researchers with objective support for evaluating human biomedical status.

When instruments extract biosignals from a human body, these signals are often susceptible to noise or interferences. These effects often seriously influence the outcome of extraction. To alleviate such adverse conditions for further analysis, some common and useful techniques are often required. For example, Short-Time Fourier Transform (STFT), Wavelet Transform, and Hilbert-Huang Transform (HHT) are frequently used in cross-domain signal analysis. Such transforms provide scientists with different perspectives of the same signal. Typical discriminant statistical analysis involving Principal Component Analysis (PCA) and Fisher Discriminant Analysis (FDA) concentrate on measurement of dimensional importance. These methods help researchers select distinctive features after a signal is decomposed into subcomponents. Regarding extraction of signal subcomponents, Empirical Decomposition (EMD), Matching Pursuit (MP) [24], and Hilbert Vibration Decomposition (HVD) [25] are widely employed in the studies as they can divide an observed signal into desired parts and residues. Karagiannis and Constantinou [26] applied EMD to EEGs and examined how to effectively extract brain waves under noisy conditions, thereby enhancing the detection accuracy of physiopsychological status. Similar topics can be also found in [27]. Nevertheless, normal EMD suffers from problems like shifting, spline, etc. Advanced EMD like Ensemble EMD (EEMD) [28] and Complementary EEMD (CEEMD) [29] was developed for enhancement. In addition to the above-mentioned techniques, biomedical research also concentrated on measurement of biological status by investigating the effectiveness of various indicators, such as entropies, centroids, flatness, scatterness, and spread. Recently, Multiscale Entropy (MSE) is becoming increasingly popular because it offers sample-entropic analysis for signals. For instance, Wu *et al.* [30] proposed using MSE to analyze pulse wave velocity for diabetes patients, so that the degree of atherosclerosis could be modeled. Humeau *et al.* [31] investigated microvascular blood flow by utilizing MSE as time-series signals could be examined in different levels. More recently, with the emergence of advanced wireless network technology, Body Sensor Networks (BSNs) were highlighted in research and have a wide range of applications, particularly for biomedicine. For example, Harvard University launched two biomedical research projects “CodeBlue” and “Mercury” [32] to investigate the integration of RFID, wearable devices, and biomedical processing. The RFID-based wireless wearable devices were used for in-patients so that caregivers can monitor patients’ status. Likewise, Massachusetts Institute of Technology (MIT) coworked with General Electrics (GE) and built the “Medical Electronic Device Realization Center (MEDRC)” [33]. Such an institute has stimulated many projects to develop state-of-the-art equipments and devices.

In a whole, although biomedical processing has a critical influence on healthcare technology, medical instruments are usually expensive and unwieldy for personal use. This has accordingly limited the practicability. Designing a device that is appropriate for household environments still requires much effort in the future.

## 3. Affective computing

Recently, affective computing [34, 35] has lead to considerable researcher interest as the professor of Massachusetts Institute of Technology, Rosalind Picard, launched a research group, studying human emotions and other affective phenomena (http://affect.media.mit.edu/).

Although psychologists, neurologists, or biologists have put enormous effort in investigating the primal feelings of humans since several decades ago, there is no consensus on the total number of emotion categories due to emotional ambiguity [36, 37]. Besides, many works have pointed out that human emotions still lack precise definitions [36, 37]. These problems have also deepened difficulty of emotion identification and synthesis.

Despite such problems, affective computing is still an important part in healthcare because mind health is as important as body health. This may help users evaluate their emotional states in many applications, subsequently facilitating caregiving. Thus, how to determine the mind status of humans by combining extracted data or to deeply investigate the origin of aesthetics, ethics, patriotism, etc., becomes a challenging task.

In addition to the aforementioned biometric approaches, affective signals can also be obtained from user behavior, such as facial expressions [38], emotional speech [39], spoken language [40], body gestures [41], and gaits [35]. During data acquisition, noncontact sensors like cameras or microphones are often required to capture human behavior. Compared with contact detectors, such a method allows analysts to evaluate users from a distance and does not cause too much inconvenience to users. Nevertheless, its accuracy rate is not as high as that of contact detectors.

Research examples can be found in the subjects of the above-mentioned MIT project, like "Automatic Stress Recognition in Real-Life Settings," "Exploring Temporal Patterns of Smile," "Facial Expression Analysis Over the Web," "Mapping the Stress of Medical Visits," "Analysis of Autonomic Sleep Patterns," "Autonomic Nervous System Activity in Sleep," and "Causal Learning and Autism" (For details, see http://affect.media.mit.edu/projects.php).

## 4. Human-machine interaction

Rather than capturing bioinformation from humans, as biosignal processing and affective computing do, human-machine interaction (HMI) or computer-human interaction (CHI) [42] discusses the interaction between users and machines. Human-machine interaction applications usually rely on sensors or controllers to receive the input from users and then send feedback to them via responsive components. Human-machine interaction is considerably significant in healthcare technology because human-machine interface design directly involves the user practical experience while they operate machines. The study of human-machine interaction is often related to ergonomics [43], psychology, and Kansei engineering [44]. Developing a comfortable and friendly interactive environment, which can serve users' needs, is of prior concerns in human-machine interactive science.

Over the past six decades [45], human-machine interface has gradually evolved from mechanical buttons, control levers, steering wheels, and operative handles into intelligent peripherals that can bionically simulate human cognition and responses. Furthermore, recent progress of artificial intelligence [46], like machine learning and pattern recognition, has also enhanced the usability and facility of human-machine interfaces, allowing computers to communicate, make logical deduction, formulate plans, and solve problems. Such development has unquestionably shortened the gap between humans and machines. For those who require healthcare, devising a user-friendly interface both in devices and environments is important. Assistive technology and smart ambient technology are famous examples that interpret human-machine interfaces well.

## 5. Smart ambient technology

With the increase of interactions between humans and their surroundings, smart ambient technology becomes increasingly important in healthcare. Research on smart ambient technology focuses on two aspects. One is the human factor, and the other is the environmental design. The former investigates human characteristics ranging from genders, ages, personal qualities, emotions, experience, to preferences. The latter discusses the topic of different environments. For instance, location-aware research examined the accessibility of a technique when such a method is applied to various places, like homes, schools, offices, public space, and transportation facilities. Smart ambient technology is interested in integration of human factors and environmental designs. Examining the inter-effects between these aspects and create a user-friendly access to platforms is of priority concerns for smart ambient technology in healthcare.

### 5.1. PlaceLab

Project House_n [47] was developed by the Department of Architecture, Massachusetts Institute of Technology, USA. The objective of this project was to create a virtual living space — PlaceLab [48], where various sensors were deployed all over the rooms to monitor the behavior of subjects. Moreover, the interactions between subjects, house structures, and technologies were also recorded during the simulation. By deciphering the captured data, researchers were capable of designing a human-centric and user-friendly house that allows residents to comfortably control any appliance, furniture, and devices, subsequently enhancing their health.

### 5.2. Aware Home

The Aware Home [47] was sponsored by the project of the Aware Home Research Initiative (AHRI) and executed by Georgia Institute of Technology, USA. The Aware Home Research Initiative (AHRI) [49], Luke Project House_n, the idea of such a project also focused on the relation between residents and technology. Based on this idea, three topics were investigated in this simulation house — Healthy living, digital entertainment, and sustainable energy-saving.

### 5.3. Smart House

To research living models of the future, Panasonic Corporation designed a future living space — Eco & Ud House [47] — at Tokyo Panasonic Center. The technology intensively involved pervasive computing and universal designs [50]. Based on these concepts, the research team broadly used large displays and radio-frequency identification (RFID) devices to enrich interactive interfaces for a family. Furthermore, the team also designed a smart lobby and home-offices to enhance the usability of the house. Such a design has become a paradigm for smart houses. More recently, to promote the idea of environmental sustainability, Panasonic Corporation further extended the original architecture of Eco & Ud House and redesign as Smart House [51]. The new demonstration house also attracts considerable attentions.

## 6. Conclusion

As the success of well-being research grabs headlines all over the world, a growing trend towards heterogeneous integration between social science and engineering technology becomes popular. National policies are subsequently made along with the advance of ICT during city development. Although it is still difficult to balance resources on the needy, governments, academia, and industry should be tightly combined together such that social care systems can be fulfilled in practice. Recent emergence of cloud-platform technology [52] has shed light on healthcare technology. With the use of cloud platforms, human-machine interaction can therefore exceed the limit of distance, enabling remote computing. Patients can receive more assists from equipments, and caregivers can relieve their own burdens [53-55]. Similar human-centric technologies, like robotic technology, wearable computing [56], pervasive computing (i.e., ubiquitous computing) [57], assistive technology [58], internet of things [59], body sensor networks [60], social networking [61], somatosensory technology, and Kansei engineering [44] have gained considerable attention in recent year. More importantly, big data and machine learning are currently pioneering the research trend. Integration of these technologies into care technology is a hotspot in the future. Many benefits will be brought to humans, subsequently extending current healthcare technologies into a seamless level.

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