Health 4.0: Digital Twins for Health and Well-Being

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Abstract With the increasing prevalence in the use of wearables, social media, smart living, and personalized recommender systems for consumer health, it becomes imperative to converge these technologies to provide personalized, context driven, proactive, and preventive care in real time. Digital Twins are a convergence technology and involve making a digital replica of any living or nonliving entity. At present, Digital Twins are extensively used in Industry 4.0 where Digital Twins help in optimizing the performance of machines by proactive and predictive maintenance. This chapter gives an overview of the existing literature and aims to provide an overview of existing literature on Digital Twins for personal health and well-being—key terminologies, key applications, and key gaps.

Keywords Digital Twins · Personal health · Well-being · Convergence · Wellness · Artificial intelligence

1 Introduction

Industry 4.0 is the current trend of automating manufacturing using sensors, actuators, intelligent prediction softwares, and data visualization. The hallmark of Industry 4.0 is data visualization using advanced 3D modelling and predictive analytics, using data from the sensors, providing proactive information on the health of a machine. Digital Twins is the technology at the heart of industry 4.0 and El Saddik has defined Digital Twins as "a convergence technology, which promises to bridge the gap between real and virtual" [1]. Another feature of the Digital Twins is value creation for the customer through product life cycle management once the product is out of the factory, thus pushing the manufacturing industry

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A. El Saddik et al. (eds.), *Connected Health in Smart Cities*,
https://doi.org/10.1007/978-3-030-27844-1_7

from a mass to customized manufacturing mindset. This essentially means industry 4.0 is making manufacturing personal, customized, and putting the customer at the heart of production. This very shift, from mass manufacturing to consumer-centric manufacturing is what Health 4.0 can learn from. At present, there is no consensus on the definition of Health 4.0. However, drawing from the principles of Industry 4.0, Health 4.0 can be defined as shift from mass and reactive healthcare to personalized and proactive healthcare. Therefore, the Digital Twins becomes the technology, which holds the promise to deliver Health 4.0.

1.1 Health and Well-Being Definitions

There is no one universal definition of health. In fact, there are four main schools of thought on the definition of health:

1. Medical Model of Health Definition: Popular around the 1920s, health is defined as a "A state characterized by anatomic, physiologic and psychologic integrity; ability to perform personally valued family, work and community roles; ability to deal with physical, biologic, psychological and social stress" [2].
2. Holistic Model of Health Definition: In 1946, World Health Organization (WHO) definition, "A state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" is the most commonly used definition of health [3].
3. Wellness Model of Health Definition: Promoted by the WHO definition was "The extent to which an individual or group is able to realize aspirations and satisfy needs, and to change or cope with the environment. Health is a resource for everyday life, not the objective of living; it is a positive concept, emphasizing social and personal resources, as well as physical capacities" [4]. For the purpose of this chapter, the wellness definition of health is used as a reference.
4. Ecological Definition of Health: In the mid-1990s, there was a push toward an ecological definition of health and an ecological definition is "A state in which humans and other living creatures with which they interact can coexist indefinitely" [5].

In addition, it is relevant to this chapter to also mention the definitions of well-being and wellness.

1. Well-being: "A good or satisfactory condition of existence; a state characterized by health, happiness, and prosperity; welfare" [6].
2. Wellness: The state of being in good health, especially as an actively pursued goal [7]. Wellness is hence an active process through which people become aware of, and make choices toward, a more successful existence [8]. The National Wellness Institute promotes six dimensions of wellness: emotional, occupational, physical, social, intellectual, and spiritual [8].

1.2 Parameters for Health and Well-Being

As we can see that there is a wide range of definitions on health which cover the different aspects of health and health is multidimensional. We curated a comprehensive list of parameters which help in determining the health and well-being of a person. This list is made using the four definitions of health, and consists of physical, lifestyle, mental, socioeconomic, and contextual factors, which determine the health and well-being of a person. World Health Organization [9], Ottawa Charter of Health Promotion [10], and Wikipedia [11–13] were used to populate this list. The purpose of this list is to showcase the complexity of individual health and well-being. This list is for informational purpose only and should be used for any form of diagnostic or prognostic purpose by individuals or organizations.

1. Physical health parameters: Generics, history of illness or diseases (past or present or family), vital signs—heart rate, temperature, blood pressure, respiratory rate, laboratory profile (blood, urine, stool tests), radiology and imaging (X-rays, scans), etc.
2. Lifestyle parameters: Diet, sleep, exercise, stress, quality of life, sexual health.
3. Mental and psychological health parameters: Consciousness, orientation (in time, place, and person), personality, attitude, emotions, mood, mental health illness, addictions, emotional intelligence, decision-making skills, resilience, relationships (personal and professional), job satisfaction, meaningful life, thought patterns, beliefs, and motivation.
4. Socioeconomic parameters—Education, income, housing, employment, and workplace conditions.
5. Gender parameters—Gender identity and sexual orientation.
6. Contextual parameters—Location (home, work), leisure and entertainment preferences, hobbies, environment quality (air, water, noise, radioactivity, built), neighborhood (walkability, safety, access to grocery), access to health system, life expectancy in the country of residence, peace and security in the country of residence, well-being index, quality of life index, social justice, and equity.
7. Cultural parameters—Religion, language, gender roles, and culturally distinct traditions.

1.3 Digital Transformation in Health

Personal health or consumer health informatics is a subdomain of biomedical and health informatics and is defined as "the study, development, and implementation of computer and telecommunications applications and interfaces designed to be used by health consumers" [14, 15]. The field of consumer health informatics started 25 years ago with the vision that one day, the end users or the patients will be in charge of their own health [15]. Scientific information in the field of consumer health informatics has grown significantly over the past 25 years and there has

Table 1 Summarizing the digital transformation of web, industry, and health

Version	Web	Industry	Health
1.0	Read only web [16]	Mechanization, water power, and steam power [17]	Printed health information
2.0	The writing and participating web [16]	Mass production, assembly line, and electricity [17]	Online communities, social media, patient-generated content, and wearables [18]
3.0	The semantic executing web [16]	Computer and automation [17]	Personalized health-related information [19]
4.0	Mobile web—Connects all devices in the real and virtual world in real time [16]	Cyber physical systems and Digital Twins [17]	Virtualization and personalization [20]

Table 2 Design principles for Health 4.0 [21, 22]

Sr. No.	Health 4.0
Principle 1	Interoperability
Principle 2	Virtualization
Principle 3	Decentralization
Principle 4	Real-time capability
Principle 5	Service orientation
Principle 6	Modularity
Principle 7	Safety, security, and resilience

been an evolution of consumer health with the evolution of the World Wide Web. The evolution of World Wide Web from 1.0 to 4.0 has brought about evolution of industry from Industry 1.0 to 4.0 and now this effect is spilling over to Health and we are seeing a momentum toward Health 4.0. Table 1 provides a synopsis of this digital transformation.

In the book, "Health 4.0: How Virtualization and Big Data are Revolutionizing Healthcare," the authors have laid the design principles of Health 4.0 and these are heavily borrowed from the principles of Industry 4.0 [21, 22]. They defined Health 4.0 as "Health 4.0 is progressive virtualization in order to enable the personalization of health and care next to real time for patients, professionals and formal and informal carers." Table 2 summarizes the design principles for Health 4.0.

2 Digital Twins

2.1 Defining Digital Twins

In a white paper by Deloitte, "Industry 4.0 and the Digital Twins technology," the authors have identified Digital Twins as the anchoring technology for

Industry 4.0 [23]. In his paper, "Digital Twins: A Convergence of Multimedia Technologies, El Saddik has defined Digital Twins as "Digital replications of living as well as non-living entities that enable data to be seamlessly transmitted between the physical and virtual worlds." According to El Saddik, "Digital Twins facilitate the means to monitor, understand, and optimize the functions of all physical entities and for humans provide continuous feedback to improve quality of life and well-being" [1]. The concept of Digital Twins in depicted in Figure 1.

2.2 *Digital Twins for Health and Well-Being*

Digital Twins (DT) technology plays a fundamental role in shaping the future of healthcare. Personal Digital Twins is a data-driven technology that reflects the health status of individuals inferred from the continuously collected data. It represents a priceless source that can be utilized in a triangular fashion: preventive healthcare, medical healthcare, and effective communication between DTs.

DT for preventive healthcare will enhance people's awareness about their health through the biofeedback features, and help them take the right action by means of personalized recommendations among others. Medical healthcare is also enhanced by the DT concept in terms of enabling health institutions and health-related organization to provide smart health services and telemedicine. Figure 1 illustrates the convergence of technologies to bring about the realization of the DT concept.

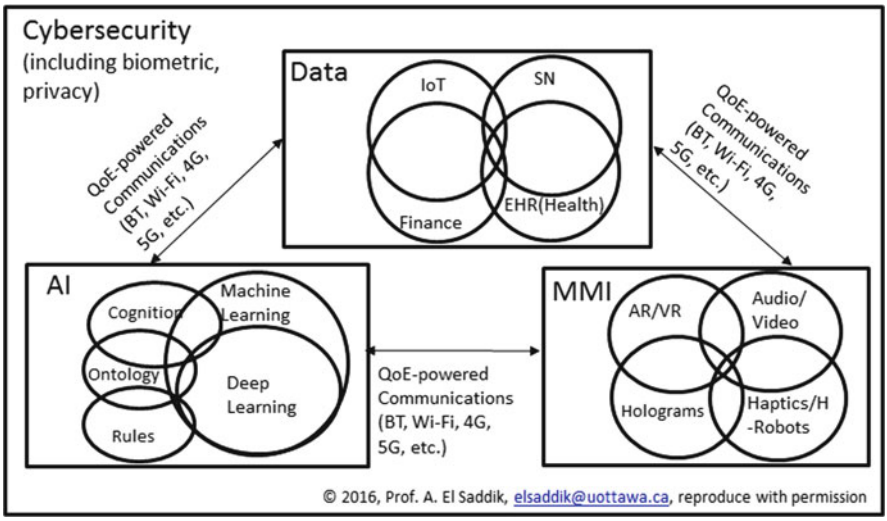

Fig. 1 Digital Twins Multimedia Ecosystem for health and well-being

2.3 Digital Twins Characteristics

The following Digital Twins characteristics are derived from [1]:

1. Unique Identifier: To communicate with its twin
2. Sensors: To replicate the senses of the real twin, i.e., sight, hearing, taste, smell, and touch
3. Artificial Intelligence: To make fast and intelligent decisions on behalf of the real twin
4. Communication: To interact in near real-time with the environment, real twins, and/or other Digital Twins
5. Representation: To interact with real twin or other twins, virtual representation can be in the form of 3D avatar, hologram, or even a humanoid social robots
6. Trust: To carry out sensitive tasks and decision-making of the real twin
7. Privacy and Security: To protect the identity of its twin as well as its privacy

3 Health Through Digital Twins

In Sect. 1 of this chapter, we had mentioned the different parameters for health and well-being and these different parameters for health can be considered as different pieces of the puzzle, which help construct the entire story of a person's health and well-being. The physical and mental parameters of a person's health help assess the current status of an individual's body and mind whereas the lifestyle parameters are contributing factors to a person's current health status. The lifestyle parameters are influenced by social, cultural, economic status, and context of an individual and thus there exist interdependencies of multiple parameters, which determine the health of a single individual. Therefore, we cannot simply tell an individual to make a health behavior change or resolve a health condition without understanding the completely understanding all the parameters of health. Since these many parameters are measured through different methods (such as wearables, social media, and laboratory tests), there becomes a need to converge the different data points of a person in one place. Apart from converging the data in one place, it also becomes imperative to help a user make use of the data and thus comes in the need for analytics and feedback for health and well-being.

Apart from this based on the geography of a person, the Digital Twins can help in grocery shopping, consumption of fresh fruits and vegetables, help increase walking in the neighborhood based on walkability and temperature of neighborhood and also suggest walking groups through different social media or group activity platforms. Thus, the Digital Twins not only used body parameters to help make a decision for behavioral change but also considers the social and contextual factors.

Thus, a Digital Twins is made from the convergence of multimedia technologies involving big data, predictive analytics, visualization techniques, cybersecurity, and communications. The Digital Twins can be as simple as one sensor or one body

parameter or can be as complex as a complete human body from genomic to gross body level. Since human beings are not just their biological bodies but also their physical and social environments, contextual factors become very important in designing a Digital Twins for health and well-being. Once the anatomy of a Digital Twins is understood, it is important to understand its physiology or functionality. The main function of the Digital Twins is to communicate with its real twin or with other Digital Twins (which may be possible in the near future) and help make the best decisions based on the complete set of parameters. We have illustrated this concept through three different case studies.

4 Case Studies

4.1 DT for Heart Care

Most heart-related diseases can be avoided only by leading a healthy life. There are risk factors associated with these diseases, alcohol consumption, obesity, smoking, sedentary lifestyle, and poor diet are the main factors. By reducing these risk factors or even suppressing them, the individual can significantly reduce the chances of being affected by any of these diseases.

With Digital Twins you can promote a healthy lifestyle as a strategy to prevent heart diseases. Digital Twins collects data from different BAN type of sensors, for example, an accelerometer, GPS, or a smartwatch that monitors heart rate and galvanic response. The AI module can use machine learning to estimate the level of physical activity for the real twin on a daily basis. From this estimation, the real twin receives recommendations on different activities outdoors or indoors to participate according to personal preferences or physical condition in the real twin.

Digital Twins knows everything about its real counterpart, based on caloric consumption, weight, clinical data, and/or biological signals obtained from different sensors, it can also detect situations related to obesity, alcohol, or tobacco consumption for which it can help the real twin to reduce or suppress effectively based on your personal preferences. This is how Digital Twins can also act as a persuasive system that supports the user to reduce or even eliminate the risk factors associated with heart disease and ultimately, prevent them. Take obesity, for example, since the Digital Twins knows about food consumption preferences, what the real twin likes or dislikes it can recommend the best meal plan that is best suited for the real twin along with a set of exercises and activities that are more adequate to the physical state of the real twin.

4.2 DT and Emotions

Digital Twins is the enabling technology that facilitates the means to monitor, understand, and provides continuous feedback to improve quality of life and well-being. Thus, a Digital Twins can consider a solution to enhance mood to enhance the quality of life and emotional well-being. The Digital Twins for emotional well-being system is a closed loop feedback system in which information taken from the human body is translated into a language perceivable by any of the human senses. The loop begins with human sensory information from the body. The physiological signals are then interpreted and converted to a recognizable emotion state. Feedback is provided to the individual through recommendations while monitoring the user behavior and action tendency. If the quality of service is not satisfied, then the system will loop back to the matching process to recalculate the feedback. Once the biofeedback information is consumed by the human brain, a change in the mental state will occur, which will cause a change in the human physiological state. The cycle then starts again.

The primary goal of Digital Twins system for emotional well-being should include tracking, assist, remind, intervene, and reinforce learning. A biofeedback loop can allow users to see their bodily reactions in real time, and assist users in finding both the positive and the negative stressful patterns in their behavior. While opportune moment detection helps provide just-in-time interventions as needed. Then, reinforce learning helps to learn the user preferences.

4.3 DT for Sport

The Digital Twins has many applications related to health and well-being, among which is sport. Indeed, Digital Twins can help improve tremendously the quality of sport both by giving the athletes access to automated training as well as by giving them the benefit of personalized feedback during and after the training.

Indeed, the DT can allow athletes to work out even in the absence of the coach but following his/her recommendations. We suggest here an application of the DT in sport, where we show that how athletes can benefit from it. We used sensors as the DT data source and actuators as DT representation to give feedback to the real twin who is here the athlete. The DT replaces temporarily the coach by helping the athlete follow his/her recommendations without the coach's presence.

We studied the case of training for soccer sprinting. As sensors, we used the smart insoles [24] in order to collect pressure point data and send it to the DT storage. The DT was configured by the coach for each athlete following their level, then the DT sends notifications to the athletes to inform them of the availability of a new training set for them. The athlete can start their sprint training at their own preferred time, during which the DT accompanies them with tracking and feedback. The feedback is delivered through haptic armbands that signal to the athlete when to start sprinting

and when to switch to periods of recovery for the duration recommended by the coach. After the training is completed, the DT makes it available to the coach (and the athlete) by means of visualizations in the form of graphs and feet heatmaps showing the results of the training that the coach can analyze and provide the next training recommendation based on the athlete performance. We performed a pilot study with three soccer athletes who reported that the DT for sport proved very useful for them. They rated it at an efficiency of eight out of ten and declared that they would adopt it to facilitate their sprint training.

The Digital Twins system can also automate the performance analysis using artificial intelligence, and act as a coach assistant, providing him/her with suggested athlete recommendations and waiting for the coach's approval before notifying the athlete of the training outcome and next steps.

5 Conclusion

Digital Twins bring about the promise to help improve the health and well-being of individuals, provided they are able to get their trust and provide data privacy. Some challenges exist among which delivering a high degree of personalization, which is context aware, culturally apt, matching user's lifestyle, and preferences. Our current interest is the study of role of incentives to self-health behaviors and links them to create a well-being economy or to initiate dialogue for a well-being economy. In the end, we need consumer evangelism and participation in use and scale of digital technologies for personal health and well-being.

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