Digital Twins

The Convergence of Multimedia Technologies

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Originally developed to improve manufacturing processes, digital twins are being redefined as digital replications of living as well as nonliving entities that enable data to be seamlessly transmitted between the physical and virtual worlds. 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.

Future smart cities will depend on developing systems that can address the computational demands of expanded digitized data and related advanced software in fields such as health and wellness, security and safety, transport and energy, and mobility and communications. The convergence of technologies and scientific knowledge promises to boost citizens' well-being and quality of life.

Digital twins—virtual representations of physical entities—are a promising means to accomplish this convergence. Gartner identified digital twins as one of the Top 10 Strategic Technology Trends of 2018,[1] and Market Research Future predicts that the digital twin market will reach $15 billion by 2023.[2]

DIGITAL TWINS: ORIGINS AND EVOLUTION

The use of digital twins became popular during the digitization of machinery and production systems in the manufacturing industry beginning in the early 2000s. General Electric (GE), for example, builds cloud-hosted digital twins of its machines that process information collected from sensors using artificial intelligence, physics-based models, and data analytics to better manage those machines.[3] Michael Grieves has argued that the digital twin, as a "virtual representation of what has been produced," is a "critical component of an enterprise-wide closed-loop product lifecycle" that reduces costs, fosters innovation, improves productivity, and ensures quality products.[4]

The concept of digital twins can be broadly applied to many technologies and is thus likely to disrupt industries beyond manufacturing. It is therefore critical to expand its definition. By enabling the seamless transmission of data between the physical and virtual world, digital twins will facilitate the means to monitor, understand, and optimize the functions of *all* physical entities, living as well as nonliving.

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For example, biologists who have created a digital twin of a tree would be able to digitally examine its internal and external components; measure the amount of oxygen released, water consumed, and sunlight received; determine the age of the tree and follow its growth from seedling to adult; and monitor and combat harmful pests or diseases before they spread to other parts of the tree.

Digital twins of humans would also enable the collection and analysis of physical, physiological, and contextual data to improve quality of life and enhance well-being.[5] For example, a stroke could be predicted before it occurs, enabling preventive steps to be taken. Machine and deep learning techniques could also be used to detect lifestyle patterns and predict potential health problems. In addition, contextual data such as information about the environment, age, emotional state, and preferences could be gathered and analyzed to fully understand and characterize a user's holistic condition.

DIGITAL TWIN CHARACTERISTICS

Under this new definition, digital twins would have several characteristics.

Unique identifier. Digital twins would each have a unique identifier in order to communicate with their twin.

Sensors and actuators. Real twins could be equipped with sensors so that digital twins could replicate their senses—sight, hearing, taste, smell, and touch—using the appropriate actuators, depending on application needs.

AI. Digital twins should be equipped with a controller embedded with ontologies, machine learning, and deep learning techniques in order to make fast and intelligent decisions on behalf of their real twin.

Communication. Digital twins should be able to interact in near real time with the environment, real twins, and/or other digital twins as Figure 1 shows. Communication, including the sense of touch (haptics), must occur within 1 ms and thus must follow 5G and Tactile Internet standards.

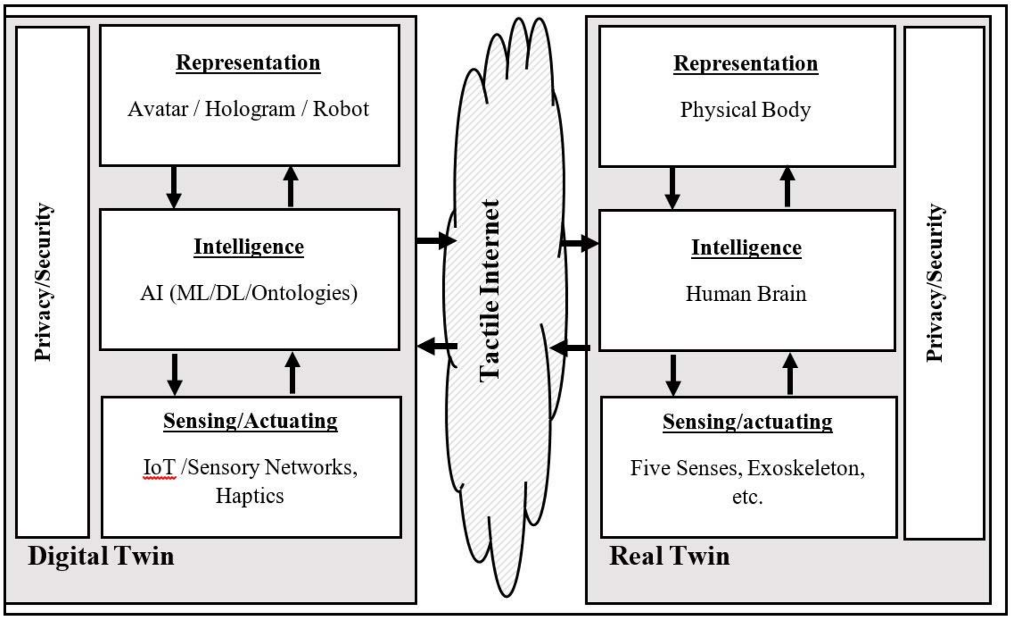

Figure 1. Communication/interaction between digital and real twins.

Representation. Digital twins could have a virtual representation as a 3D avatar, hologram, or even a humanoid social robot but it could also be software components without a tangible representation, depending on the application.

Trust. For digital twins to handle sensitive tasks such as managing financial transactions or a stock portfolio for their real twin, or interacting on the real twin's behalf in meetings, real twins must be able to trust their digital twin.

Privacy and security. Digitals twins should be able to protect the identity and privacy of their real twin. This would require the use of advanced cryptography algorithms and biometrics techniques (ECG-biometrics, haptic biometrics, and so on) as well as the resolution of regulatory and political issues.

MAKING DIGITAL TWINS A REALITY

Realizing such digital twins will necessitate the support of several key technologies.[6]

Augmented, virtual, and mixed reality. Digital twins could be generated with 3D technologies and displayed as a hologram or using AR/VR/MR devices (for example, Microsoft HoloLens), as depicted in Figure 2. For instance, if a person is at work and his daughter gets sick at home, he can use sensors installed in his office to generate his real-time digital twin and appear in front of his daughter as a hologram to comfort her. Hence, people in different locations could interact as if they were in the same space.

Figure 2. A subject interacting with the holographic representation of his digital twin.

Haptics. Digital twins can enhance communications by integrating haptic properties. For example, if Alex shakes hands with Lisa's digital twin, the digital twin could provide appropriate haptic feedback to Lisa.

Robotics. Humanoid as well as soft robotics technologies could be leveraged to let digital twins physically act on behalf of their real twin.

5G and Tactile Internet. The emergence of the 5G and Tactile Internet, which aims to providing ultra-low-delay and ultra-high-reliable communications, has enabled a paradigm shift from conventional content-oriented to control-oriented communication, particularly for human-in-the-loop applications that are highly delay sensitive and require a tight integration of communication and control mechanisms. Digital twins would provide an always-active twin feedback loop that improves the service quality of the physical systems.

Cloud computing. Offloading computation and control to cloud computing infrastructures would make digital twins more scalable and ensure that they are available to assist their real twin anywhere, anytime.

Wearables. Wearable technology is attracting many users. The considerable amount of physiological data gathered daily by these devices could be used by digital twins to more efficiently support their real twin.

IoT. Contextual data could be fed from users to their digital twin through the IoT, and feedback could be sent to the environment, enabling users to interact more smoothly with their surroundings as well as remote locations.

AI. IoT data is processed using algorithms that are continuously improved with updated user data. Using such time-series data, a user's digital twin could suggest actions to control or avoid potentially harmful situations.[6]

IMPROVING HEALTH AND WELL-BEING

Imagination is the only limit to digital twin applications; perhaps the most powerful is improving health and well-being.

Digital twins could show what is happening inside their real twin's body, making it easier to predict the occurrence of an illness by analyzing the real twin's personal history and the current context such as location, time, and activity.[7] Digital twins could also provide patients with customized recommendations on how to improve their health. For example, they could act as a mentor to a diabetic by tracking food consumption, physical activities, and daily life routines; they could also search the virtual world for other digital twins with diabetes to glean insights on improving quality of life.

Digital twins could likewise play an important role in well-being. They could detect stress levels using sensory technology and determine the causes of stress. Using intelligent algorithms, they could compute their real twin's pattern of stressful situations to offer advice on how to avoid or reduce stress. Digital twins could also detect emotional changes in their real twin and send feedback to, for example, help reduce sadness or anger based on the real twin's preferences such as listening to favorite music or engaging in favorite activities (dancing, watching a movie, walking, and so on). Moreover, digital twins could help guide athletes with optimized performance and fitness training protocols based on personalized physiological, psychological, and contextual information.

The consequences of exercise routines and eating and sleep habits often do not materialize until a while later. Digital twins could shorten that gap by giving their real twin insight into the potential consequences of lifestyle decisions and to generate if-then scenarios to understand how the choices they make could cause their health to improve or deteriorate. Even if you have some understanding of the detrimental consequences of poor choices on your health and well-being, and are under the care of a health practitioner, this is not nearly as effective as seeing an actual projection of what you would look like if, for example, you continue to smoke, get insufficient exercise, or maintain an unhealthy diet. Likewise, looking in the mirror every day and seeing no noticeable change after implementing a new regimen can discourage you from sticking to it, but a projection of what you would look like in, say, three months could sufficiently motivate you to follow through.

OTHER DIGITAL TWIN APPLICATIONS

Other digital twin applications range from e-learning to financial management to virtual tours to shopping to online social interactions. For many such applications, digital twins must be highly personalizable in order to effectively interact on behalf of their real twin with other people or digital representations.

For example, media such as photos, videos, and sound recordings enable us to hold onto the past much better than our memories allow and to recall people who have touched us throughout our life. Digital twins might make it possible to also restore the smell, touch, and hugs of deceased loved ones. In addition, digital twins would continuously absorb information about their real twin, training their neural networks using the latter's actions and decisions. Digital twins would continue to exist after their real twin passes away, enabling loved ones to continue to communicate with deceased persons. In this way, digital twins would extend humans' presence beyond their biological limitations.

Another application is dating. The popularity of dating sites is increasing, but information on these sites is not always accurate, in part because users must manually input subjective information about their personality. Some people do not know themselves well, while others enter false information. Digital twins could help provide more accurate descriptions of their real twin on such sites at different privacy levels. They could also be used to simulate a real-life hookup to determine if it is a good match.

CONCLUSION

Realizing the full potential of digital twins will require a convergence of the above-mentioned technologies. In particular, more research is needed to improve traditional data collection and processing methods and to implement the communication interface between real and physical twins.[8] In addition, digital twin applications need to be accurate to earn users' confidence and trust, and be robust enough to allow users to live their normal lives. The system must have security mechanisms to guarantee users' privacy and protect their personal data, and be able to detect failures and missing data.

Foreseeing the emergence of different realizations of a digital twin, it would also be imperative to standardize technologies to interoperate in the long term. Moreover, to facilitate collaboration worldwide, digital twins must incorporate mechanisms to accommodate a diversity of cultures. There are also legal issues that must be resolved, such as how much responsibility digital twins should be entrusted with to act on behalf of individuals, and what entity is liable for any harmful actions attributed to a digital twin.

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