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Abstract	Digital Twin (DT) is one of the important enabling technologies for Smart Manufacturing and Industry 4.0, with a huge potential for many impactful applications in healthcare and industries. This paper presents a conceptual model of a DT system, with a proof-of-concept (POC) prototype of a robot for demonstrations and further investigations of DT applications in telehealth and in-home healthcare. The successfully developed POC prototype were tested to evaluate time delay, and possible errors when operating and controlling the virtual and physical models of a robot. The proposed conceptual model of a DT system can be used for demonstrations about DT, with further developments for potential applications in healthcare and industries, especially when it is integrated with emerging technologies such as artificial intelligence, machine learning, big data analytics, smart sensors, augmented reality and virtual reality.

Keywords (separated by '-')	Digital Twin - Industry 4.0 - Human-robot Interaction - ROS - Unity

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A Conceptual Model of Digital Twin for Potential Applications in Healthcare

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Abstract. Digital Twin (DT) is one of the important enabling technologies for Smart Manufacturing and Industry 4.0, with a huge potential for many impactful applications in healthcare and industries. This paper presents a conceptual model of a DT system, with a proof-of-concept (POC) prototype of a robot for demonstrations and further investigations of DT applications in telehealth and in-home

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Keywords: Digital Twin · Industry 4.0 · Human-robot Interaction · ROS · Unity

1 Introduction

DigitalTwin(DT)isoneoftheimportantenablingtechnologiesforSmartManufacturing and Industry 4.0, with a huge potential for many impactful applications in healthcare and industries [1–3]. A DT system basically has three main elements: the physical element, the digital or virtual element, and the connection element that connects the physical and the digital elements. A digital element is a digital replica of a physical element which is a potential and actual physical object such as devices, engineering systems and processes. With the use of real-world data as well as real-time simulation and optimization, DT systems can be used to control, monitor and predict how a product, a system or process performs and behaves, leading to enhancement of quality of decision-making and

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process optimization, as well as real-time control, monitoring and analysis of important performance indicators, and developing effective plans for predictive maintenance of products, equipment, production lines and facilities. Especially, with the availability of real-timedata,interactions andresponses,DTenables effectivemultidisciplinarycollaborations and improved communications, to quickly and optimally make more informed decisions.

With the rapid advancements of digital transformation and smart technologies in recent decades, there have been more and more efforts and investments to develop impactful applications of DT and associated emerging technologies such as artificial intelligence (AI), machine learning (ML), big data analytics, smart sensors, augmented reality and virtual reality (AR/VR), especially applications in healthcare and medicine, including food and drug delivery, virus disinfection and telehealth services, as well as telesurgery or remote surgery and medical rehabilitation with robots [2–6].

This paper presents a conceptual model of a DT system, with development of a proof-of-concept (POC) prototype for demonstrations and further investigations of DT applications in healthcare and medicine, via the use of mobile robots with basic functions for applications in telehealth and in-home healthcare. A POC prototype of a DT system for a mobile robot was developed; it aims to effectively and conveniently manage and monitor operations of a robot for specific applications in telehealth and in-home healthcare, with the following key activities of design and development of DT, including (i) Building a physical element of a DT system; (ii) Building a virtual element of a DT system; (iii) Development of a connection element of a DT system, with data collection and transfer between the physical and the virtual elements; (iv) Development of a computation and simulation system; and (v) Local data collection, storage and cloudbased backups. The POC prototype of a DT system was successfully developed based on the latest development of simulations and interaction technologies, including AR/VR, a real-time 3D development platform (Unity) for building 2D and 3D applications such as games and simulations [7], and the open-source Robot Operating System (ROS) that helps build robotic systems [8].

2 Materials and Methods

2.1 Working Principle and a Structure of a Digital Twin System

Aconceptual model withthefundamental elements ofaDTsystemispresentedinFig. 1. There are three main elements: the physical element, the digital or virtual element, and the connection element that connects the physical and the digital elements. In this work, the physical and virtual elements are connected to each other through the TCP socket protocolsuite.WiththeproposedDTsystem,thevirtualmodelandthephysicalelements of a robot can interact with each other in which the data and/or information can be transferred and/or transmitted in two ways. When a robot operates in a certain environment, with the changes of a robot's state, such as a robot's location in its environment, the robot state data are collected by sensors, and they are then transferred and/or transmitted to a central processing unit (CPU). The collected data are optimized and processed at CPU, and they are transferred and/or to the virtual element of a robot, as the input data for the central processor of the virtual element which process and control the virtual robot in the virtual environment, and finally to display and store necessary information and data for specific applications, especially the important information and data for real-time control and monitoring of a robot.

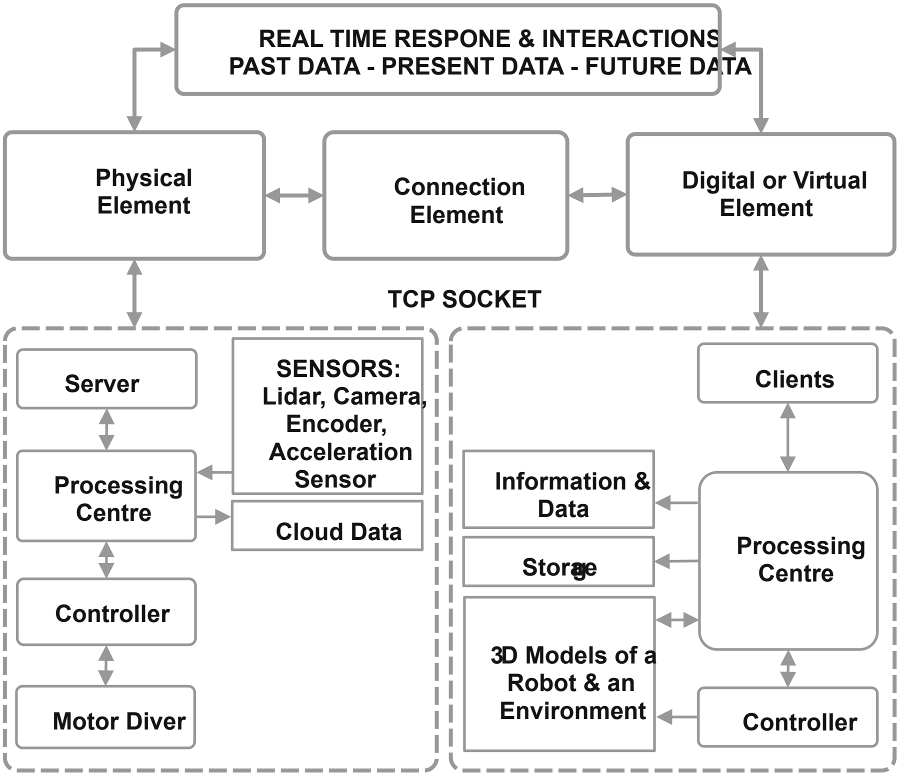

Fig. 1. A conceptual model with fundamental elements of a Digital Twin system.

Similarly, when controlling a virtual robot in the virtual element of a DT system, information and data of the state of a virtual robot are transferred to the processing centre, and they are then transmitted to the physical element of a DT system to control a physical robot. The data received from a virtual element of a DT system are processed, to generate signals to control the physical robot, such as to control movements of a robot.

The data and information are stored locally and on the cloud platform, and they are used to train algorithms for simulations and optimizations, especially to minimize errors between operations and controls of the physical and virtual models of a robot.

2.2 A Physical Element of a DT System – A Physical Robot Model

Figure 2 presents the physical and virtual models of a robot. A robot was built with a steel frame which has a rectangular shape with the size of 500x400x30 mm (Length x Width x Height). Four mecanum wheels are used for the driving function of a robot, and they are driven by four GP36 planetary geared motors. A lidar sensor is mounted on top of the robot for obtaining the best scanning view.

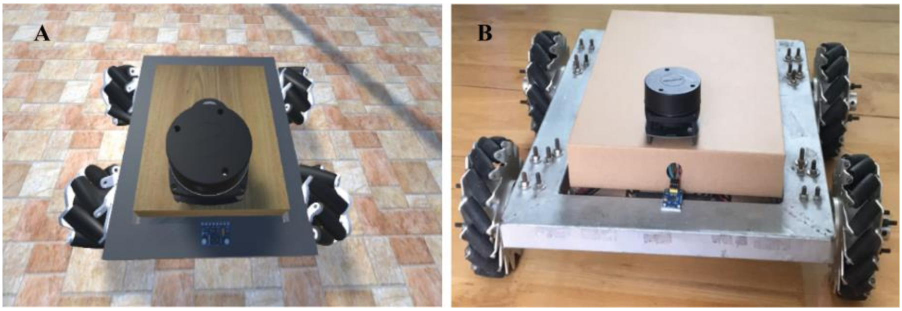

Fig. 2. A 3D model in the 3D virtual environment (A) and a physical model of a robot (B).

The instantaneous speed of a robot v is calculated as shown in Eq. (1) in which $\Delta(S)$ is the travel distance and (t) is the travel time. The travel distance (S) is calculated based on the number of the counted encoder pulses (E) within the travel time (t), the numberofcountedencoderpulseswhenthewheelturnswithonerevolutionofthewheel, and the circumference of the wheel C. The number of counted encoder pulses when the motor turns with one revolution of the wheel is calculated based on the deceleration ratio (a) and the number of pulses when the encoder rotates one revolution (b).

$$v = \frac{\Delta(S)}{\Delta(t)} = \frac{\Delta(E) * C}{a * b * \Delta(t)} \quad (1)$$

In this study, the physical robot model is the mobile robot. The mobile robot uses the GP36 planetary geared motor with Encoder - DC Motor - 1:27-500CPR. The circumference of each wheel (C) is 40 cm. The following is the formula for calculating the speed of each wheel:

$$v_i = \frac{\Delta(E) * C}{a * b * \Delta(t)} = \frac{(E_{cur} - E_{pre}) * 40}{500 * 27 * (t_{cur} - t_{pre})}, i = [0, 1, 2, 3] \quad (2)$$

where $\mathbf{V_i}$ [cm/s] is the speed of the wheel, E_{pre} is the number of encoder pulses of the wheel at the previous measurement (t_{pre}), E_{cur} is the number of encoder pulses of the wheel at the current time (t_{cur}), a is the deceleration ratio, and b is the number of pulses when the encoder rotates one revolution. The acceleration of each wheel is calculated by the following formula:

$$a_i = \frac{\Delta(v_i)}{\Delta(t)}, i = [0, 1, 2, 3] \quad (3)$$

The robot uses the lidar sensor to scan for obstacles. The scanning radius is about 0.15–6 m with a 360-degree angle range. Data is transferred from the lidar to the central processor via the USB port. The data include the header, the scan start angle, the scan end angle, theangular distance between measurements, the timebetween measurements, the time between scans, the min range value, the range value maximum, and the data range. The distance is calculated using the following formula:

$$d = \frac{v * t}{2} = \frac{0.034 * t}{2} \quad (4)$$

where d [cm] is the distance from the lidar to the obstacle, t [μ s] is the time of the laser pulse emitted to the obstacle and back to the sensor, and v [cm/μ s] is the speed of sound.

2.3 A Virtual Element of a DT System – A Virtual Robot Model

The virtual model of a robot was built based on the physical model of the robot and then imported into the 3D virtual environment. The initial 3D virtual environment where an empty environment is unknown. Based on the data taken from the sensor of the physical model, the 3D virtual environment of the real environment is to be constructed.

2.4 Two-Way Data Transmission

The virtual model and the physical model of a robot are connected by the socket TCP protocol, with the built transmission pipeline. The place that sends or receives data is called a node. These nodes have to be named; however, it is importantly noted that, there should be no case in which the nodes have the same name. Nodes communicate with each other through pipes, called topics; and information travels in this pipeline, called messages. Sending and receiving messages between the nodes requires synchronisation between the data type and the topic.

2.5 Data Storage

Data is collected and stored locally and backed up in the cloud platform. The values of the sensors after being taken are sent to the central processor at the processing centre. The data will be processed and saved in the local storage. The cloud backup has a frequency of about 10 Hz, and it slows down the system processing speed. Therefore, the system backs up these data on the cloud platform after a period of time. A part of the data collected from the lidar sensor is shown in Fig. 3, and the data storage process is presented in Fig. 4. It is noted that, the graph of data was not sketched continuously. The data collected from the lidar are sketched out if the range is blocked by obstacles or they are left blank when nothing is in the scanning area of the lidar sensor.

2.6 A Mobile Application for Monitoring and Interacting with a Physical Robot Model of a DT System

Inordertomonitorandinteractwithaphysicalrobotofa DTsystem,amobileapplication was developed; It conveniently allows the user to control and monitor the activities of the physical robot through its virtual robot model. Users can control a physical robot to perform tasks such as delivery of food, water, or necessary items to the desired location for application cases of telehealth and in-home healthcare.

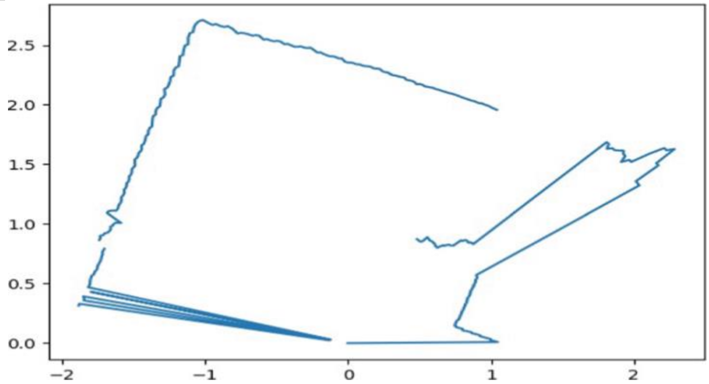

Fig. 3. A part of data collected from the lidar sensor.

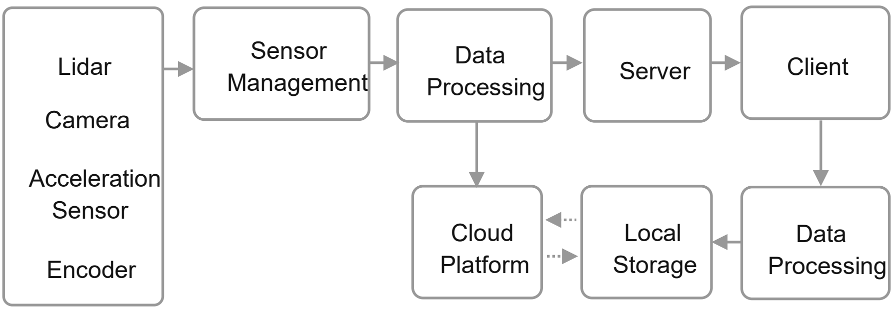

Fig. 4. A diagram of data storage and data processing for a DT system.

2.7 Analysis of Kinematics of a Robot

The robot uses four mecanum wheels, a type of omnidirectional wheel. That helps the robot move more flexibly than conventional wheeled robots. This is due to the roller mechanism with the shaft penetrating 45° to the main axis of rotation of the wheel. The calculation of robot positions is an important problem in autonomous robot systems; and development of the forward kinematics is necessary for calculating robot positions. The coordinate system is attached to the robot as shown in the Fig. 5. The speed of a robot is calculated based on Eq. (5). Where v_x is the speed of a robot in the x-axis, v_y is the speed of a robot in the y-axis, v_ω is the rotational speed of a robot in the z-axis, R is the vehicle radius, ω_i is the angular velocity of the wheel i (i = 1..4), and l_1 and l_2 are the distance between the wheel axle and the vehicle's center of gravity along the y and x axes.

$$\begin{bmatrix} v_x \\ v_y \\ v_\omega \end{bmatrix} = \frac{R}{4} \times \begin{bmatrix} 1 & -1 & 1 & -1 \\ 1 & 1 & 1 & 1 \\ \frac{1}{l_1+l_2} & \frac{1}{l_1+l_2} & \frac{1}{l_1+l_2} & \frac{1}{l_1+l_2} \end{bmatrix} \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix} \quad (5)$$

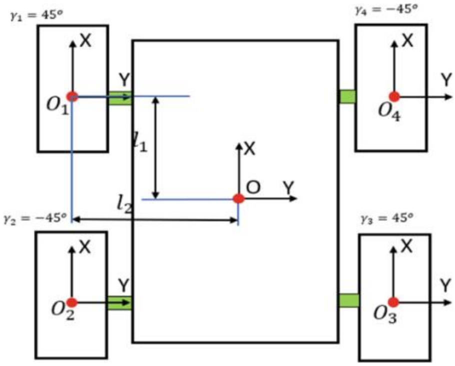

Fig. 5. A coordinate system of the robot OXY, and a coordinate system of the wheel OiXY (i = 1, 4).

2.8 Latency Calculation

It is required that the virtual robot is operated and controlled in parallel with the physical robot in a DT system, and in the ideal cases, there should be real-time interactions and responses without a delay. The problem of latency is therefore important, and it is an important criterion for evaluation of a DT system. The process of calculating the time delay (latency calculation) is presented in Algorithm 1 as follows:

Algorithm 1: Latency Calculation

Input: t, t_{pre}, t_{sum}, Δ_{adv}, Δ_t, i;
$t_{pre} \leftarrow 0$; $\Delta_{adv} \leftarrow 0$; $i \leftarrow 0$;
$t_{sum} \leftarrow 0$; $\Delta_t \leftarrow 0$; **while** true
do $t \leftarrow$ GET (time);
  $i \leftarrow i + 1$; Δt
  $\leftarrow t - t_{pre}$; t_{sum}
  $\leftarrow t_{sum} + t$;
  $\Delta_{adv} \leftarrow t_{sum}/i$;
  $t_{pre} \leftarrow t$;
end
Output: Δ_t, Δ_{adv};

Where t is the time at which the state data of the physical and the virtual robots are obtained. t_{pre} is the time at which the data was retrieved last time compared to the current one. t_{sum} is the total system uptime. i is the number of times the data is retrieved. $_t$ is the system latency and $_{adv}$ is the average system delay. The system runtime is obtained through the GET() function.

3 Results and Discussions

Experiments and demonstrations were done to test and evaluate the developed POC prototype of a DT system, with the focus on evaluation of the system latency and the possible errors between the virtual and physical robots when they are operated and controlled in both the virtual and the physical environments.

3.1 The Latency of a DT System

The process of transferring data between the physical and virtual robots in a DT system has a time delay. The system communicates through the WiFi network with a specific IP address. The frequency of the system is shown in Fig. 6, in which the average latency of the system is about 0.028 s and an average frequency is about 36 Hz. With this frequency, the system can satisfy the basic requirements for demonstrations of the POC prototype of a DT system.

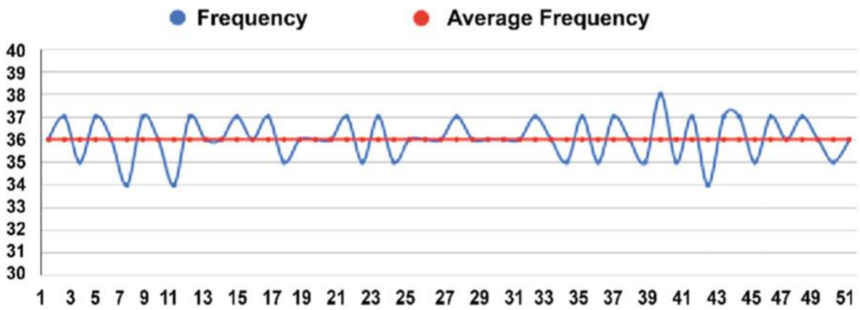

Fig. 6. A system frequency. The vertical axis is the frequency value (Hz) and the horizonal axis is the time value (s).

3.2 Analysis of Possible Errors When Operating and Controlling the Virtual and Physical Robots

The physical and the virtual robots are operated and controlled in parallel. However, there are problems related to acceleration, velocity, and errors of sensors, that lead to errors between the positions of the physical and virtual robots. The DT system was tested at speeds below 100 mm/s on the flat surface. Figure 7 presents errors between the positions of the physical and virtual robots.

Velocity calculations and simulations from sensor values are also performed to help the virtual robot behave as closely as possible to the physical robot. However, the simulation always has errors due to sensor errors, delay and moving terrain. The relative error of instantaneous velocity between the physical and virtual robots is calculated by the formula: $E_{relative} = 100 \times \left|\frac{v_{real} - v_{virtual}}{v_{real}}\right|$. The instantaneous velocity error is shown in

Table 1 and Fig. 7. The error fluctuates about ±5% from the real instantaneous velocity. Under the above experimental conditions, the error is acceptable. However, when the condition occurs in the real environment, the error will change significantly. In order to minimize possible errors, simulations and AI/ML algorithms should be developed and implemented, especially to simulate and predict the next state of data to help reducing errors and gradually homogenising interactions and communications between the physical and virtual robots.

As shown in Table 1 about the error ratio between the instantaneous velocities of the physical and the virtual robots, the largest instantaneous velocity in the sample data is 33.61 mm/s and the smallest instantaneous velocity is 0.08 mm/s with the largest relative error of 3.23%. It is noted that, Column 2 in Table 1 is the time the instantaneous velocity data that are collected since the DT system starts operating.

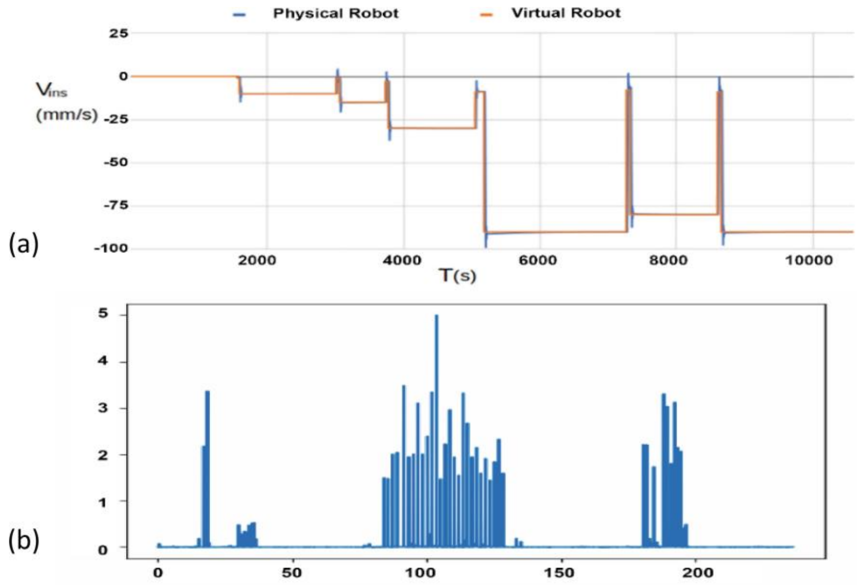

Fig. 7. The graphs of instantaneous velocity errors between of the physical and the virtual robots: (a) the instantaneous velocities, and (b) the error ratio between the instantaneous velocities.

4 Conclusion and Future Work

Under the impacts of Smart Manufacturing and Industry 4.0, there has been an emerging need to investigate and develop DT systems for different applications in healthcare and industries. In this paper, a conceptual model of a DM system, with a proof-of-concept (POC) prototype, were successfully developed and demonstrated, with the basic tests for further developments of potential applications, especially in telehealth and in-home healthcare, where the robots can be used for delivery of foods and drugs, virus disinfections, health monitoring and telehealth services. The future work which are well-aligned with this study include the following (i) integration of AR/VR to enhance interactions and user-experiences when using a DT system; (ii) development of a Simultaneous

Table 1. The errors between instantaneous velocities of the physical and the virtual robots.

STT	Time (s)	$V_{physical}$ [mm/s]	$V_{virtual}$ [mm/s]	Error [mm/s]	Relative error [%]
1	18.853	10.5523	10.2312	0.3211	3.0429
2	91.558	15.6166	16.1512	-0.5346	3.4232
3	98.763	34.8426	35.5456	-0.7031	2.0176
4	106.912	30.5213	31.1567	-0.6354	2.0818
5	143.295	33.6148	32.5345	-0.0587	0.1747
6	188.308	31.8922	30.8345	1.0576	3.2301
7	193.762	12.1184	11.7652	0.3532	2.9146
8	213.032	0.0797	0.0795	0.0002	0.2479

Localization and Mapping (SLAM) system for minimizing possible errors between the physical and virtual robots; (iii) integration of smart sensors and effective solutions for improving a system safety and security; (iv) full developments of a DT system with telepresence robots for specific applications in telehealth and in-home healthcare.

References

1. Wu, Y., Zhang, K., Zhang, Y.: Digital twin networks: a survey. IEEE Internet Things J. **8**(18), 13789–13804 (2021)
2. Liu, X., et al.: A systematic review of digital twin about physical entities, virtual models, twindata, and applications. Adv. Eng. Inform. **55**, 101876 (2023)
3. Mazumder, A., et al.: Towards next generation digital twin in robotics: trends, scopes,challenges, and future. Heliyon **9**(2), e13359 (2023)
4. Qadri,Y.A.,etal.:Thefutureofhealthcareinternetofthings:asurveyofemergingtechnologies.IEEE Commun. Surv. Tutor. **22**(2), 1121–1167 (2020)
5. Tamantini, C., et al.: A robotic health-care assistant for covid-19 emergency: a proposed solution for logistics and disinfection in a hospital environment. IEEE Robot. Autom. Mag. **28**(1), 71–81 (2021)
6. Raza,M.,etal.:Telehealthtechnology:potentials,challenges andresearchdirectionsfordeveloping countries. In: Vo Van, T., Nguyen Le, T., Nguyen Duc, T. (eds.) Development of Biomedical Engineering in Vietnam. IFMBE Proceedings, vol. 63, pp. 523–528. Springer, Singapore (2018). https://doi.org/10.1007/978-981-10-4361-1_89

7. Unity, a real-time 3D development platform for building 2D and 3D application, like gamesand simulations.:www.unity.com. Accessed Feb 2023
8. ROS, the Robot Operating System for building robot applications. www.ros.org. Accessed Feb 2023