Application of digital twin in space engineering using augmented reality and internet of things technology

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Digital twin (DT) is the latest technology, which helps in generation of exact digital replica of the physical system. In this work, an in-house DT of a thermo-vacuum chamber and payload is developed. This research paper covers the development and implementation of an in-house cross-platform software application, a mobile AR app, and a Microsoft HoloLens 2 application, which provides real-time sensor data with voice control. The objective of this research is to study the potential of DT technology in real time monitoring of testing of payloads in thermovac system. Results demonstrate that the developed software applications provide a comprehensive 1 : 1 scale 3D visualization of the chamber along with essential sensor parameters for users to monitor the chamber and payload status, leading to a more effective decision making.

Keywords: Augmented and virtual reality, digital twin, industrial internet of things, space engineering.

THE thermal and vacuum (or thermovac) chambers are crucial for testing and verifying gear and equipment in space simulation environments, such as satellites, space probes and manned spacecraft. These chambers mimic the hostile environment of severe temperatures, vacuum, and radiation, allowing engineers to assess the performance, durability and dependability of space hardware and equipment under realistic conditions. The testing process, on the other hand, can be difficult and time-consuming, requiring considerable data collection and analysis as well as specialized personnel to run and maintain the chambers.

Digital twin (DT) technology has been developed as a viable method for producing virtual replicas of physical systems for examination, optimization and control. DT of the thermovac chamber and payload developed at the Space Applications Centre (SAC), Indian Space Research Organisation (ISRO), Ahmedabad, can provide real-time monitoring, profiling, diagnostics and predictive maintenance capabilities, boosting the safety, productivity and cost-effectiveness of the testing process. The goal is to develop an interactive and immersive simulation that can deliver real-time data, three-dimensional visualizations and forecasts to engineers and technicians for optimizing and debugging the testing process. The present study aims to demonstrate the potential of DT technology for enhancing space hardware testing and research. By developing a DT of the thermovac chamber, we can reduce the complexity and cost of the testing process, enhance safety and reliability, and improve the overall performance of space hardware and equipment.

Previously, an operator had to constantly monitor the sensor data displayed on a two-dimensional tabular format (Figure 1), manually mapping each data point corresponding to the respective location on the physical entity with the help of computer-aided design drawings. The data were stored in a local server/storage and visualized only after the test using MS Excel. However, with the successful implementation of DT, we can visualize all the (relevant/additional) sensor data at our convenience. This also enables real-time profile generation and analysis over certain time intervals. Also, one need not constantly monitor all the data points at all times since an alert is issued whenever any sensor value exceeds some mentioned threshold. DT provides less clutter and ease of access to each significant value at any given time by making it intelligent enough to understand which sensor value is important at a certain view with the help of proximity to the sensor in the virtual world. Different views of DT can be controlled either using the arrow keys and mouse, or voice commands.

Across the world, many researchers have studied the potential of DT for future applications. Uhlemann *et al.*[1] have provided a comprehensive overview of the DT concept and its applications in industry 4.0. DT, according to the authors[1], is a virtual representation of a physical system that may be used to model how the real system would behave in certain scenarios. Kritzinger *et al.*[2] have done a thorough analysis of the literature on the use of DT in manufacturing and suggested a classification system for classifying the literature. They classified DT applications in manufacturing into four major categories: product, process, production and supply chain, and further classified each application area in accordance with its unique attributes, such as its data sources, modelling strategies and use cases[2]. Onaji *et al.*[3] presented a conceptual framework for implementing DT technology in manufacturing, and provided case studies to illustrate its practical applications. They considered each element of the framework for DTs, such as data collection, modelling and simulation, and visualization and analytics.

Chamber-A thermocouple and vacuum readings

CHAMBER VACUUM 1.24395E-06 mbar

THERMOCOUPLE	Value °C	THERMOCOUPLE	Value °C
TC-55	6.4	TC-109	5.2
TC-56	4.0	TC-110	4.7
TC-57	14.7	TC-111	4.4
TC-58	7.2	TC-112	4.7
TC-59	6.7	TC-113	3.1
TC-60	6.3	TC-114	3.0
TC-61	26.4	TC-115	3.0
TC-62	26.7	TC-116	3.0

Figure 1. Web-based data monitoring system.

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They have also discussed the main obstacles and opportunities for using DT technology in manufacturing and mentioned the difficulties of DT technology, including the requirement for specialized knowledge and the possibility of data security and privacy problems[3]. Pires *et al.*[4] have provided an overview of the DT concept in the context of industry 4.0. They have discussed several tools and technologies – such as sensors, data analytics and simulation software – that make it possible to build and use DTs. They have also described how DT technology is used in industry 4.0 for a variety of purposes, such as product design, production planning, and maintenance and repair, and have emphasized the advantages of this technology, including increased effectiveness, lower cost and higher quality[4]. Tao *et al.*[5] have provided a comprehensive review of the state-of-the-art of DT technology in the industry. They have highlighted several elements that make up a DT, such as data collection, modelling, simulation, visualization and analytics. Their study has also covered different industrial uses of DT technology, such as product design, planning of production, and maintenance and repair. The authors have outlined the potential advantages of DT technology, including increased productivity, lower cost, and higher quality, and provided examples of successful commercial use of DTs[5]. They have also discussed the potential effects of DT technology on industrial processes as well as the future directions of the industry[5].

The proposed work goes beyond previous limitations by combining various aspects through an interactive and immersive human–machine interface (HMI) for data visualization using DT. The highlights of the present study are as follows.

(a) To the best of our knowledge, this study demonstrates a working DT, which is the only indigenous implementation of its kind in the domain of manufacturing and space engineering.

(b) The model was developed at SAC, ISRO, without incurring additional costs to the office. It demonstrates industry 4.0, internet of things (IOT) and smart solution that can be scalable for all the major laboratories across India.

(c) The novelty of this work lies in the optimization of the complex model, implementation of DT using IOT and 3D model, and deployment of the solution over multiple devices, including mobile platforms, desktop machines, HoloLens (AR device) and Oculus (VR head-mount device). This cross-platform compatibility sets it apart from existing DT applications, allowing users to access DT seamlessly, regardless of the preferred device or technology.

(d) The implemented features such as sensor data profiles and heatmaps, which can also be generated based on the real-time values of various sensors.

(e) The implemented voice assistant helps users explore various sensor data and profiles of DT. We can just 'speak' to the DT the way we talk to other human beings.

Figure 2 shows the flow of the implementation algorithm in sequence to understand how this work has been implemented and the various utilities, plugins and software used in the process. Initially, a complex engineering 3D model is taken as an input and preprocessing is carried out to simplify the complex 3D model as well as to make it compatible with the development of DT. In the next step of real-time data processing, data are extracted from the network system and mapped according to the actual sensors mounted on the physical system. Further, an indigenous DT software is developed, and taking inputs of preprocessing steps and solutions is deployed on multiple platforms. The detailed methodology is described below.

The three-dimensional mechanical model of the thermovac chamber is taken as an input, which contains the physical properties of the model, including shape, measurements, tolerance, etc. This model is built using Creo Parametric[6] (Figure 3). Due to the complexity of the model and the number of meshes it contains, spawning the model becomes a

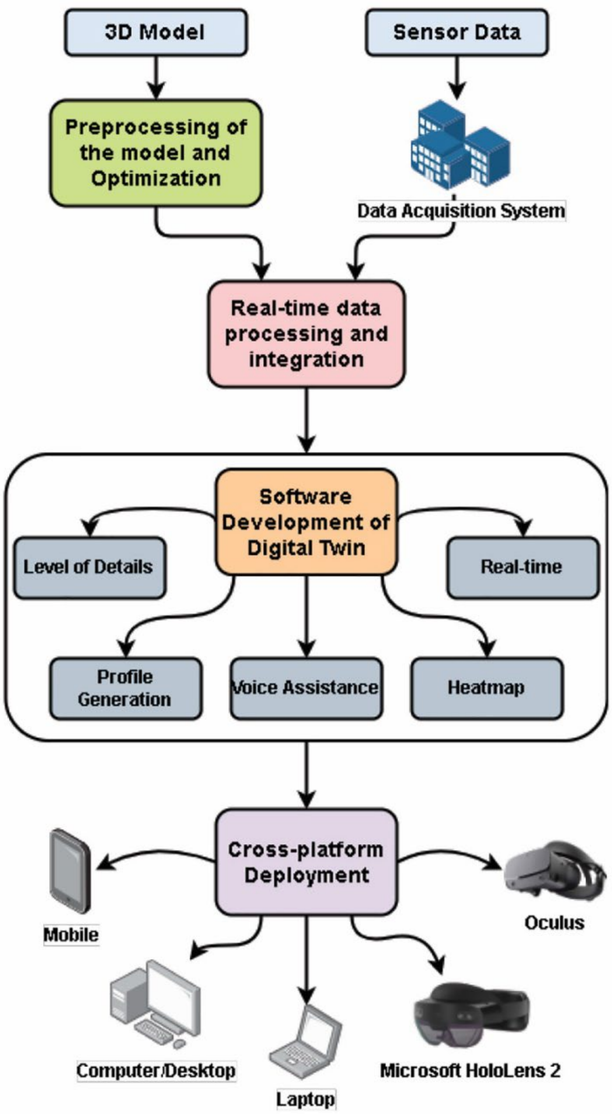

Figure 2. Flow of implementation.

challenging task. Preprocessing is the foremost step to enhance the performance and improve the visual quality of DT. Optimization is performed in Blender, which is an open-source, versatile 3D modelling, animation and rendering software. It offers modelling techniques such as polygon modelling, subdivision surface modelling, sculpting and parametric modelling with an in-built modifier system[7].

Preprocessing involves optimization of the model, viz. removing trivial geometries that do not contribute to important details of the model according to user requirements. After discussing model intricacies with the concerned team and understanding the placement of significant sensors, trivial components were eliminated. Further, polygon counts were reduced using Blender's Decimate modifier or Re-mesh modifier to simplify the model geometry while preserving the important details. This helps reduce the complexity of the model and improve performance.

Finally, the optimized model is exported in the .FBX format (AR/VR framework compatible) because it retains joints and constraints (Figure 4).

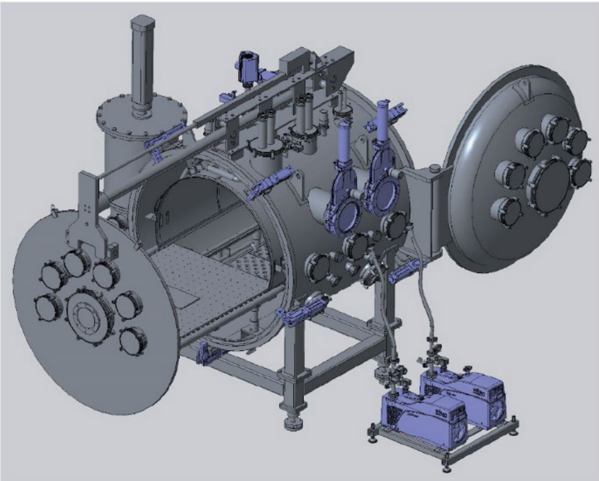

Figure 3. Three-dimensional model of the thermovac chamber.

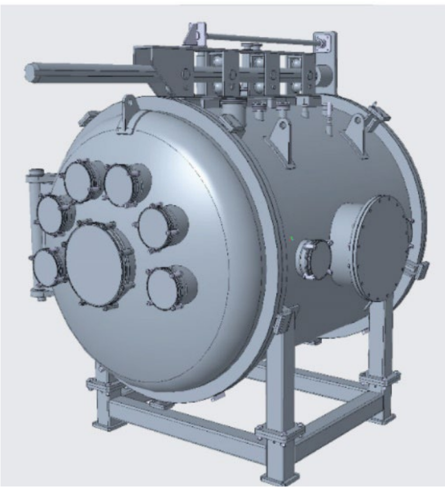

Figure 4. Optimized model.

Data from the physical model were acquired in a local workstation class machine and hosted locally in the format shown in Figure 1. The WebRequest functionality in Unity3D was utilized to retrieve real-time data from the web console of the chamber. This involves establishing a connection with the application program interface (API) that provides the required information. However, data were available as HTML document with essential tags such as <th>, <tr>, and <td> representing 'Table Header', 'Table Row', and 'Table Data' respectively. UnityWebRequest was used to send HTTP requests and receive responses asynchronously. Once the HTML document is acquired, it must be parsed with respect to the HTML tags, as mentioned above. A module was designed to parse the HTML data, which were then stored as an output in JSON format. Several calculations, conversions and transformations were performed on the data to ensure their alignment with the representation and units of the physical twin.

Next, the preprocessed sensor data were augmented onto DT in the AR environment on the mobile and Windows platforms using the Mixed Reality Toolkit (MRTK). It is a framework that provides tools, components and associated C# scripts to ease the development of mixed reality experiences in Unity. Initially, MRTK was integrated into the project by importing its package and configuring it according to the documentation[8]. It offers features that can facilitate data augmentation in AR/VR; for instance, spatial mapping, hand and gesture tracking, and object manipulation. Here, using its spatial mapping capabilities, virtual objects representing the twin were aligned with the real-world environment, ensuring the accuracy of the DT in terms of data-positioning. It provides pre-built components for voice commands as well, making it easier to implement hands-free interactions in AR. Moreover, it offers a wide range of visual effects that can be applied to virtual objects representing DT. This helps in the visual representation of augmented data, such as changing the colour of a zone based on the heatmap and interpolating the values in absence of sensor data to approximate the value at a region where the sensor is not present. In turn, this results in visual indicators that highlight specific data points. To obtain the real-time augmented data, the event system and update mechanisms of MRTK were utilized. It periodically retrieves data from the API using coroutines (), and when the new data are received, it updates the visual and textual properties of the virtual object representing the twin. This ensures that the twin reflects the updated information and maintains synchronization with the physical entity. MRTK also helps in implementation of user interactions and custom visualization of the data. Using MRTK, UI elements can also be easily mapped for information.

The AR mobile app has been designed to provide users with a seamless experience of interacting with DT (Figure 5). This app allows users to view the thermovac chamber in an AR environment, providing an immersive experience that feels like being physically present in the test chamber.

Users can interact with the DT using voice commands and gestures. The AR mobile app also provides real-time data on the temperature, pressure and other critical parameters of the chamber. Users can view these data in graphical form to better understand the performance of the chamber. The cross-platform software application is designed to provide a user-friendly interface for accessing DT. It is compatible with Windows, MacOS and Linux operating systems, making it accessible to a wide range of users. The software application provides users with real-time data on the thermovac chamber, including temperature, pressure and other parameters. Users can interact with DT using the intuitive graphical user interface (GUI) of the application. The software application also provides advanced features such as data processing and visualization, allowing users to analyse the performance of the thermovac chamber in real time. Figure 6 shows the home view of DT in Windows OS. Figure 7 depicts DT of the payload, which is placed inside the DT of the thermovac chamber. All the different views, i.e. home view, left view, right view, top view and payload view, are accessible using integrated voice commands. The Microsoft HoloLens 2 app is designed to provide an AR experience of the thermovac chamber (Figure 8). The app uses the HoloLens 2 headset to provide users with an immersive experience that feels like being physically present in the test chamber. Users can interact with DT using voice commands and gestures. The Microsoft HoloLens 2 app also provides real-time data on the temperature, pressure and other critical parameters of the chamber. Users can view their data in graphical form to better understand the performance of the chamber.

One of the significant advantages of DT is its advanced voice command capabilities. For any model shown above, one can access any sensor data or view by simply giving voice commands such as ‘twin, show me left view’ or ‘twin, show me payload’, making it easy to operate without needing physical input devices. This feature is handy in a testing environment where users may have to wear protective gear, making it challenging to employ traditional input devices.

DT of the thermovac chamber is an innovative application that uses IOT, AR and industry 4.0 capabilities to develop a virtual representation of a physical system. This study demonstrates the potential of DT technology in the testing of payload and other critical systems while providing users with an immersive experience that feels like being physically present in the test chamber. It also provides users with real-time augmentation of data on the performance of the chamber, making it easier to make informed decisions.

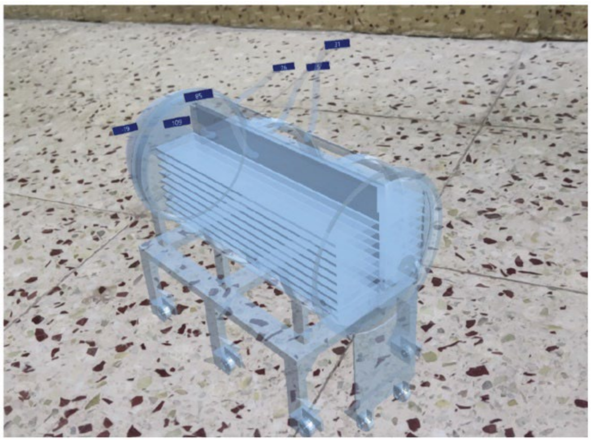

Figure 5. Demo of mobile application.

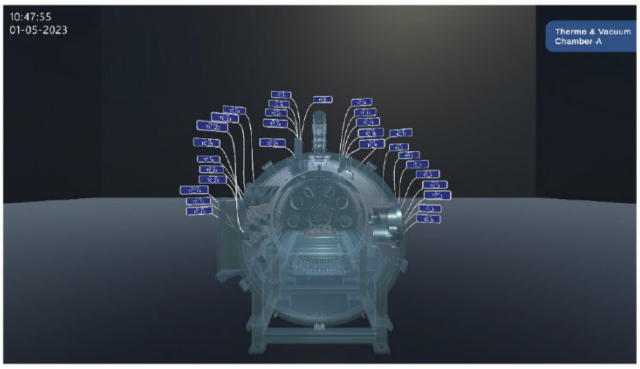

Figure 6. Desktop software application.

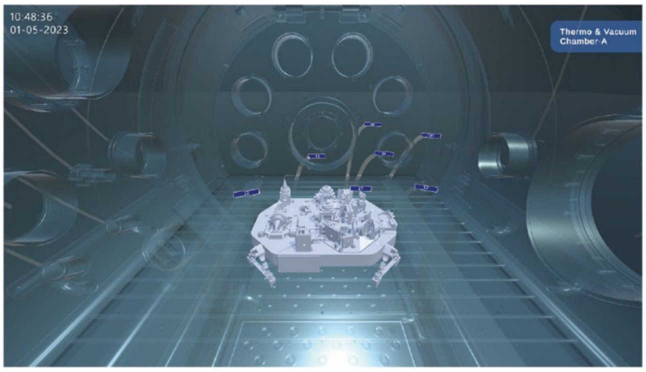

Figure 7. Digital twin of payload.

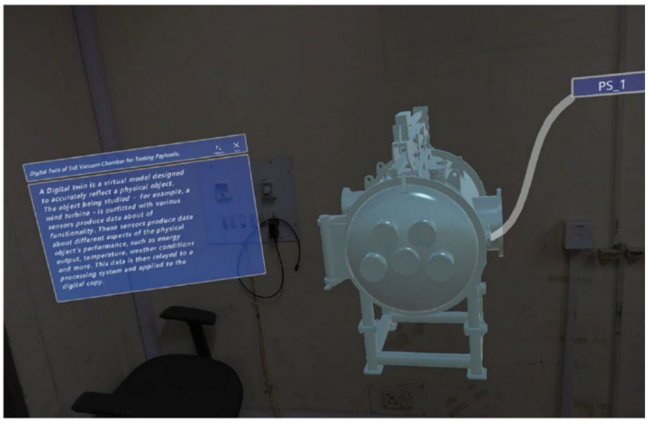

Figure 8. Demo of Microsoft HoloLens application.

In conclusion, DT technology can revolutionize the traditional method of monitoring data on a 2D screen with an overwhelming number of data points, by having a 3D, interactive interface that focuses on selective data points that matter the most at any given time. In future, DT can be scaled up to all the complex engineering systems available at SAC ISRO to make data visualization accessible to all the concerned authorities in real time. Further, DT technology, along with IOT, can be extended to various domains and industries. Its implementation can also be used to analyse and optimize environmental impacts such as energy use, waste management or even water consumption. This will ultimately reduce the carbon footprint and support sustainability goals.

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Effect of date palm sugar on metabolic disorders in experimental diabetic rats

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Diabetes is a metabolic disease with multifactorial causes. There are two types of diabetes in humans: type-1 diabetes, which occurs when the immune system attacks and eliminates insulin secreting cells, and type-2 diabetes, which can be triggered by a variety of factors, the most important being lifestyle, but can also be caused by various genotypes. Date palm sugar (DPS) is nutritive with good potential in treating diabetes due to the presence of polyphenols that have strong antioxidant properties. We assess various parameters in normal rats, sugar-treated rats and diabetes-induced rats, including body weight, food intake, water intake, blood glucose level, insulin level, insulin resistance, lipid profile, atherogenic index, adiponectin, resistin and TNF-α. The study results reveal that DPS contributes to significant improvement in diabetic rats. Thus, DPS is a beneficial substitute compared to other sugars in treating diabetes.

Keywords: Date palm sugar, diabetes, experimental rats, nicotinamide, streptozotocin.

DIABETES is a significant threat to global public health that is rapidly worsening, with the maximum influence on working-age adults in developing nations. It affects at least 177 million individuals globally, and this figure is expected to nearly double by 2030, reaching 366 million[1]. There are two major types of diabetes, with type-2 being more common in adults of varying ages and constantly burgeoning in adolescents and young children. According to the literature, type-2 diabetes is currently increasing among children worldwide, and it seems to have risen significantly in the last 15 years[2]. Moreover, up to 45% of newly diagnosed cases of diabetes among adolescents are type-2. Also, type-2 diabetes accounts for 70% of new cases among native Americans and 80% of new paediatric diabetes cases in Japan[3,4]. According to an epidemiological study, the number of diabetic patients is significantly increasing in the Asia-Pacific region[5]. In addition, type-2 diabetes affects 3% of the population in Europe, and its administrative costs account for 5% of all healthcare spending[6]. When β-cells are unable to compensate for the lack of insulin action, type-2 diabetes is characterized by a progressive decrease of insulin action, also known as insulin resistance[7].

Date palm fruits have been found to have tremendous potential in treating diabetes due to the presence of polyphenols, which have high antioxidant properties. Date palm sugar (DPS) also displays similar properties. Other potential

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