DIGITAL TWIN

Virtual factory replication

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Manufacturing is a matter of fundamental importance to the economic strength of our country. More than any other industry, a globally competitive manufacturing sector translates inventions, research discoveries, and new ideas into better or novel products or processes.

However, the uncertain economic conditions are posing enormous challenges to the manufacturing sector, due to which leadership in manufacturing and, as a consequence, innovation performance are at risk.

On the other hand, advanced manufacturing technology is changing the face of manufacturing, making it leaner and smarter—and raising the prospect of an industrial revival. From the digitisation of equipment, processes, and organisations to materials with custom-designed properties, a host of new designs, production, and business capabilities are opening the way to the new types of manufacturing, referred to, collectively, as advanced manufacturing. It is providing the path forward to revitalise the leadership in manufacturing, and in the near future, will best support economic productivity and ongoing knowledge production and innovation in the country.

Advanced manufacturing is not limited to emerging technologies; rather, it is composed of efficient, productive, highly integrated, tightly controlled processes across a spectrum of globally competitive manufacturers and suppliers. For advanced manufacturing to accelerate and thrive in the country, it will require the active participation of manufacturing communities, educators, workers, and businesses, along with state and central governments.

I am happy that EM has been quite successful so far in its role of educating its readers, providing them with a comprehensive overview of the multi-faceted developments in the manufacturing technology world, in every issue. Hope you will find this issue too a useful and interesting read, as always!

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A&D India – the only industrial magazine in India that offers a three-dimensional perspective on technology, market and management aspects of automation

GET AUTOMATED NOW!
This article introduces the concept of a “Digital Twin” as a virtual representation of what has been produced. Compare a Digital Twin to its engineering design to better understand what was produced versus what was designed, tightening the loop between design and execution.
Virtual products are rich representations of products that are virtually indistinguishable from their physical counterparts. The rise of manufacturing execution systems on the factory floor has resulted in a wealth of data collected and maintained on the production and form of physical products. In addition, this collection has progressed from being manually collected and paper based to being digital and collected by a wide variety of physical non-destructive sensing technologies, including sensors and gauges, coordinate measuring machines, lasers, vision systems, and white light scanning.

In light of these advances, it is timely to explore how the Digital Twin can move from an interesting and potentially useful concept that aids in understanding the relationship between a physical product and its underlying information to a critical component of an enterprise-wide closed-loop product lifecycle. These tasks will both reduce costs and foster innovation in manufacturing of quality products.

Digital Twin concept model

The Digital Twin concept model is shown in Figure 1. It contains three main parts: physical products in real space, virtual products in virtual space, and the connections of data & information that ties the virtual and real products together.

In the decade since this model was introduced, there have been tremendous increases in the amount, richness, and fidelity of information of both the physical & virtual products. On the virtual side, we have improved the amount of information available. We have added numerous behavioural characteristics so that we can not only visualise the product, but we can test it for performance capabilities.

We have the ability to create lightweight versions of the virtual model. This means that we can select the geometry, characteristics, and attributes that we require without carrying around unnecessary details. This dramatically reduces the size of the models and allows for faster processing.

These lightweight models allow today’s simulation products to visualise and simulate complex systems and systems of systems, including their physical behaviours, in real-time and with acceptable compute costs.

These lightweight models also mean that the time and cost of communicating them electronically is substantially less. They now can be shared not only with the organisation but also throughout the supplier network. This enhances collaboration in both reducing time to understand and enhancing both quality and depth of understanding of product information and changes.

As importantly, we can simulate the manufacturing environment that creates the product, including most operations, both automated and manual, that constitute the manufacturing process. These operations include assembly, robotic welding, forming, milling, and other manufacturing floor operations.

On the physical side, we now collect more and more information about the characteristics of the physical product. We can collect all types of physical measurements from automated quality control stations, such as coordinate measuring machines (CMMs). We can collect the data from the machines that perform operations on the physical part to understand exactly what operations, at what speeds and forces, were applied. For example, we can collect the torque readings of every bolt that attaches a fuel pump to an engine in order to ensure that each engine/fuel pump attachment is successfully performed.

Extending model lifespans

The amount and quality of information about the virtual and physical product have progressed rapidly in the last decade. The issue is that the two-way connection between real and
virtual space has been lagging behind. Global manufacturers today either work with the physical product or with the virtual product. We have not developed the connection between the two products so that we can work with both of them simultaneously.

The typical way we do this is to develop a fully annotated 3-D model. We then develop a manufacturing process that will realise this model with a Bill of Process (BOP) and Manufacturing Bill of Materials (MBOM). The more sophisticated and advanced manufacturers then simulate the production process digitally.

However, at that stage, we then simply turn over the BOP and MBOM to manufacturing and leave the virtual models behind. In many cases currently, we even dramatically water down the usefulness of the model by producing 2-D blueprints for the factory floor.

There are manufacturers who are bringing 3-D models to the factory floor by way of terminals stationed in the work cells. However, even here there is not real integration and connection between the virtual model and the physical product taking shape on the factory floor. The terminal model merely serves as a reference, and a human has to perform the connection between the virtual and the physical product on an ad hoc basis.

As shown in Figure 2, linking the physical product with the virtual product could take the form of the 3-D model not only appearing on the screen but also incorporating actual dimensions from the physical product.

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Digital Twin fulfillment requirements

In order to deliver the substantial benefits to be gained from this linkage between virtual and physical products, one solution is to have a Unified Repository (UR) that will link the two products together.

Both virtual development tools and physical collection tools would populate the Unified Repository. This would enable two-way connection between the virtual and physical product.

On the virtual tool side, design and engineering would identify characteristics, such as dimensions, tolerances, torque requirements, hardness measurements, etc, and place a unique tag in the virtual model that would serve as a data placeholder for the actual physical product. Included in the tag would be the as-designed characteristic parameter.

When the design is released for production, these tags would be collected from the virtual product model and used to create the UR. A lightweight model with the tags and their characteristics and geometrical location would also be created.

On the physical side, these tags would be incorporated into the MES in the Bill of Process creation at the process step where they will be captured. As the processes were completed on the factory floor, the MES would output the captured characteristic to the UR.

The final step would be to incorporate this back into the factory simulation. This would turn the factory simulation into a factory replication application. Instead of simulating what should be happening in the factory, the application would be replicating what actually was happening at each step in the factory on each product.

The factory replication application would be in constant
The capability of the Digital Twin lets us directly see the situation and eliminate the inefficient and counterproductive mental steps of decreasing the information and translating it from visual information to symbolic information and back to visually conceptual information.

Digital Twin model use cases

The digital twin capability supports three of the most powerful tools in the human knowledge tool-kit - conceptualisation, comparison, and collaboration. Taken together, these attributes form the foundation for the next generation of problem solving and innovation.

Conceptualisation

Unlike computers, humans do not process information, at least not in the sense of sequential step-by-step processing that computers do. Instead, humans look at a situation and conceptualise the problem and the context of the problem. While they can do this looking at tables of numbers, reports, and other symbolic information, their most powerful and highest bandwidth input device is their visual sight.

What currently happens is that humans take visual information, reduce it to symbols of numbers and letters, and then re-conceptualise it visually. In the process, we lose a great deal of information, and we introduce inefficiencies in time.

The capability of the Digital Twin lets us directly see the situation and eliminate the inefficient and counterproductive mental steps of decreasing the information and translating it from visual information to symbolic information and back to visually conceptual information.

With the Digital Twin to build a common perspective, we can directly see both the physical product information and the virtual product information, simultaneously. Instead of looking at a report of factory performance and re-conceptualising how the product is moving through the individual stations, looking at Digital Twin simulations allows us to see the progress of the physical product as it is moving and actually see information about the characteristics of the physical product.

Instead of looking at an array of numbers on tolerance measurements, we can look at the products lined up in the virtual factory and see the actual trend lines that indicate a problem is developing.

Because we have tagged the products with the designed characteristics, we can select those tags and see the designed parameters and the actual parameters simultaneously.

Comparison

The next tool that humans use in assessing situations is the idea of a comparison. We compare unconsciously and continuously our desired result and our actual result in order to determine a difference. We then decide how to eliminate that difference. Comparison is one of most powerful intellectual tools that we possess.

When we have the virtual product information and the physical product information completely separate, we still can do that comparison. However, it is inefficient, as we have to look at the physical product information, find the corresponding virtual product information, and then work out the differences.

With the digital twin model, we can view the ideal characteristic, the tolerance corridor around that ideal measurement, and our actual trend line to determine for a range of products whether we are where we want to be. Tolerance corridors are the positive and negative deviations we can allow before we deem a result unacceptable.

Depending on how we implement this capability, we can see the differences in terms of colour, with colorus progressing from green - there is no difference, to yellow - we are in our...
tolerance corridor, to red - we are beyond the tolerance corridor. We can then make instantaneous decisions about the differences.

We can do this with measurements, tensile strength, torque readings, and pretty much any characteristic where we can define the desired characteristic in some sort of a measurement, either quantitative or even qualitative. We can enable this capability for a single product or a range of products. Using the example from above as to trend lines, we could overlay the ideal trend on the actual trend lines.

Having this capability, also allows us to do the comparisons and adjust future operations. For example, if we were seeing tolerances on the plus side of our ideal measurement, we could change parameters in the operations of cells further down the line to adjust them to err on the side of negative tolerances. Instead of degenerating into tolerance stacking, we could ensure tolerances were distributed around a mean.

**Collaboration**

The most powerful things that humans do is collaborate with each other in order to bring more intelligence, more variability of perspectives, and better problem solving and innovation to situations. With the Digital Twin capability, we can look at any physical product at any stage on the factory floor and overlay the virtual product on top of it. This capability of virtual products can be extended across multiple factories. This means that individuals across the world can not only look at the performance of their own factory, but they can also be monitoring how they are doing against factories in other parts of the world. A problem that arises in one factory can be identified and controlled not only in that factory, but the solution can be immediately transferred and implemented also in other factories across the globe.

In the past, factory managers had their office overlooking the factory so that they could get a feel for what was happening on the factory floor. With the Digital Twin, not only the factory manager, but everyone associated with factory production could have that same virtual window to not only a single factory, but to all the factories across the globe.

**Conclusion**

Over the last decade, there have been dramatic advances in the capabilities and technologies of both the data collection of the physical product and the creation and representation of the virtual product, the Digital Twin. The issue is that while the data information of each of these areas has increased dramatically, the connection between the two data sources has lagged behind.

This article has proposed that the connection between the data about the physical product and the information contained on the virtual product be synchronised. This will open up an entire new set of use cases.

Specifically by merging the virtual product information as to how the product is to be manufactured and the information about how the product is actually being manufactured, we can have an instantaneous and simultaneous perspective on how the manufactured product is meeting its design specification goals.

By using this information, we can change digital factory simulation, which attempts to predict how the product is to be manufactured, into a digital factory replication, which shows how the product is actually being manufactured. We can then compare it against the design specifications.

Focusing on the connection between the physical product and the virtual product enables us to conceptualise, compare, and collaborate. We can conceptualise visually the actual manufacturing processes. We can compare the formation of the physical product to the virtual product in order to ensure that what we are producing is what we wanted to produce. Finally, we can collaborate with others in our organisation and even throughout the supply chain to have up-to-the-minute knowledge of the products that we are producing.

Focusing on this connection between the physical product and the virtual product will improve productivity, uniformity of production, and ensure the highest quality products. □

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