Journal of
Data Acquisition and Processing

ISSN: 1004-9037
https://sjcjycl.cn/
DOI: 10.5281/zenodo.777599

MATHEMATICAL MODELLING AND IMPLEMENTATION OF A TEMPERATURE SENSOR FOR DIGITAL TWIN APPLICATIONS

Raghuveer Chandaluri
VFSTR, Vadlamudi

Dr.Usha Rani.Nelakuditi
Professor, ECE, VFSTR,Vadlamud

Abstract:
Now we are in the 4th rig rebellionwitnessing digital physical interfacewith the digitalization of all the activities, processes and products of day to day life experiencing as digital footprints. Rapid advances in Sensor technology, AI, VR and Big Data results in emergence of a new technology known as Digital win(DT) especially for manufacturing sector.DT isa digital replica of live as well as nonlive entities that enable data transmission between the physical and virtual world, to monitor, understand, and optimize the functions of all physical entities and provide continuous feedback to improve the quality of life and well-being. However, the research of DT for Product Life Cycle (PLS) management is still at theinfant stage. Application framework and design cycle are not very clear. The lack of referable application cases is also a problem. Hence this paper deals with the systematic modeling and hardware implementation of a embedded temp monitoring system was propose in line with the concept of Digital Twin.
Index Terms— Digital Twin, data fusion, modeling, systemgen, hardware co-simulation.

Introduction

With the wingleading in tacit high tech and reports replevin, Digital Twin (DT) has becomes one of the key research in the directions of manufacturing and academia.DT wasoriginally emerged to improve manufacturing processes.At present, emergence of high performance and low cost computing hardware driving the people around the world to adopt digital technologies for their applications. Digital Twinning is nothing but mapping a physical asset, object, process or system and creating a virtual evolving replica.It means digital copy of an asset. Digital twin is used to detectpresent behavior and also to predict future behavior of the aid.

By placing sensors in physical systems realtime data can be collected. The data then updates the state of the twin and enabling it as a remotely accessible proxy. The collected data is used to create twin can predict the maintenance and failure conditions of the physical equipment. Digital twins are not only part of design phase and even they are part of life cycle of a physical asset hence they can assess the behavior of a physical copy to various stresses and other conditions. For understanding the better and to predict, optimize the asset this DT's are very helpful. DT integrates the digital information of an asset with the operational data stream of equipmentwhen it is in use. DT and Big Data are reinforcing technologies can integrate data throughout the lifecycle of physical asset and generates large volumes of data which can be processed by analytics .

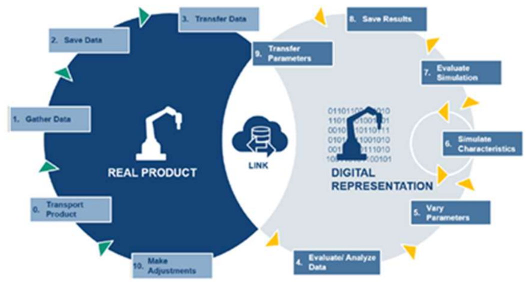


Fig.1:Example of Digital Dual

DIGITAL TWIN

Physically,data collection and maintenance of digital twins are implemented usingfour stages as shown in Fig.2namely data collection, data pipelines, data integrity and data egress. In this we have two types of data.They are model and time series data. For buliding digital copy of an equpment or process and relationship between physical and virtual is determined by the model data.The observations of the state of some physical thing at a given time is called time series data. It can be either continuous or discrete.This both data are very helpful to built the digital system. In data pipelines step, Model is developed by the merging of data source and collected data. Later that data transformed into the graph.Data Integrity means to detect actual data from the data pipe lines and issue with real asset and to detect the connection of real and virtual asset. Data Egress deals with the outputting data in batch and streaming modes for later use. Batch mode will be used where decision support is needed where as streaming is used in low latency applications.

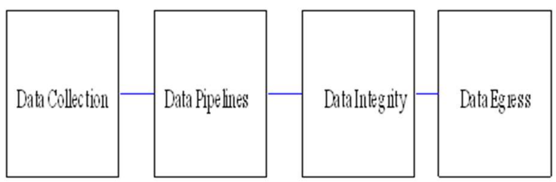


Fig2. Four steps in Digital Twin

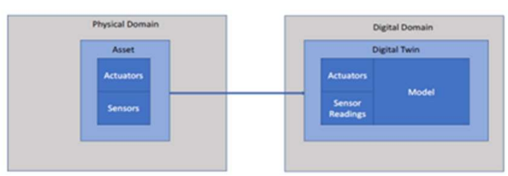
The logical architecture of DTs comprises of four components.

(1) Data modeling

(2) Simulation,

(3)Hardware Implementation

(4)Verification



Logical Architecture

Here the logical architecture varies the according to the asset and it perform one or more operations.

Data collection of asset is done by using sensor and it's atmosphere and it's represent the aid state in the domain of digital and it is saved for further use.

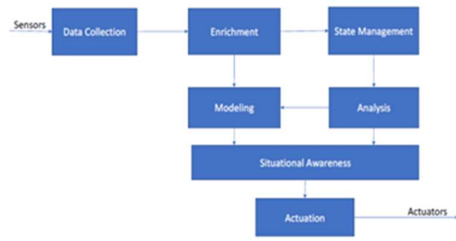


Fig.3:Process of collecting data

1.Literature Survey

The word Digital Twin first introduce by the Grieves in his “ Product Lifecycle Management (PLM)” [6].

He was introduced but the concept, details and its explanationwas very attenuate at that time period. A action done for the form of DT. It includes mainly three steps one is physical product, another one is virtual product, and the final one is their connections. In 2010 this DT's have a very vast growth in that years.The concept of DTs was revisited.For the corresponding twin based on the DT as a various-physics, various-scale, probabilistic, ultra-fidelity simulation that reflects, in a timely manner, Now- a- days the famous research topic is DT. According to Gabor et al. [8], to apprehend in a distinct scales weather it may be a time or space scale the smashing simulation is DT.It was developed by taking the data from particular asset which means already alive assetand super well-lighted. According to Maurer [9], the manufacture process and yield pursuance is designed by a is a virtual copyof an digital twin. Digital dualgoverning to some special notions. Due to this DTs becomes progressively concrete.

Formation, Incubation, and Growth are the three theoretical stages development of DTs. The first appearance of DT should date to the presentation made by Grieves in 2003,Few articles were published in this period from 2003 to 2011, so it is classified as the formation stage.TheSatellite Communication, Artificial Intelligence, Cloud computing, Business Intelligence,Drones, Robotics and simulation technologies contributed to the rise of DTs. In 2011,was rapidly developed.

The first journal article was published In the year of 2012.The definition of DTs was formalized and envisioned by the NASA, its prospects in the aerospace industry [7]. to the DT research was more and more efforts were devoted since.Therefore, this period is regarded as the incubation stage. The first white paper was publishedin the year of 2014, which means reflected the growth of DTs from one conceptual idea to numerous practical applications [6]. The conclusion that digital dual would be useful to several diverse industries beyond the aerospace industry further promoted its development.According to the Gartner Digital dual is as one of the preeminenttechnological trends in the later decade.

3. Proposed Method

In this work in the direction of building DT,an embedded system for the maintenance of room temperature was modeled, simulated, and verified. The block diagram of embedded data acquisition system is shown in Fig1.

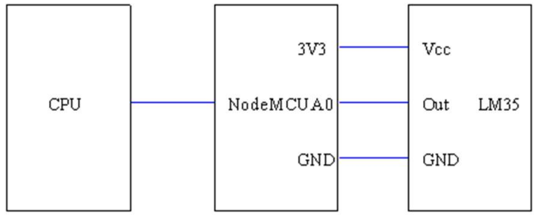


Fig2: Basic Block Diagram of Data Acquisition

Data Acquisition:

NodeMCU microcontroller and LM35 temperature sensor are used for acquiring temperature and obtaineddata wasstored in thinkspeak cloud. Fig2 shows the embedded system with temperature sensor nodemcu and their interconnections.

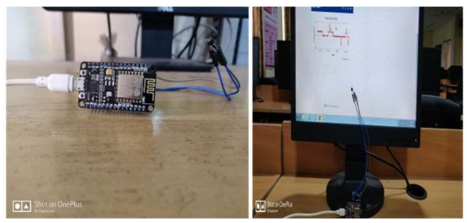


Fig3:Embedded System used for maintenance of Room Temperature

The program was developedfor automatic storing of data by using android IDE and IoT. Visualizations and analytics are performed using cloud shown in Fig. Table represents the sample data for 15 days.

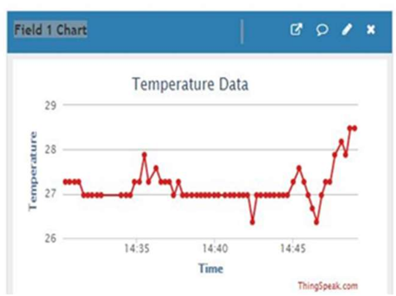


Fig4: Temperature data for one day stored in think speak cloud

Table:Time Series Temperature Data for fifteen days

	Temperature(°C)									
D / T	1	2	3	4	5	6	7	8	9	10
9	31	29	28	27	26	27	27	26	31	31
10	31	29	29	27	26	28	26	26	26	30
11	31	29	29	28	26	26	30	29	30	27
12	32	30	30	28	27	28	26	26	29	30

13	31	30	31	29	27	29	28	27	27	31
14	31	30	31	29	28	28	28	28	30	30
15	30	31	29	29	27	30	29	29	31	29
16	31	30	31	28	27	30	29	28	29	27
17	31	29	29	27	27	30	27	27	27	29
Avg	31	29	29	27	26	28	27	26	29	29

Mathematical Model Generation:

Data is represented as scatter plot as shown in Fig. to observe the variations oftwo-dimensional data

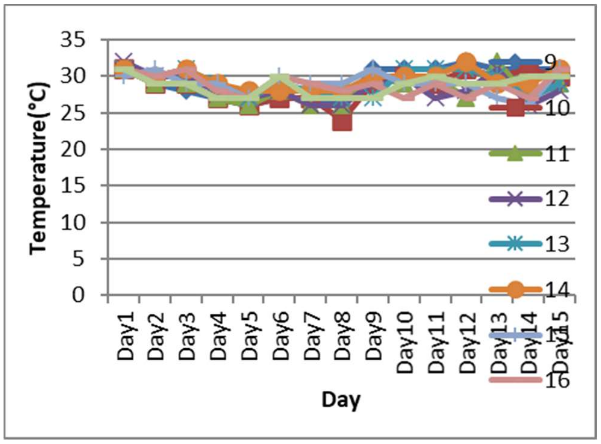
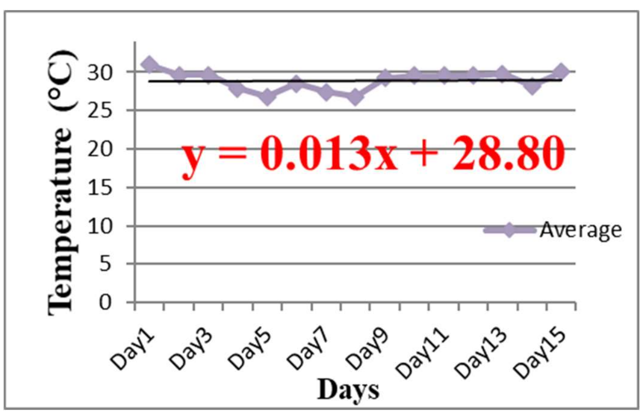


Fig5:Hour wise Temperature Variations on various Days

Mathematical model is derived from average values of data samples computed on every day data as shown in figure using regression analysis. For judgement of The regression analysis is a statistical method used to estimate the relationships between dependent and independent variables.



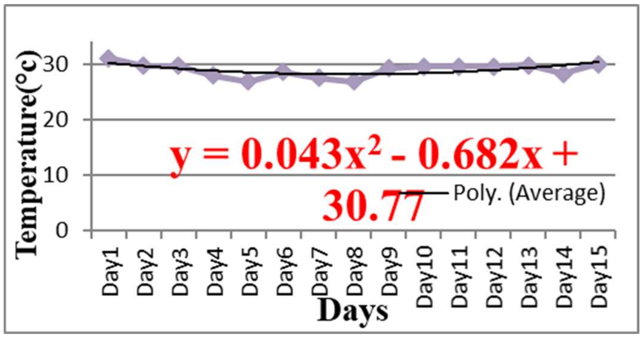


Fig6:Mathematical model of an embedded temperature monitoring system

In this case both linear and non-linear modeling are observed and their mathematical modeling are represented as$Y=0.013X+28.80$and $Y=0.043X2-0.682X+30.77$ respectively.

4.Implementation

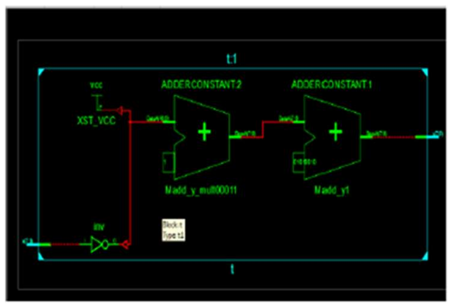


Fig.7 RTL Schematic of Linear System

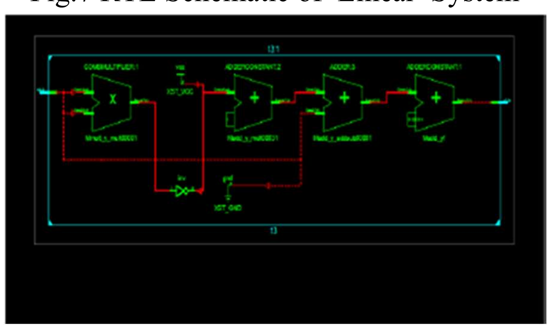


Fig.8RTL Schematic of Non-Linear System

The linear and nonlinear modelings are coded in verilog and implemented in FPGA. The schematic and simulation results are shown in fig

Fig9: Simulation results for linear equation

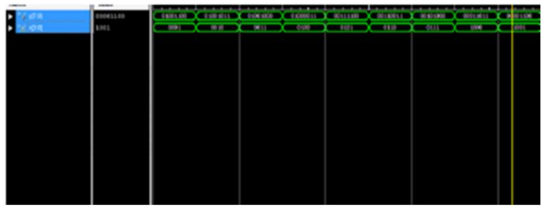


Fig10: Simulationresults for non-linear equation

HDL implementation is supporting only fixed point data. Real time data consists of floating point representations. Hence to obtain a solution in real time this model was implemented in FPGA hardware using systemgen flow as shown in Fig.11

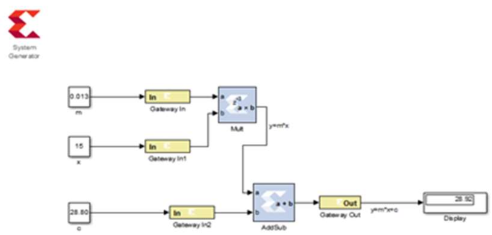


Fig.11:Linear model of temperature system

In above figure shows the virtual model of a temperature sensor by dumping this system into a FPGA board. Subsystem was created for developing a bit stream file. Creating of a subsystem for this model is shown in figure12.

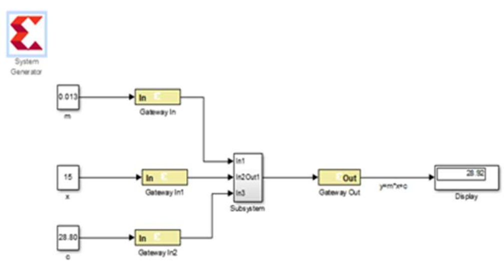


Fig.12:Subsystem for bit stream file

Architectures of the models was developed using simulink and Xilinx blocks are shown in Fig.11

While handling bigger systems they can be converted as subsystems as shown in Fig.12
The virtual model of aembedded temperature monitoring systemported into a FPGA board. Subsystem was created for developing a bit stream file. After implementation using JTAG cable the co-simulation block is shown in fig

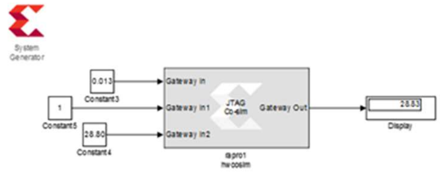


Fig13: Developing Bitstream to Dump in FPGA Board

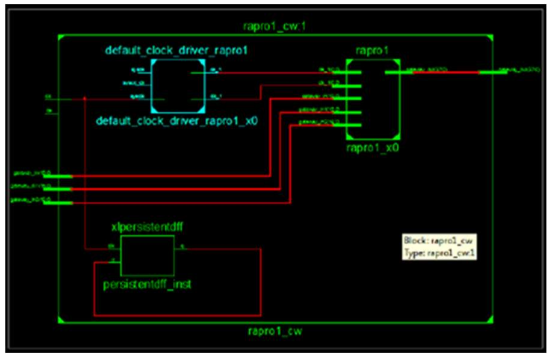


Fig.14:RTL Schematic Using SystenGen

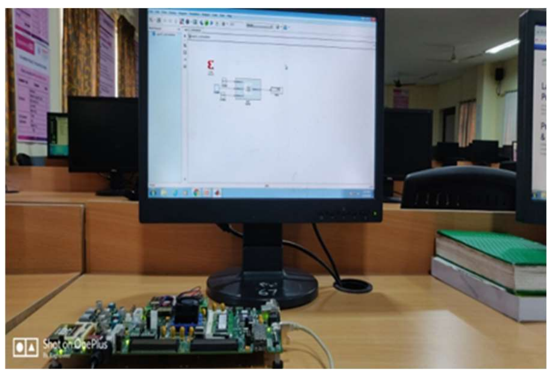


Fig15: Finally virtual model dumped to FPGA kit

Virtual model of temperature sensor was implemented in vertex-6 FPGA kit. Finally the virtual model system is shown in a Fig.15

5. Conclusion

Now days due to digitalization, lot of data is generating from the devices connected through the internet. To perform predictions and analysis on this data parameters and models are to be predicted. Systems performance can be improved and many predictions can be done in better way by twinning the real physical model i.e. to model and analyze the asset. In this direction this work carried out on one of the important component of modeling and implementation of the virtual model. In this case as an example sensor is modeled and implemented in FPGA. This model is modeled as a combinational one. Hence it is responding only for the present inputs. Hence accuracy is less.

6.Future Scope

- Model has to be converted as a sequential so that previous state also involved in predicting outputs.
- Each components physical behavior also to be modeled and need to be incorporated.

Integration of both the data models are is performed

References

[1] Kusiak A., “Smart manufacturing must embrace big data,” Nature, 2017, Vol.544, No.7648, pp. 23-25.

[2] Q. L Qi., and F. Tao, “Digital Twin and Big Data Towards Smart Manufacturing and Industry 4.0: 360 Degree Comparison,” IEEE Access, vol.6, pp.3585-3593, Jan. 2018, doi:10.1109/ACCESS.2018.2793265.

[3] F. Tao, M. Zhang, J. F. Cheng, and Q. L. Qi, "Digital Twin Workshop: A New Paradigm for Future Workshop,” Comput. Integr. Manuf. Syst., vol.23, no.1, pp.1-9, Jan. 2017, doi: 10.13196/j.cims.2017.01.01

[4] F. Tao, W. R. Liu, J. H. Liu, X. J. Liu, Q. Liu, T. Qu, T. L. Hu, Z. N. Zhang, F. Xiang, etc., “Digital Twin and its Potential Application Exploration,” Comput. Integr. Manuf. Syst., vol.23, no.1, pp.1-18, Jan. 2018, doi: 10.13196/j.cims.2018.01.001

[5] S. Weyer, T. Meyer, M. Ohmer, D. Gorecky, and D. Zühlke, “Future Modeling and Simulation of CPS-based Factories: An Example from the Automotive Industry,” IFAC Papersonline, vol.49, no.31, pp. 97-102, 2016. doi: 10.1016/j.ifacol.2016.12.168.

[6] M. Grieves, “Digital Twin: Manufacturing Excellence Through Virtual Factory Replication,” Whitepaper,2014.http://www.apriso.com/library/Whitepaper_Dr_Grieves_DigitalTwin_ManufacturingExcellence.php

[7] E. Glaessgen, and D. Stargel. The Digital Twin Paradigm for Future NASA and U.S. Air Force Vehicles. 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference. [Online]. Available: https://arc.aiaa.org/doi/pdf/10.2514/6.2012-1818.

[8] T. Gabor, L. Belzner, M. Kiermeier, M. T. Beck and A. Neitz, "A Simulation-Based Architecture for Smart Cyber-Physical Systems," 2016 IEEE International Conference on Autonomic Computing (ICAC), Wurzburg, 2016, pp. 374-379. doi: 10.1109/ICAC.2016.29.

[9] T.Maurer, “What is A DigitalTwin?” ,2017. https://community.plm.automation.siemens.com/t5/Digital-Twin-Knowledge-Base/What-is-a-digital-twin/ta-p/432960.

[10] E.J. Tuegel, “The Airframe Digital Twin Some Challenges to Realization,” 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, Hawaii, 2012, pp.1812.

[11] M. Schluse and J. Rossmann, "From simulation to experimentable digital twins: Simulation-based development and operation of complex technical systems," 2016 IEEE International Symposium on Systems Engineering (ISSE), Edinburgh, 2016, pp. 1-6. doi: 10.1109/SysEng.2016.7753162.

[12] F. Tao and M. Zhang, "Digital Twin Shop-Floor: A New Shop-Floor Paradigm Towards Smart Manufacturing," in IEEE Access, vol. 5, pp. 20418-20427, 2017. doi: 10.1109/ACCESS.2017.2756069.

[13] E.J. Tuegel, A. R. Ingraffea, T. G. Eason, and S. M. Spottswood, “Reengineering Aircraft Structural Life Prediction Using A Digital Twin,” Int. J. Aerospace Eng., vol.2011, pp.1687-5966. Aug.2011, doi:10.1155/2011/154798s are investing huge amount for creating their own digital twin.
[14] G. Schroeder et al., "Visualising the digital twin using web services and augmented reality," 2016 IEEE 14th International Conference on Industrial Informatics (INDIN), Poitiers, 2016, pp. 522-527. doi: 10.1109/INDIN.2016.7819217
[15] S. Haag, and R. Anderl, “Digital Twin-Proof of Concept,” Manuf. Lett., 2018, doi: 10.1016/j.mfglet.2018.02.006.
[16] F. Tao, Y. Cheng, J. F. Cheng, M. Zhang, W. J. Xu, Q. L. Qi., and Cheng Ying, “Theories and Technologies for Cyber-physical Fusion in Digital Twin Shop-floor” Comput. Integr. Manuf. Syst., vol.23, no.8, pp.1603-1611, Aug.2017. doi.10.13196/j.cims.2017.08.001. 2017.
[17] C.B. Zhuang, J. H. Liu, H. Xiong, X. Y. Ding, S. L. Liu, and G. Weng, “Connotation, Architecture and Trends of Product Digital Twin.” Comput. Integr. Manuf. Syst, vol.23, no.4, pp. 53-768, Apr.2017. doi: 10.13196/j.cims.2017.04.010.
[18] F. Tao, Sui F, Liu A, et al. “Digital twin-driven product design framework,” Int. J. Prod. Res., Feb.2018. doi: 10.1080/00207543.2018.1443229.
[19] T.H.J. Uhlemann, C. Lehamnn, and R. Steinhilper, “The Digital Twin: Realizing the Cyber-Physical Production System for Industry 4.0,” Procedia CIRP, vol.61, pp.335-340, 2017. doi: 10.1016/j.procir.2016.11.152.
[20] M. Schluse, M. Priggemeyer, L. Atorf and J. Rossmann, "Experimentable Digital Twins—Streamlining Simulation-Based Systems Engineering for Industry 4.0," IEEE Transactions on Industrial Informatics, vol. 14, no. 4, pp. 1722-1731, April 2018. doi: 10.1109/TII.2018.2804917
[21] G.L. Knapp, T. Mukherjee, J. S. Zuback, H. L. Wei, T. A. Palmer, A. De, and T. DebRoy, “Building Blocks for A Digital Twin of Additive Manufacturing,” Acta Mater., vol.135, pp.390-399, Aug.2017, doi: 10.1016/j.actamat.2017.06.039
[22] F. Tao, J. F. Cheng, Q. L. Qi, M. Zhang, H. Zhang, and F. Y. Sui, “Digital Twin-driven Product Design, Manufacturing and Service with Big Data,” Int. J. Adv. Manuf. Technol., vol.2018, no.94, pp.3563. Mar.2017. doi: 10.1007/s00170-017-0233-1
[23] K. M. Alam and A. El Saddik, "C2PS: A Digital Twin Architecture Reference Model for the Cloud-Based Cyber-Physical Systems," in IEEE Access, vol. 5, pp. 2050-2062, 2017. doi: 10.1109/ACCESS.2017.2657006
[24] Y. Liu, “Lockheed Martin Space Systems Company Makes Use of Digital Twins Speed F-35 Fighter Production.” Available from: http://www.sohu.com/a/212980157_613206
[25] B. Schleich, N. Anwer, L. Mathieu, and S. Wartzack, “Shaping the Digital Twin for Design and Production Engineering,” CIRP Ann. Manuf. Tech, vol.66, no.1, pp. 141-144, 2017. doi:10.1016/j.cirp.2017.04.040
[26] Available from: https://www.ibm.com/internet-of-things/spotlight/digital-twin