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ЦИФРОВЫЕ ДВОЙНИКИ В ПРОМЫШЛЕННОСТИ: ГЕНЕЗИС, СОСТАВ, ТЕРМИНОЛОГИЯ, ТЕХНОЛОГИИ, ПЛАТФОРМЫ, ПЕРСПЕКТИВЫ.
ЧАСТЬ 1. ВОЗНИКНОВЕНИЕ И СТАНОВЛЕНИЕ ЦИФРОВЫХ ДВОЙНИКОВ. КАК СУЩЕСТВУЮЩИЕ ОПРЕДЕЛЕНИЯ ОТРАЖАЮТ СОДЕРЖАНИЕ И ФУНКЦИИ ЦИФРОВЫХ ДВОЙНИКОВ?

Анализируется история возникновения и развития цифровых двойников. Для определения их назначения, состава и границ используется аналогия с литературными двойниками. Показывается правомерность использования метафоры двойника в применении к широкому кругу задач автоматизации управления, инжиниринга и обучения в промышленности. В следующих частях работы будут рассмотрены ключевые технологии, прикладные платформы и практические внедрения цифровых двойников; будут также обсуждены перспективы развития и социально-экономические последствия широкого распространения цифровых двойников.

Ключевые слова: цифровые двойники (ЦД), киберфизические системы (КФС), метафора двойничества, Internet of Things (IoT), большие данные, фундаментальное моделирование, машинное обучение, гибридное моделирование.

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Список литературы

1. *Pettey, C.* Prepare for the impact of digital twins // Gratner, 18.09.2017. URL: https://www.gartner.com
2. *Cunbo Z. et al. C*onnotation, architecture and trends of product digital twin // Computer Integrated Manufacturing Systems. 2017. 23(04):753-768.
3. *Rasheed A. et al.* Digital Twin: Values, Challenges and Enablers from a Modeling Perspective // IEEE Access. 2016. No.4:1-33. URL:
4. *Grieves M.* Digital twin: Manufacturing excellence through virtual factory replication. White paper, 2014. URL: http:// www.apriso.com.
5. *Barricelli B.R. et al.* A Survey on Digital Twin: Definitions, Characteristics, Applications, and Design Implications // IEEE Access. 2019. 7:167653-167671.
6. *Степин В.С.* Классика, неклассика, постнеклассика: критерии различения / В кн.: «Постнеклассика: философия, наука, культура» - СПб.: Издательский дом «Міръ». 2009. С.249 -295.
7. *Rosen R. et al.* About the importance of autonomy and digital twins for the future of manufacturing // IFAC-Papers On Line, 2015. 48(3):567-572.
8. *Grieves M.* Virtually Perfect: Driving Innovative and Lean Products Through Product Lifecycle Management. Cocoa Beach - FL, USA: Space Coast Press. 2011.
9. *Lee J. et al.* A Cyber-Physical Systems Architecture for Industry 4.0-based Manufacturing Systems // Manufacturing Letters, 2015. 3:18-23.
10. *Grieves M., Vickers J.* Digital twin: mitigating unpredictable, undesirable emergent behavior in complex systems//Transdisciplinary perspectives on complex systems, 2017. Pp. 85-113.
11. *Jones D. et al.* Characterising the Digital Twin: A systematic literature review // CIRP Journal of Manufacturing Science and Technology, 9.03.2020.
12. *Tuegel E.J. et al.* Reengineering aircraft structural life prediction using a digital twin // International Journal of Aerospace Engineering, 2011. Vol. 2011, Article ID 154798.

13. *Shafto M. et al.* Modeling, Simulation, Information Technology and Processing Roadmap. Washington, DC, USA: NASA; 2012.
14. *Warwick G.* GE advances analytical maintenance with digital twins // Aviation Week & Space Technology. 2015.
15. *Fei T. et al.* Digital twin workshop: A new paradigm for future workshop. Computer Integrated Manufacturing Systems. 2017. 23(1):1-9.
16. *McCannel D.C.* What is a digital twin? (Plus 3 industries which already benefit), 21.03.2018.
17. IIoT Platform Creates a Digital Twin of F-35 Manufacturing Facilities, 06.12.2017.
18. *Canedo A.* Industrial IoT lifecycle via digital twins // Proc. 11th IEEE/ACM/IFIP International Conference on Hardware/Software Codesign and System Synthesis, 2016. Article No. 29.
19. *Negri E. et al.* A review of the roles of digital twin in cps-based production systems // Procedia Manufacturing, 2017. 11:939-948. URL:
20. *Abramovici M. et al.* Reconfiguration of smart products during their use phase based on virtual product twins // CIRP Annals - Manufacturing Technology, 2017. Pp. 69- 78. doi: 10.1016/j.cirp.2017.04.042.
21. *Bruynseels K. et al.* Digital twins in health care: Ethical implications of an emerging engineering paradigm//Frontiers Genetics, 13.02.2018. URL: https://doi.org/10.3389/fgene.2018.00031.
22. *Ríos J. et al.* Framework to support the aircraft digital counterpart concept with an industrial design view // International Journal of Agile Systems and Management (IJASM), 2016. 9(03):212-231.
23. *Gabor T. et al.* A simulation-based architecture for smart cyber-physical systems // IEEE International Conference on Autonomic Computing (ICAC 2016). Pp.374-379.
24. *Winter S., Tomko M.* Beyond Digital Twins – A Commentary // Environment and Planning B: Urban Analytics and City Science, 2019. 46(02):395-399.
25. *Дозорцев В.М., Ицкович Э.Л., Кнеллер Д.В.* Усовершенствованное управление технологическими процессами (APC): 10 лет в России // Автоматизация в промышленности. 2013. № 1. С. 12-19.
26. *Heng A. et al.* Rotating machinery prognostics: state of the art, challenges and opportunities // Mechanical Systems and Signal Processing (MSSP), 2009. 23:724-739.
27. *Batty M. D*igital twins. Environment and Planning B: Urban Analytics and City Science, 2018. 45(5):817-820. doi: 10/1177/2399808318796416.
28. *Dozortsev V.M., Mironova A.S.* Operators' Structural Knowledge Evaluation as a Feedback in Computer-Based Training in Context of the Novel «Anna Kareinina» // 17th International Industrial Simulation Conference (ISC'2019), 2019. Pp. 26-31. Lisbon, Portugal. June 5-7, 2019.
29. *29. Skytt V. et al.* Locally refined spline surfaces for representation of terrain data // Computers & Graphics, 2015. 49:58-68.
30. *30. Дозорцев В.М. и др.* Компьютерный тренинг операторов: непреходящая актуальность, новые возможности, человеческий фактор // Автоматизация в промышленности, 2015. № 7. С. 8-20.
31. *31. M. Bacic.* On hardware-in-the-loop simulation // Proc. 44th IEEE Conference on Decision and Control, 2005. Pp. 3194-3198. URL: https://academic.microsoft.com/ paper/1495653194.
32. *32. Lin B. et al.* A systematic approach for soft sensor development. A systematic approach for soft sensor development // Computers & Chemical Engineering, 2007. 31 (5–6):419. doi: 10.1016/j.compchemeng.2006.05.030.
33. *33. Keiper W. et al.* Reduced-order Modeling (ROM) for Simulation and Optimization: Powerful Algorithms as Key Enablers for Scientific Computing. Springer, Berlin, 2018.
34. *34. Dozortsev V.M., Kreidlin E.Yu.* State-of-the-art automated process simulation systems // Automation and Remote Control, 2010, Vol. 71, No. 9, Pp. 1955-1963.
35. *35. LeCun Y. et al.* Deep learning // Nature 521, 436-444 (28 May 2015).
36. *36. von Rüden L. et al.* Informed machine learning - towards a taxonomy of explicit integration of knowledge into machine learning // arXiv preprint arXiv:1903.12394, 2019.
37. *37. Raissi M. et al.* Physics-informed neural networks: A deep learning framework for solving forward and inverse problems involving nonlinear partial differential equations // Journal of Computational Physics, 2019. 378:686-707.
38. *38. Wortmann F., Flüchter K.* Internet of things // Business & Information Systems Engineering, 2015. 57(3):221-224.
39. *39. Dasgupta D.* Advances in artificial immune systems // IEEE computational intelligence magazine, 2006. 1(4):40-49.
40. *40. Kassner, L. et al.* The Social Factory: Connecting People, Machines and Data in Manufacturing for Context- Aware Exception Escalation // Proc. of the 50th Hawaii International Conference on System Sciences, Jan. 2017. Pp. 173-1682.
41. *41. Sofka C.* Dying, Death, and Grief in an Online Universe: For Counselors and Educators. 2012. Springer, N.-Y. 271 p.
42. *42. Deuter A.A., Pethig F.* The Digital Twin Theory - A New View on a Buzzword // PLM Portal, München, 18.03.2019. https://www.plmportal.org

Dozortsev V.M. Digital twins in industry: genesis, structure, terminology, technologies, platforms, outlook. Part 1 – Origin and evolution of digital twins and how the present-day definitions reflect their matter and functionality

The paper analyzes the origins and evolution of digital twins. Their destination, composition, and scope are described with the analogy of doubles in literature. The relevance of using the metaphor of twinship with reference to a wide range of control automation, engineering, and training tasks in various industries is shown. Key digital twin technologies, platforms, and application cases will be discussed in the following parts.

Keywords: digital twins, cyber physical systems, digital thread, twinship metaphor, Internet of Things (IoT), big data, first-principles modeling, machine learning, hybrid modeling.