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Allen, L., Atkinson, J., Jayasundara, D. et al. (2021) Data visualization for Industry 4.0 : a stepping-stone toward a digital future, bridging the gap between academia and industry. Patterns, 2 (5). 100266. ISSN: 2666-3899

https://doi.org/10.1016/j.patter.2021.100266

Patterns

Opinion

Data visualization for Industry 4.0: A stepping-stone toward a digital future, bridging the gap between academia and industry

Louis Allen,[1] Jack Atkinson,[1] Dinusha Jayasundara,[1] Joan Cordiner,[1] and Peyman Z. Moghadam[1,*]
[1]Department of Chemical and Biological Engineering, The University of Sheffield, Sheffield S1 3JD, UK
*Correspondence: p.moghadam@sheffield.ac.uk
https://doi.org/10.1016/j.patter.2021.100266

Here, we analyze the potential of advanced data-visualization dashboards as an enabling technology for Industry 4.0. High-dimensional, real-time visualization allows the graphical expression of complex process variables at a fraction of the cost of full-scale digitalization. It is therefore a more achievable goal for smaller firms looking to transition to digital manufacturing and poses a realistic stepping-stone approach for Industry 4.0.

Industry is undergoing a fourth industrial revolution, coined Industry 4.0 (I4.0), seeing the implementation of cutting-edge technologies such as cloud manufacturing (CM), Internet of Things (IoT), cyber-physical systems (CPS), and big data analytics (BDA). There is a significant pressure on industry to adopt and integrate these technologies to push manufacturing toward "smart factories" that can make intelligent decisions and control their own manufacturing processes. These changes have led to data-oriented operations that require thoughtful implementation of visualization techniques and software to realize the full value of data; classical visualization strategies do not work well to preserve the benefits of data visualization within the changing status quo driven by I4.0.

The challenges in implementing I4.0 are multifaceted and include obvious technical and economic challenges as well as cultural and social issues. It is critical that the benefits of effective data visualization such as improved decision making, improved *ad hoc* analysis, and improved collaboration[1] can be preserved in industry's transformation. Providing insight into data is a key purpose of visualization; it is fundamental for summarizing large datasets quickly and intuitively and therefore takes an important place in manufacturing, where decisions are becoming more data driven and the amount of data generated is accelerating exponentially. Moreover, visual analysis can be used at all levels of an organization, from technical staff to management, and so when used effectively, the knowledge communicated through them can have far-reaching business impact.

"We are currently preparing students for jobs that don't yet exist, using technologies that haven't been invented, in order to solve problems, we don't even know are problems yet." This quote by former Education Secretary Richard Riley was featured on the foreword of a 2019 report by the Universities of the Future[2] that attempts to identify the skills required for adapting to I4.0. This sentiment is felt beyond education, and adapting the incoming and especially the existing workforce to be digitally literate and relevant for I4.0 remains a challenge. Something that is exacerbating this challenge is the aging of the workforce in manufacturing, especially in OECD (Organization for Economic Co-operation and Development) countries.[3] Retraining this demographic in data analytics and data science is a challenge, but their existing skills and knowledge of current manufacturing processes are invaluable. These skills can be utilized by providing easy-to-use visualization software that lowers the barrier for analyzing and understanding large datasets and recruits the experience of this workforce to potentially provide valuable insight in troubleshooting or optimizing manufacturing processes.

Manufacturing processes will continue to produce data, but a lot of businesses, particularly small and mid-size enterprises (SMEs), lack the resources and expertise to implement solutions that can take advantage of these data. A 2020 survey of UK firms, which were mostly SMEs, found that big data analytics and machine learning ranked as high-benefit but also high-complexity tools to implement for operations.[4] Commercial software like Tableau (https://www.tableau.com) offer accessible platforms for analytics and visualization with minimal programming knowledge required for use but aren't specific to the manufacturing industry, which could benefit highly by tools like predictive maintenance and control, as reflected in the survey.

The move toward digital manufacturing remains an abstract concept to firms that simply cannot muster the capital to make the jump. Firms in this scenario are left in a state of limbo, unable to move forward themselves, while competitors benefit from the advantages of increased digitalization. Therefore, these firms are at a disadvantage when compared to their much larger corporation rivals. The question becomes, what can these firms do to close the gap? The answer for many lies in the realm of data visualization and analytics software.

The importance of data visualization as a tool for I4.0 is widespread, and well documented, but unfortunately, many manufacturing industries have been rather slow in engaging with such tools—perhaps because of lack of skills and knowledge. Manufacturing involves complex multivariate systems, which produce high volumes of high-velocity data, and therefore, the computational requirement to compile, analyze, and gain insight into this data is significant; for many, the ability to return real-time process insight

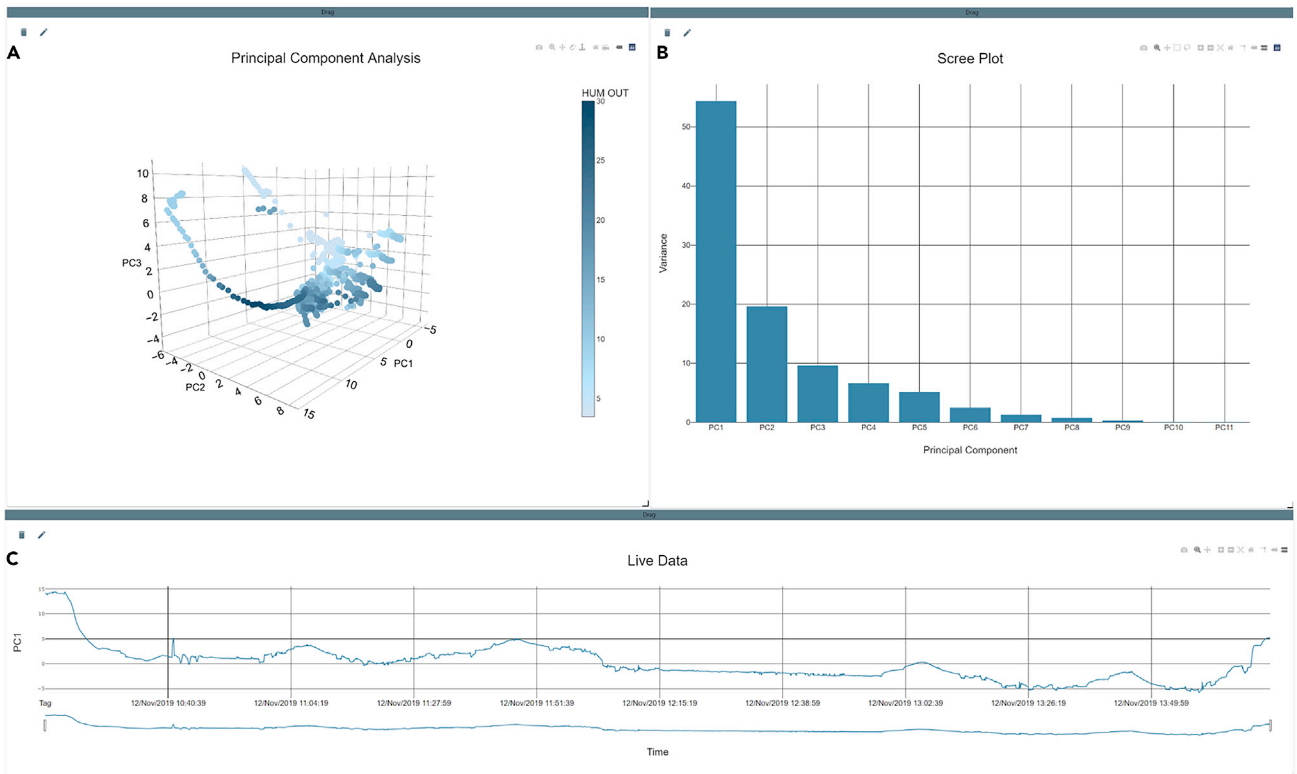

Figure 1. Wiz dashboard developed in Siemens' MindSphere
(A) Four-dimensional visualization principal-component analysis. (B) Supporting scree plot and (C) real-time data feed from a tablet manufacturing line at the Diamond Pilot Plant at the University of Sheffield.

is a daunting task. Clearly, the development of one-stop-shop solutions to provide a birds-eye view over massive datasets provides invaluable process insight in a much more efficient manner. In a world where machines talk to each other, and day-to-day human tasks are being automated, graphical interpretation remains a field that emphasizes the need for creative input and lateral thinking and promotes innovative problem solving. This outside-the-box problem solving will ultimately define the role of the human operator as control of more and more of our routine tasks are handed over to smart-manufacturing counterparts. Employing people's natural visual capacity is fundamentally intuitive and does not require high levels of training or expertise in data handling. Therefore, data visualization can be thought of as non-discriminatory—it allows the same level of insight regardless of academic fortitude or computational knowledge. This encourages information transparency within organizations, reducing the appearance of barriers between upper management, engineering experts, and manufacturing operating staff, promoting a greater level of communication.

IoT, a key technology in I4.0, provides a new platform for visualization. Significant effort has been made to describe IoT and its variations including Internet of Manufacturing Things (IoMT) and Semantic Web of Things for Industry (SWeTI) architectures as a series of layers.[5,6] The top application/interface layers of these frameworks present new opportunities for visualizations that are well connected to multiple live data sources, providing good support for emerging trends such as dashboards. Dashboards are experiencing increasing use in industry due to their monitoring and decision-support capabilities and can be combined with live data analytics to increase their power. Compared to the established human-machine interface (HMI) counterparts used extensively for monitoring and controlling processes, these dashboards can provide a more customizable interface that also acts as a platform allowing access to deeper data analytics such as principal-component analysis (PCA), clustering, or regression. Advanced dashboard front-end applications show promise in the handling of big data and are applicable as a stepping-stone for moving from traditional manufacturing approaches toward I4.0. Additionally, they stand as a smart investment for many smaller firms that want to gain higher levels of process insight but cannot afford the high price point that comes with full-scale digitalization. In order to take full advantage of this emerging data visualization paradigm, there needs to be further research into how it can be applied in different domains, situations, and functions.

A step change in the way industry collaborates with academia must be realized to help manufacturing industries adopt and benefit from I4.0 and the tools that it provides. On the one hand, manufacturing industries are feeling the exacerbating pressure of how quickly I4.0 technologies are transforming the field and are falling behind to engage with state-of-the-art data visualization solutions. On the other hand, research is often slow at materializing into tangible tools or strategies in industry, and this is rooted in a lack of communication between the two sectors. Agile and collaborative response will ensure the best integration of these technologies and in turn enhances their business value, shrinking the gap that currently exists between what is theoretically possible to implement from new or novel research and what is used in the day-to-day lives of the people handling data in industry.

Wiz, which provides a one-stop shop for data analysis and visualization, is an example of how this increase in collaboration can drive I4.0-focused data visualization and produce tangible tools for both industry and academia. Scientists and non-scientists alike can use Wiz to better understand their data, and because Wiz is web based, anyone with a dataset and a browser can use it without the need to code or even download a software. Wiz is freely available at https://wiz.shef.ac.uk/ since its publication in *Patterns*.[7] Our team is further developing Wiz into a dynamic dashboard that would integrate its functionalities (e.g., five-dimensional visual analytics and multivariate data analysis) and other built-in analytics to Siemens' MindSphere. This is an excellent step toward greater collaboration between academia and industry and needs to pave the way for how visualization platforms can be successfully developed in manufacturing settings. The visualizations will be displayed on an enterprise-quality dashboard allowing users to customize what key performance indicators are displayed and where they are displayed (Figure 1). The dashboard will allow the user to apply and execute various analytical techniques including statistical methods, dimensionality reduction, and noise reduction in the data. By combining the dashboard with IoT for condition and process monitoring, machine learning algorithms can be added to the platform to make use of cutting-edge I4.0 techniques such as predictive maintenance and quality control. Lastly, this platform will be used for capturing and creating insights from data created by digital twins and other data-driven models.

It is clear that common and well-established commercial-grade dashboard applications lack an industry focus and cannot offer the range of visualizations to properly represent the complex relationships between production variables. Therefore, they lack applicability to some of the more complex areas in manufacturing, including research and development, and complex manufacturing processes such as biopharmaceutical production. In order to be considered a truly I4.0 standard technology, the further integration of process-relevant analytics and visualization must be considered. It is important to consider the cultural integration of technologies such as these for use in an aging workforce. Measures should be taken to ensure the ease of use and increased accessibility of the software, with minimal training and upskilling required to gain access to intuitive data visualization. This will allow for a more seamless transition to a digital way of working, bridging the gap for many firms that have felt that a lack of expertise is the main barrier to entry to I4.0. The conception of the I4.0 visualization dashboard offers a realistic stepping-stone approach to firms wanting to transition to digital manufacturing, allowing for process insight at a fraction of the cost of full-scale digitalization. Advancements in these types of technology have shown promising results, and work must continue before this technology can be fully applied as a tool to guide industry into its fourth revolution.

ACKNOWLEDGMENTS

P.Z.M. thanks the Corporate Information and Computing Services (CiCS) and Partnerships and Regional Engagement at the University of Sheffield for providing partial funds for the development of Wiz. P.Z.M. also thanks John Dale and Carl McGrath from the University of Sheffield and Stefan Balan and David Moss from Siemens for useful discussions.

DECLARATION OF INTERESTS

P.Z.M. has financial interest through Monoclinic Ltd.

WEB RESOURCES

Tableau, https://www.tableau.com
Wiz, https://wiz.shef.ac.uk/

REFERENCES

1. Sucharitha, V., Subash, S., and Prakash, P. (2014). Visualization of big data: its tools and challenges. International Journal of Applied Engineering Research *9*, 5277–5290.
2. Universities of the Future (2019). Industry 4.0 implications for higher education institutions: state-of-maturity and competence needs. https://universitiesofthefuture.eu/wp-content/uploads/2019/02/State-of-Maturity_Report.pdf.
3. Calzavara, M., Battini, D., Bogataj, D., Sgarbossa, F., and Zennaro, I. (2020). Ageing workforce management in manufacturing systems: state of the art and future research agenda. Int. J. Prod. Res. *58*, 729–747. https://doi.org/10.1080/00207543.2019.1600759.
4. Masood, T., and Sonntag, P. (2020). Industry 4.0: Adoption challenges and benefits for SMEs. Comput. Ind. *121*, 103261. https://doi.org/10.1016/j.compind.2020.103261.
5. Zhang, Y., Zhang, G., Wang, J., Sun, S., Si, S., and Yang, T. (2015). Real-time information capturing and integration framework of the internet of manufacturing things. International Journal of Computer Integrated Manufacturing *28*, 811–822. https://doi.org/10.1080/0951192X.2014.900874.
6. Patel, P., Ali, M.I., and Sheth, A. (2018). From raw data to smart manufacturing: AI and semantic web of things for industry 4.0. IEEE Intell. Syst. *33*, 79–86. https://doi.org/10.1109/mis.2018.043741325.
7. Balzer, C., Oktavian, R., Zandi, M., Fairen-Jimenez, D., and Moghadam, P.Z. (2020). Wiz: A web-based tool for interactive visualization of big data. Patterns *1*, 100107. https://doi.org/10.1016/j.patter.2020.100107.

About the authors

Dr. Peyman Z. Moghadam is a lecturer at the Chemical and Biological Department at the University of Sheffield, and his group is leading the field of high-throughput simulations and quantitative big data methods for accelerated discovery of functional materials. Prior to joining Sheffield, he was the head of the computational group at the Adsorption and Advanced Materials Lab at the University of Cambridge for 3 years. From 2013 to 2015, he did a postdoc at Northwestern University after completing his PhD in chemical engineering at the University of Edinburgh. He has published 42 papers (*h*-index: 27). In 2019, P.Z.M.'s big data visualization software, Wiz, won 1st prize at the University of Sheffield software competition and was subsequently published on the front cover of *Patterns*. His group leads the development of data visualization/analytics dashboards for Industry 4.0 applications.