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Industrial 2040: A Vision of the Future State of Design and Manufacturing

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Abstract

Predicting the future is an incredibly difficult task that humans have been trying to accomplish since we first conceived time. Even today, there are entire fields of work dedicated to the pursuit of mastering our own timeline : meteorology, astronomy, economics, entrepreneurship… the list goes on. While predicting the future as a whole can be a daunting task, we believe that predicting the future state of manufacturing is an achievable and realistic goal. Specifically, we aim to predict what successful manufacturing companies will look like in the year 2040. We will use current-day trends as well as cutting-edge research to predict the trajectory of manufacturing to the year 2040, and provide examples of the advanced technologies and engineering principles that will set apart successful manufacturing companies. In this paper, we will focus on the use of three-dimensional holograms, networked microfactories, and unsupervised AI in industrial 2040.

Setting the Scene

Manufacturing is a field built on adaptability. Historically, manufacturers that were entrenched in their own dogmas, unwilling to accept change and innovate along the way, failed. In current times, the manufacturing companies that have managed to stay on top of our constantly changing markets have been those who continue to innovate, anticipate difficulties, and are open to new ideas. We believe the companies that best embody these traits in 2040 will be the most successful. While the environment and logistics of 2040 will likely be somewhat different than today's, the principles that guide a successful manufacturing company will surely be our best window to catch a glimpse of industrial 2040.

The most difficult part of catching this glimpse, however, is predicting what kinds of obstacles successful manufacturers will need to use these aforementioned principles in order to overcome. Thus, we must first paint a picture of what industrial 2040 looks like. Some may argue that the growing field of robotics will have completely replaced workers with automation in large-scale industrial settings. They will say that robots are "free labor" after initial costs, and that they can perform operations much more precisely and efficiently than their human counterparts. Because of this, they argue, human workers will no longer be able to compete in the assembly line labor market. However, one particular group of engineers in Japan would disagree.

In one of Toyota's car manufacturing plants, dubbed "Takaoka #2," Japanese engineers actually disproved the idea that automation is flat-out "better" than human workers. For context, the main issue with most large car manufacturing plants is that they are aimed at producing one car, fast. This makes retooling very time-consuming and expensive, and it means that if market fluctuations occur while Toyota (or any other car manufacturer) is pumping out the next batch of cars, Toyota has no room to adjust. Takaoka #2, on the other hand, specializes in flexibility. Cars can be run through its assembly line in a huge range of speeds, which allows Toyota to scale production up and down as it sees fit. Workers can be moved to and from almost anywhere on the line; and virtually as many of them as Toyota likes. Takaoka #2 boasts a shockingly open floor plan, which replaces heavy, stationary robots with smaller robots that can be moved simply using a forklift. Human workers work alongside these robots to perform tasks that are too complex or mobile for a robot to complete—which has even been verified by time studies. In this plant, an incredible degree of flexibility has been reached, which has empowered Toyota to adjust to the market in ways that no other car manufacturer has; better yet, they have done it by decreasing automation.

However, one particular form of automation will likely see an uptick in popularity among industrial 2040 manufacturers. Unsupervised AI has been a growing field especially recently, and it already has many obvious advantageous use cases. In a paper by Daniel Lieber et al. in 2013, a method of identifying low and high quality steel bars with unsupervised AI was outlined. This method had a prediction accuracy of over 80%, even though the plots being analyzed by the AI were visually identical according to observers. This study demonstrates the great utility and potential of unsupervised AI as a quality control checkpoint within a manufacturing process, and how it may easily surpass human quality control as the technology continues to develop.

While supervised AI has been popular for several decades now, unsupervised AI has found new traction as researchers find new ways to enhance machine learning in various ways. One key advantage is that unsupervised AI does not require labeled data sets that have already been organized for the AI to make use of. Essentially, this means that unsupervised AI can have a closed, independent data stream that takes raw data as input and gives its user the calculations and interpretations that they need. This approach to data parsing may yield better results than that of supervised AI, according to Zaadnoordijk et al. According to their paper titled "The Next Big Thing(s) in Unsupervised Machine Learning: Five Lessons from Infant Learning," infant learning is the closest representation we have of unsupervised machine learning. Therefore, if we can learn how infants' brains can make use of the huge data stream they are exposed to from birth, we can learn how to start and develop unsupervised AI with unprecedented capabilities.

There are several main points that Zaadnoordijk et al. make in their paper about the minds of infants. One such point is that there are starting conditions in infants' brains that guide how they take in data from the moment they are born. Babies' brains actually share many structural similarities with adult brains. They have pre-programmed networks that make sense of the data they are being fed, with several of these networks often acting in tandem to understand relations between pieces of data. Furthermore, babies' brains have the capability of selectively using some data while omitting other information. Infants' cognitive development is also heavily dependent on time. This is why we have a linear, time-dependent approach to teaching curriculum to babies. Lastly, Zaadnoordijk et al. posit that babies can sometimes learn more rapidly by observing and interacting with others, like their parents. As development of unsupervised AI continues, Zaadnoordijk, Cusack and Zaadnoordijk believe that new ground can be reached if developers take their findings and apply them to AI models. AI models can become much more independent and useful in the real world, they argue, if they have a similar data analysis approach to infant brains. With this next generation of machine learning, industrial applications such as quality control, time series analysis, and process engineering will allow unsupervised AI to become a new key tool for manufacturing success in industrial 2040.

For us, unsupervised AI is a field of study that is particularly meaningful and promising. We are working with our university in a research program to develop smartwatches and corresponding software that may be worn by workers performing assembly operations—both during training and during real assembly—that can be used to provide invaluable information to supervisors. Furthermore, we aim to replace human supervision in many cases with this watch, since human supervision is known to induce stress in the worker, thus providing inaccurate data. Use cases include analyzing specific assembly operations within a product flow to locate difficult and time-consuming tasks, unsupervised time studies, and training new workers. We aim to quantify consistency and accuracy meaningfully such that supervisors could, for example, release workers for training not based on time in training, but instead on how consistent a worker is at a particular operation. We aim to make the entire process unsupervised, which will enable the software to make sense of raw data without human intervention. This will be an extremely useful tool for manufacturing plants and managers, and we see it becoming a key part of industrial 2040's approach to new employee management and overall data collection.

Even though it seems unlikely that advanced technology will allow complete manufacturing automation in 2040, it may enable significant new capabilities for human workers. For example, in my own work within a manufacturing facility, I have noticed how dependent workers are on visual references. Standard work manuals do a fair job of providing this aid, but they are slow and cumbersome to read through between operations. As production continues to accelerate in pace, successful companies have found ways to cut down unnecessary time spent by workers between operations - and this will be no exception. It is likely that as technology improves, these manuals will be replaced with something much more intuitive and rapidly available to workers. One possible technology that fits this use case is 3D holograms.

Google Glasses and other similar 2D "augmented reality" devices have already shown how useful a visual aid can be for workers today, but they are not inexpensive or "game-changing" enough to be widely used in industry. Holograms, on the other hand, could in theory, replace standard work documents and even human mentors. They can be seen by anyone from any angle, without the need of specialized, expensive personal equipment like augmented reality glasses. According to Abid Halim et al., 3D holograms can be seen at any viewing angle, allowing for a realistic, life-like interpretation of objects. Holograms could even allow workers to see inside of the parts and assemblies they are working with. They can be projected alongside or on top of the materials that a worker is using, and could even be used to project assembly operations to be performed by a worker to provide a high level of detail and interaction. Using holograms, new hire training can be performed without wasting materials and space. Abid Halim et al. envision an industry in which employees can perform training in a safer environment with extremely limited expenses when compared to traditional hands-on training. Finally, their ability to be rapidly used by the worker in real time means there is less non-value added time spent looking through a standard work book.

Another new, impactful development in manufacturing is the introduction of "microfactories." Arrival, an electric vehicle company based in London, has pioneered the use of these relatively tiny manufacturing units. Arrival's idea is to open numerous microfactories in a distributed network across the US and Europe, allowing for better production flexibility and lower start-up costs. While typical car manufacturing plants cost hundreds of millions to start up and operate yearly, Arrival's plants will cost a fraction of this price. Case in point, Arrival is opening a plant in South Carolina that costs about $41.2 million, and will be able to produce about 10,000 electric vans per year. Most car manufacturing plants produce roughly 100,000 vehicles a year, so it seems that Arrival has cut costs and production by plant by roughly an order of magnitude. This has many benefits - namely, convenience of location, energy efficiency, and flexible production networks. Because these plants are relatively small, they can be built in a much larger variety of locations, which expedites transportation of produced vehicles to surrounding areas and partners. Furthermore, each plant will need just a fraction of the energy demanded by larger, contemporary plants. This will help Arrival to realistically achieve its carbon-neutral goal while not sacrificing the low start-up costs per plant, as carbon-neutral solutions are much cheaper and more feasible for smaller plants. Finally, these microfactories will be able to link up in a production and supply chain network, which allows Arrival to scale its production up or down according to the market demand and any supply chain issues. This will help reduce losses that have historically bankrupted vehicle manufacturers like GM and Chrysler. These manufacturers had rather "clunky" production networks that were devastatingly one-speed and slow to respond to change. Meanwhile, Arrival can simply reduce the production in one or several plants depending on material availability and demand at any given time very quickly, and without mass layoffs and extra costs associated with larger plants. We see this nimble approach to manufacturing as the future of successful manufacturers, as markets continue to be increasingly variable and as supply chains are further strained.

Research Challenges to be Encountered

Whenever testing a new idea there will always be challenges and hurdles to overcome. This is the same in manufacturing, testing the usability of three-dimensional holograms, networked microfactories, and unsupervised AI.

Research Challenges for Three-Dimensional Holograms

Challenges concerning the use of three-dimensional holograms are that holograms are not as easily seen and viewed in fluorescent lighting, it takes a lot of time to develop three-dimensional holograms, and applying holographic projection in manufacturing and design are very expensive(RF Wireless World, 2012).

Research Challenges for Networked Microfactories

Challenges concerning the use of networked microfactories are scaling down the tools and components to make processes shorter, being able to monitor processes of micro-machining is not as easy and beneficial as standard factories, and the main challenge is keeping the forces of machines under the breaking force of the tools in use while increasing productivity(Chae, Park, Freiheit, 2005) . This is to prevent tools from wearing and breaking as quickly while allowing microfactories to perform a key trait which is to increase productivity and efficiency.

Research Challenges for Unsupervised AI

Challenges concerning the use of unsupervised AI include overfitting the data where performance decreases as the amount of data increases, the quality of the data if there is an imbalance where sample sizes are larger or smaller than other areas, and applying the developed ML models after the application and suitability of the algorithm in certain settings has been studied in depth (Usama, 2019).

Mode of Operation

The implementation of these new ideas can change the way a company operates and produces their products. We seek to understand how companies operate using three-dimensional holograms, networked microfactories, and unsupervised AI.

Mode of Operation for Three-Dimensional Holograms

Ways companies can operate using three-dimensional holograms include being able to improve training, design, and visualization in production areas (Mattk, 2022). Three-dimensional holograms allow employees to look at and manipulate three-dimensional images of products to allow for a better understanding of certain areas. Implementation of three-dimensional holograms can greatly enhance production processes.

Mode of Operation for Networked Microfactories

Ways companies can operate using networked microfactories include small batch production of a wide variety of products instead of traditional mass production of one product. Microfactories are manufactured with automatic machine tools, CNC tools, robotic arms, assembly systems, and even more (EID Robotics 2021). The operation of microfactories is heavily dependent on automation and robotics.

Mode of Operation for Unsupervised AI

Ways companies can operate using unsupervised AI are using intelligent, self-optimizing machines that automate production processes(Lieber, et al. 2013). While improving production processes, they also use previously recorded data to predict when efficiency could decrease. Operations involving unsupervised AI also include monitoring of the production process to detect efficiency loss and quality defects.

Key Challenges to Overcome

Haleem et al. discuss limitations and challenges involving the development of 3D holograms in their paper. One substantial issue is the creation of a 3D holographic image itself. The initial investment to get the equipment and expertise is very high. So too is the processing power required to develop these holograms. Holography is extremely high-density in terms of data, so industrial entities will either need to come up with substantial initial capital or form key partnerships with cloud computing platforms by the year 2040. Another issue with 3D holography that manufacturers will need to deal with is the equipment needed to display a 3D hologram in situ. In order to display such an image, at least two light rays need to be exactly synchronized at a very specific point in space. Achieving this is a matter of extreme precision and environmental control, the likes of which are very challenging to accomplish even in a laboratory setting. Manufacturers will need to take these factors into account when developing their own holography platforms, and will likely need to invest in companies that are able to mitigate these issues in their own designs.

The development of the next generation of unsupervised AI will also have its own unique challenges. Researchers will need to dive even deeper into the neural networks that exist in human brains if they wish to make new AI behave similarly. This will require working alongside neurologists to understand at a detailed, low level how the human brain works, and how this can be mimicked in a digital setting. They will need to learn how to develop starting network conditions in the AI models that allow for faster learning and development if they wish to achieve the level of independence and plasticity that Zaadnoordijk et al. discuss in their paper. In order to achieve anything close to the neural density of human brains, immense processing power will be needed. All of this means that manufacturing companies will need to hire data scientists, computer scientists, and technicians to start up such a system and keep it functional and state-of-the-art.

As microfactories become a cornerstone of manufacturing flexibility and success, new challenges will arise that have never before been seen by many industrial companies. For example, lean manufacturing—an engineering principle that minimizes waste while maximizing efficiency—will need to be implemented in an entirely new setting. Inventory is seen in lean manufacturing as a burden: the less inventory on-site, the better. Since microfactories will have much less extra space than their contemporary counterparts, new systems of inventory management will need to be developed. A network of microfactories may need one or more central warehouses to store inventory, and a delivery system will need to be created—one whose effectiveness is especially important for manufacturers who are moving towards just-in-time (JIT) production. It will be particularly important for these networks that inventory information on each part and material be reliably updated. Another challenge for microfactory manufacturing systems is supply chain management. Since the ultimate goal of companies who use microfactories is flexibility, each microfactory will have a variable demand for materials. The versatility of both the inventory management system and the supply chain feeding it will determine the degree of flexibility for these companies' production. This means that manufacturers will need to have supply prediction capabilities to stay ahead of shortages, and have several supply streams in case one is compromised by shortages or other external factors such as sanctions or pandemics, as we plainly see today. One tool that manufacturing companies could leverage to accomplish this is AI-powered predictive analytics. If industrial companies feed AI data from their supply chain, the AI could recognize trends that, once learned and leveraged, allow companies to predict when a material shortage may occur and plan accordingly, without interrupting their supply stream. This will be an entirely new approach for manufacturing and design companies, but the ones that manage to execute it will be the most successful in industrial 2040.

Needed Partnerships

When implementing these new ideas, the company may need to partner with other companies who specialize in those areas to produce the best and most efficient processes while also staying in their area of competence. We are going to understand what partnerships may be needed for three-dimensional holograms, networked microfactories, and unsupervised AI.

Industry Partnerships for Three-Dimensional Holograms

Partnerships needed for three-dimensional holograms are companies who have the holographic engineers and the resources to develop successful and useful three-dimensional holograms. Some of the leading companies of three-dimensional holograms are HYPERVSN, VividQ, MDH Hologram Ltd., SeeReal Technologies, Nanjing DSeeLab Digital Technology Co.,Realfiction Holdings AB, Holoxica, CY Vision, Voxon Photonics, and Light Field Lab, Inc.

Industry Partnerships for Networked Microfactories

Partnerships needed for networked microfactories are warehousing companies to house their microfactories. Also companies that have developed innovative and efficient technologies to run their production lines. An example of this is when company Alfa Laval partnered with Wayout International to produce microfactories for sustainable water supply(Alfal Laval, 2021). Alfa Laval has developed technology to purify and reuse materials, which promotes positive use of natural resources(Alfal Laval, 2021). Wayout International develops reliable microfactories for clients to produce local water with a small economic footprint(Solar Impulse Foundation, 2022).

Industry Partnerships for Unsupervised AI

Partnerships needed for unsupervised AI are companies who have the research computer scientists and the technology to develop successful and beneficial unsupervised AI specific to their company's processes. Some of the leading companies in developing unsupervised AI are Anduril Industries, Sift, Nauto, Tempus, and Salesforce.

Partnering with Government Agencies:

NSF

Partnering with the National Science Foundation would enable the possibility of funding for research regarding the implementation of these new technologies in manufacturing.

Department of Commerce

Partnering with the Department of Commerce would allow connections with Universities and Colleges.

NIST

Partnering with the NIST would be beneficial to the company so that all engineering standards are known and followed in all areas.

Partnering with Educational Institutions:

Tech

Partnering with Technical colleges would allow companies to have easier access to trained technicians to help maintain their machines automated with unsupervised AI.

4-year

This would enable engineers from those schools to do research and development of how three-dimensional holograms could be advanced and used more in manufacturing. Which would allow Industrial Engineers to be able to analyze and understand their production processes and how to improve productivity and efficiency.

K-12

Partnering with K-12 schools would allow companies to inform the next generation how traditional manufacturing has changed form. Manufacturing was hard hats and grease, but now is unsupervised AI controlling entire production lines.

With regards to three-dimensional holograms, microfactories, and unsupervised AI our company will benefit from partnering with a Cloud Computing service with access to secure data storage, databases, and networking throughout the whole company.

Needed Technologies

For companies to successfully implement these new ideas and become globally competitive, they need to obtain the necessary technology to support their employees. We are going to understand what technologies are needed for a company to be successful when using three-dimensional holograms, networked microfactories, and unsupervised AI.

Needed Technology for Three-Dimensional Holograms

Technology needed for three-dimensional holograms are called holographic projectors and three-dimensional hologram printers. Holographic projectors shine white light through holograms, which results in bright two or three dimensional images(Markgraf, 2018). Three-dimensional hologram printers take multiple images from many different perspectives and the images are used to create unique individual recordings for each pixel of the hologram(Litholio, 2022). This new and innovative technology will allow employees to be able to easily analyze and understand products.

Needed Technology for Networked Microfactories

Technology needed for networked microfactories are advanced computing, robotics, and AI tech. There are also a lot of IT service organizations that can enable the transition to a microfactory-as-a-service model and catalyze further development(Jhawar,Vaidyanathan, 2021). Implementing these technologies and services in microfactories can help them become more efficient and globally competitive.

Needed Technology for Unsupervised AI

Technology needed for unsupervised AI are special algorithms specific to your company's needs. Algorithms that can adjust to irregularity using previously recorded and gathered data, and empower the needed robots used in the production line. While also being able to predict efficiency losses and detect quality defects.

Conclusion

From analyzing current trends in manufacturing, bleeding edge industrial engineering, and further research, we posit that three main areas of technology will be key to design and manufacturing success in 2040: three-dimensional holograms, networked microfactories, and unsupervised AI. From our research in these areas, we have outlined a blueprint for their successful application: the research challenges to be faced, the key challenges to overcome, the needed partnerships, and the needed technology for these new methods of manufacturing.

While Industrial 2040 is still almost two decades away, successful design and manufacturing companies are always planning for the long-term future of their facilities - in 2040 and beyond. We believe that by taking advantage of the technologies we have outlined, and by using the approach that we laid out for their industrial implementation, these companies will be prepared for Industry 4.0. High levels of automation, networking, and worker capability will mark their entry into this period. Soon, we will see which companies are able to make this transition successfully, and which ones are ill-prepared for Industrial 2040.

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