Automation and AI in Manufacturing

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SUMMARY:

This paper views the complex world of automation and the impact it could have on the future of manufacturing through the eyes of a high school intern. The paper walks through the history of automation developments, understands the key emerging trends, identifies the current state of technology and business imperatives, then discusses potential large-scale impacts on the industry and society.

Automation refers to the technology that reduces the need for human labor and is broken into three categories: Fixed, Programmable, and Flexible. Automation is not a new field, it has been around since the 14th century with mechanical devices powered by wind and water and has exponentially grown and evolved through the years. It remains to be seen how the modern era of AI will further impact the future of automation with the availability of programmable frameworks. A majority of large-industries have made the switch from primarily manual to highly or completely automated manufacturing. With the increased availability of affordable high-performance manufacturing machinery, society will be open to a new set of opportunities that will drive the world of automation further.

One issue people believe that automation poses is its polarizing effect on the workforce. Automation is only set to replace monotonous, and repetitive tasks whereas humans still dominate the creative domain. Therefore we should direct our focus to retrain our new workforce for flexible skills that robots will not be able to replace, so these workers can maintain their status as active members of the economy and grow in a world where automation is an integral part of the future.

In my brief experience as an intern, I was exposed to new possibilities that the future of automation has in store. In time the goal of automation is to equalize the global labor cost issue by implementing economically viable, efficient machinery to combat unfair low-cost human labor.

Introduction

I have always been fascinated by the topic of automation. I grew up in Detroit, the place which is both the heart and soul of the US auto industry, where a multitude of manufacturing automation innovations came to life, as well as a place where many cutting-edge developments for future manufacturing automation and autonomous mobility are taking place today.

This past summer I had the opportunity to work as an intern and participate in activities involving some state-of-the-art developments for manufacturing robotics. My journey into the world of automation is only at its early stages and I am truly excited about the horizons these technologies open up. The goal of this paper is to study the path of automation developments from the past; understand the key emerging trends and drivers; identify the current state of technology and business imperatives through the prism of a case study example, and conclude by discussing potential large-scale impacts on the industry and society as these technologies continue to proliferate.

What is automation?

These days the word automation tends to invoke discussion around self-driving cars and AI-powered robotics, but in fact, the term automation encompasses much more. Automation generally can refer to any technology that makes a process or procedure easier to perform with reduced or eliminated human assistance. Self-driving and robotics technologies certainly belong under this umbrella, but these innovations represent just a small subset of a much larger field.

Automation can be classified into three distinct categories: fixed, programmable, and flexible automation. The various types of automation will generally fall into one of these groups.

Fixed automation refers to a system where process steps are predetermined and fixed, and the equipment and procedures cannot be modified to perform any task other than the one they were originally designed for. A common example of fixed automation is the regular analog watch. It contains a complex system of gears designed to work together with the purpose of telling you the time. The underlying design and the mechanism itself cannot be easily changed to perform other tasks.

Programmable automation is designed with an ability to be programmed, as the name suggests. This means that the steps or the parameters of the process can be modified to fit different outcomes. One way it can be achieved is by means of coded instructions the process or mechanism receives from a controller device. Many of the smart systems that exist in our homes today are good examples of programmable automation. The alarm that one sets when leaving the house and the smart thermostat that one programs are two of many programmable automation systems that we often come across in our daily life.

Flexible automation has many similarities with programmable automation, but with one critical difference: it is designed to be adjusted to perform automation tasks under changing physical or mechanical constraints and goals. One approach to achieve this is through mechanisms that can be physically altered in addition to being reprogrammed. Regardless of the underlying design principle, flexible automation is designed to be capable of adjusting both hardware (physical/mechanical) and software (controls) and ease of switching between processes. An everyday example of flexible automation could be a Raspberry Pi or Lego Mindstorms. These systems offer an ability to both add new hardware features and edit programming to adapt the architecture and to switch between various functions that may require changes to control sequences and varying hardware requirements.

History of automation

To better understand the automation development trajectory, its status today, and how it might evolve into the future, it may be useful to look back, learn the history and understand how automation began, developed and reached the status of where it is today.

Automation has been around since ancient times. In fact, some may suggest that the concept of automation goes back as far as Ancient Greeks. Long before the modern concept of robots, there were machines called automatons. These machines existed during the Italian Renaissance in the 14th century and were described as mechanical devices that were usually powered by water, wind or clockwork. However, the start of the history of mechanical automation in the modern sense should probably be considered around the end of the 18th century, with the advent of the Industrial Revolution. This was around the time when the first device that earned the name ‘computer’, Charles Babbage’s ‘Analytical Engine’ machine, was being created and when Ada

Lovelace, Lord's Byron daughter, was writing the first 'program' to control the sequence of the operations for it.

The modern concept of robots came to be in the early 1900s. The term robot was coined by Czech writer Karel Capek in a play he wrote in 1920 called *Rossum's Universal Robots*. The first-ever physical robot, named ELEKTRO, was displayed at the World's Fair in 1939 and could walk, smoke and blow up balloons with voice commands. Soon after came Isaac Asimov's three laws of robotics. These two events cemented the foundation of robotics and automation in the minds of many, which eventually led to the first autonomous robots, two tortoises named Elmer and Elsie invented by William Grey Walter in 1948.

In 1950 Alan Turing, a mathematician who came to be recognized for his role in cracking messages of the Nazi encryption device known as Enigma, developed a test that would help measure a machine's perceived intelligence and test a machine's apparent ability to "think." This test became known as the Turing test and is still in use today. The term Artificial Intelligence and the field of AI were introduced in 1956 during a conference at Dartmouth University.

By the 1980s the idea of "lights-out" manufacturing started to take hold. This concept spurred another wave of innovations in the 90s. The new wave of AI advancements produced an artificial intelligence that beat a chess grandmaster and NASA sent an autonomous robotics system to Mars. During this decade we also saw automation expanding its reach from physical hardware to control systems and software.

By 2011, the modern era of AI development was in full swing. It was made possible by the convergence of three critical building blocks: the arrival of affordable, massive, parallel computing capabilities; several critical developments in the field of machine learning and neural networks; and availability of standardized programmable frameworks such as Theano, Torch, MXNet, Caffe and eventually PyTorch and Tensor Flow to implement these new methods.

Only 60 years ago the term AI did not even exist. Our society has gone from reading about these ideas in science fiction books to now having anybody with a cell phone carrying an AI digital assistant in their pocket. At a more general level, all of the critical developments related to automation have taken place only within the last 100 years or so. And it is exciting to start imagining the kind of innovations in the field of automation and AI can bring to our society in the next 100 years.

Emerging trends of automation

If we examine any current large-scale industry, ranging from manufacturing to pharmaceuticals and medical equipment, in the past 40-50 years a significant number of processes have gone from being primarily or entirely manual to highly or completely automated. The assembly line of the Ford Model T looked nothing like the assembly line of today's Ford F-150. The differences are both drastic and exciting.

Currently deployed automation equipment is primarily designed around following pre-determined and essentially fixed set of instructions. This approach requires a significant level of fixed boundary conditions on the assembly line, including highly accurate positioning of equipment and components, and a large number of safety measures to keep operators away from powerful automated equipment for health and safety reasons.

The advent of affordable, massive, parallel compute power, maturing machine learning techniques, and proliferation of high-resolution vision hardware is now bringing a new era of possibilities into the world of automation. These new techniques are being developed to be highly flexible and adaptable to its changing environment by utilizing AI and vision technologies and no longer will require a pre-determined set of boundary conditions. Furthermore, since the sensing of the environment and reacting to the changes around it are now becoming possible, it opens up even larger opportunities to bring human-robot collaboration to new levels, where operators will be able to work side by side with highly automated, high-speed robotics systems that can dynamically react to changing conditions without impacting production output.

Similar trends fueled by machine learning, connectivity, AI, and vision technologies are also driving the advancements in the field of new mobility and autonomy. The applications may look very different on the surface, but the types of boundary conditions and underlying technologies are in fact very similar. Parallels between the two cases include the human operators on an assembly line and pedestrians in urban centers, and human-driven forklifts for in-plant logistics and surrounding car traffic operated by drivers. The list can go on. And in both cases, solutions are powered by powerful computing capability with efficient algorithms and vision and sensing equipment. Similar examples exist in other areas of industrial, financial and service industries.

These trends can have a profound effect on both industry and society. Imagine a flexible, adaptable and automated production process that now adjusts to produce a new product utilizing the same equipment and space. Imagine a consumer product, a car or a home appliance, that can now have new functionality enabled simply by installing a new version of software that has been delivered remotely. The cost of enabling new features can fall drastically as existing hardware becomes flexible enough to accept new functionality through software changes only. This in itself can lead to an entirely new set of opportunities as these technologies proliferate deeper and wider throughout industries, services and society in general.

Automation and employment

One topic that consistently comes up as an argument against automation is that automation, in particular in manufacturing and services, takes away jobs from hard-working people who don’t have a chance to find alternatives due to various reasons. Some also argue that these trends polarize the workforce by removing jobs that require little education and increasing demand for jobs with a higher skill level. There is, however, a different angle to view this issue from. An argument can be made that automation, while in fact reducing the need for monotonous and repetitive work, at the same time creates a whole new set of occupations that did not exist before.

While it’s difficult to predict the types of jobs that could be replaced as a result, the prior history of innovations has a track record of consistently creating new opportunities for a wide range of skillsets. Examples don’t stop at taxi and truck drivers coming in place of people taking care of horses -- recent examples of shared economy businesses such as AirB&B, Lyft and Uber, and

DoorDash come to mind. Therefore, the focus should not be on trying to curb automation spread, but on investing in retraining people for flexible skills that will allow them to stay active members of the economy and grow in a world where automation is an integral part of the future.

The Economist Intelligence Unit has developed and is tracking the Automation Readiness Index. The Index ranks countries based on the development of its innovation environment, education and labor market policies. According to this Index, South Korea, Germany, and Singapore rank as the top three countries with policy environments that are ready for the coming wave of automation. The United States ranks 9th. While many countries are only starting to think about how to improve policies to enable future automation, these top countries have already begun developing the right environment to support automation-fueled growth.

To successfully compete in international markets and maintain a strong manufacturing base, the United States needs to encourage innovations in automation processes, develop educational programs in relevant fields of science and technology, and offer vocational training for learning skills relevant for automated processes. These programs should be designed in a way that helps to successfully transition when automation technologies start displacing existing jobs.

Throughout the entire history of automation innovations, although machines do eventually outperform us in repetitive and monotonous tasks, humans are still continuing to be much better at creative thinking, identifying patterns and re-applying them across different fields. Thus, it is truly in our hands to prepare for changes, create programs and initiates, encourage a mindset of preparing for change instead of resisting it, and develop soft skills that machines are not capable of replacing.

Although it may seem as if jobs are currently being displaced by automation, and consequences are unpredictable, if we act now, we can develop the right framework to support the growth of automation along with the growth of employment. If federal, state and local governments, industries, and educational institutions all come together to develop policies and solutions to address the underlying issue driven by innovations in automation, such as job displacement, the economy and society will reap the benefits. Such an approach will help pave the way for our country to effectively continue to compete on a global scale.

My experience as an intern

I was fortunate to have a chance to work as an intern for the advanced robotics research team at a large automotive supplier. The internship started by getting familiar with development frameworks, programming languages and operating systems that are used by the team for their development work. I had gone through training on the ROS operating system and studied the design, operating principles and manufacturing applications of 3D cameras. During this part of the internship, I had started creating test code and developing sample applications that helped me understand the limitations and operating principles of 3D sensors.

For a part of my project, I had been developing software using an operating framework called Halcon. The target functionality for that software was to receive an image from the sensing camera and identify two spherical objects located at a fixed distance apart from each other in various pre-determined positions. This is used to calibrate the camera’s three-dimensional capabilities, which ultimately leads to the sensor’s ability to perceive distances in all three dimensions, even if the sensor is positioned at a significant distance from the perceived object.

The principle behind the camera's operation is quite simple, it is called flight time. The camera sends out and receives back a light signal, records the distance the light has traveled and reconstructs the third dimension by superimposing these distance calculations on a point-by-point basis.

Once the software has been finalized and thoroughly tested, it becomes part of a larger software package that helps the robotic arm with an end-effector and a camera installed on it to determine the location of a part in a bin, identify the part's orientation, and help manipulate the arm to perform the required procedure. Utilizing such vision technologies, in combination with robotics and flexible control systems, companies can dramatically increase manufacturing efficiencies at their plants.

Case study

To illustrate what an application of these technologies in practice looks like, let us consider the following case study. We will allow ourselves certain generalizations and simplifications in order to sufficiently detach the description from the actual industrial application being described.

First, let us describe an existing production cell that is highly automated with current state-of-the-art equipment. Our cell consists of a fully automated processing station that can process two parts in a half step cycle (second part can be placed in the station in the mid-cycle of the previous part being processed), five location-fixed material handling stations with bins of parts – two bins for incoming parts, two for finished ones – and one bin for parts with quality issues and a fixed-location checking fixture designed to verify all required targets on the finished product.

The cell is designed for a single operator whose manual tasks consist of the following steps performed in a sequence for each cycle:

- pick up the part from one of the incoming bins
- place the part inside the processing station, which operates with a two-step fixed cycle time
- retrieve the previously placed finished part from the processing station
- place it on the fixture, check all the required measurements to verify the part quality
- Depending on the quality results, the part is then either placed in one of the finished parts bins or the bin for parts with questionable quality.
- The cycle then repeats again from step one.

The key parameters that need to be taken into account while re-designing this type of cell for a flexible and adaptable automation are as follows:

- same or improved cycle time as compared to current cycle of 78 seconds
- reliability ratio above 85%
- 20% reduction in cell total footprint
- reduction of total labor
- payback for the increased cost of the system due to automation should be under 18-24 months and no special new requirements for in-plant logistics should be imposed as a result of new automation implementation.

The proposed automation solution utilizes two key innovations in order to achieve the desired goals. First: vision technology and machine-learning-based AI were utilized to perform several critical functions, such as recognition of bins, bin locations, incoming parts within the bins and parts localization, quality checks within the checking fixture, and localization within the finished parts bins. Second: dynamically calculated path trajectories for the robotics arm, based on varying bins and parts locations and results of the quality check at each cycle.

The implemented solution is able to reach the following requirements:

- cycle time 78 seconds
- reliability ratio 87%
- 18% reduction in cell total footprint
- redeployment of one operator per shift to other areas in the plant, relaxing the requirement for the location of the bins
- bins no longer needed to be placed in exact fixed locations, no special new requirements for in-plant logistics to operate the cell continuously for 3 shifts and payback of less than 18 months (see for details below).

Based on the described results the illustrated case study can be considered a very successful example of advanced automation implementation that is fundamentally different from currently used methods in the manufacturing industry.

Business case

Let us now briefly demonstrate the basic components of the business case for the application described above. Under certain generalized assumptions and simplifications, the following elements should be considered for the business case:

(1) additional costs for the modified advanced cell vs original reference cell: fixed costs for each cell: adding a robot to handle parts $40K, vision sensors hardware $15K, redesigned set of inserts for the four bins, including spare sets $5K, end-effector for robotic arm $5K, industrial computer to calculate path trajectories, run machine learning algorithms for localization and quality control, connectivity and overall control of the robot $5K, cables, connectors, and other required parts $5K, additional costs for vision system installation and calibration $10K, annual maintenance and other running costs related to vision and robot $5K per year, and

(2) existing elements that could be now removed from the original cell design: labor cost for one operator per shift $40K per year, total for two shifts is $80K per year.

Under these assumptions, the total additional one-time cost for the new advanced cell comes to $85K and $5K per year in maintenance and other related, while the annual running costs get annual savings of $80K per year. The calculated payback for the new system thus comes to between 12 and 18 months with the potential to become closer to one year. The resulting savings per cell will be $75K every year thereafter.

Labor cost

What could this really mean for both industry and society as a whole if these AI and machine-learning-based technologies married with robotics hardware and automation were to start proliferating throughout the entire manufacturing industry? One of the most obvious and certainly a significant outcome of the business case analysis is that after just over a year the plant would start saving $75K per year for each newly upgraded cell. If one can imagine that a typical manufacturing facility may contain hundreds of such cells, the bottom line of annual total cost savings per plant becomes extremely significant, measured in single or even double-digit millions of dollars. However, a much more significant impact does not become evident right away, until one starts analyzing the case in more detail.

The fundamental difference is, however, that the AI-based automated cell does not require any human operator to control the production. If one were to compare the cost advantages of running production in so-called low-cost countries, it comes down to a simple equation: cost of equipment and hardware is very similar and does not vary too much between different countries (in some cases the cost of installation could be a little different, but this is not usually a big portion of the total cost, plus it's a one-time expense). The major advantage of the low-cost countries, such as China, India, Mexico, Eastern Europe and South America, is the lower cost of labor.

Conclusion

Removal of the labor cost from the business case equation, as we have done in the described above case, opens up a completely new approach to manufacturing which can finally reverse the trend of moving jobs from high labor cost countries into the low-cost regions. This can lead to true democratization of manufacturing on a global basis, making production location decisions free from tight dependency on each region's local labor costs and as a consequence, make components and final product costs business cases completely uniform across all regions.

Thus, smart and flexible automation will ultimately create a level-playing field between high and low labor cost countries and will inevitably start bringing manufacturing jobs back to industrially developed countries, such as the US, on a long-term basis and, more importantly, on a sustainable foundation. Finally, technological advancements, such as the ones we had described in this paper, can reverse the trend of manufacturing outsourcing based on purely economic reasons and without any interference from government regulations.

In conclusion, it would also be important to add that the above considerations become even more important given the latest events related to COVID-19. The new realities now bring to light the importance of all technologies that are able to address such challenges as social distancing and local manufacturing.