Abstract: The second part of this article focuses on the transformation of the production systems in manufacturing and agriculture as a result of the convergence in the I4.0 technologies detailed in Part I. The category of general-purpose production machines is presented in detail. The interconnection of these machines and our ability to operate them remotely turn the stand-alone machines into production systems. The characteristics of these systems are studied separately for the cases of manufacturing and agriculture, showing the interrelation of the transformations in the two sectors. The I4.0 production systems give a tremendous boost in productivity as they allow the user of these systems to switch between different activities dynamically, cutting down costs and inefficiencies. The widespread deployment of such production systems fosters the emergence of a new social entity, the “prosumer.” The subsequent rationalization in the production creates the conditions where overproduction gradually dies out while it shifts the balance from mass consumption to mass customization.

Keywords: technology; production; production systems

Introduction

For over two decades, we have witnessed a hyper-consumption frenzy centered on smartphones, consumer-internet products, or a combination of both. One advertisement after another aims to convince the consumer to buy the next generation of “cool” mobile phones or applications that appear at an increasing pace. These
gadgets or applications are self-proclaimed as “smart,” but they are mostly targeting entertainment and leisure time.

At last, this frenzy is gradually receding as an increasing number of sober voices argue that production is the “killer application” for ICT, not posting pictures during our leisure time. Slowly, but steadily, it is understood worldwide that the spearhead of connectivity networks should be redirected so as to serve and support production in the context of I4.0. This is because production is the most fundamental social interaction that gives substance to our man-made material world. To measure the effectiveness of this social interaction, the notion of productivity is used, which tells us how efficient production is in terms of methods employed, the systems used, etc. In essence, productivity measures the ability of a new method to diminish the labor time needed to complete a working task. To boost productivity to new levels, a new production system is tasked to maximize the power of the processes a worker superintends or the number of agencies he sets in motion.

The key is to recognize that during the industrial era, as production systems continuously evolve, labor work becomes abstract as living labor is gradually replaced by automated machines of increasingly higher functionality and then from robotic platforms, to which the worker relates more as a watchman and regulator than a “manual” laborer. The second part of this communication focuses on the process of “abstraction,” which, as much as it diminishes the manual laboring part, enhances the intellectual abilities and the impact these processes have in manufacturing and agriculture.

Specifically, the upcoming transformation of production systems gives a qualitative leap to the process of abstract work: to maximize productivity in the I4.0 era; new production machines come into effect that abandon their single-purpose origin to become general-purpose, universal, machines and, hence, ubiquitous. It is exactly this process that gives new qualitative characteristics to the abstracted work. The key enabler is the potential to redeploy and reuse such a ubiquitous platform to accomplish a set of different tasks at will, rendering the general-purpose machine a “universal” one. In turn, these characteristics set the ground for a “delocalization” of production, and they provide the means to overcome “specialization” gridlocks (see Part I of the article). Moreover, they are fostering the concept of federated production while they create the conditions where overproduction gradually dies out.

The Impact of Technology Fusion on I4.0 Manufacturing

Digitization in Manufacturing: Advances and Contradictions

At this point, it is important to clarify the relationship between digitization and the digitization of the industry. In the most general way, the term digitization denotes the process of generation and the transmission of information into a digital format
that is implemented using apparatuses based on planar ICs technology (see Part I of the article). Adding the term “planar” is key as this word denotes a fundamental change in the methods, machinery, and materials used to create the ICs; needless to say, it is the planar IC-based apparatuses that completely dominate our technosphere today.

In Part I, it was argued that the enormous but contradictory contribution of I3.0 digitization was the development and then the expansion of the different ICT sectors, i.e., telecommunications networks, IT, IoT, and robotics, as stand-alone fields. This phase of digitization exhausted its potential because market protectionism set limits on the interoperability of the ICT systems coming from different vendors, something that also suppressed the cross-fertilization between different industrial sectors.

The starting point of I4.0 is exactly this historic limit of I3.0, i.e., it starts from the formulation of the conditions that make possible the convergence between these relatively independent I3.0 ICT fields. These conditions are the appearance of unifications innovations, like the SDN/NFV, that first made their debut in the field of connectivity networks and then spread to other industrial sectors and factors (see Figure 3, Part I of the article). Therefore, it is not accurate to say that I4.0 is a mere extension of the I3.0 digitization framework as this approach diminishes the critical role technology convergence plays and the dynamics it creates. A similar misleading statement would be to argue that since electricity is the precondition for digitization, digitization is a mere extension of electricity, so there is no difference between the I2.0 and I3.0 stages; that would not be true. The truth is that I4.0 relies on an entirely different digital-technological framework than I3.0; it relies on a material base featuring a completely different potential. Figure 1 shows in a schematic way that the convergence within the fields of F2 is reshaping production tools, giving to I4.0 unique features and capabilities that have never been seen before in the industrial era or, in fact, in any other economic epoch.

On the other hand, the term digitization of the industry refers to the application of digital technologies and techniques in the sphere of production. However, the term is often used in economic and social studies to designate both I3.0 and I4.0 stages interchangeably, prolonging the confusion for the differences between these two industrial stages. It is a fact that the digitization era in manufacturing started during the 1970s with the introduction of digital control systems based on electronic processors. The I3.0 digitization of industry was carried out under the same general conditions, and suffered from the same limitations mentioned above, and they characterized the digital technologies during the whole I3.0 era. As such, digitization in the industry was launched in a patchy and fragmented way since the introduction of the technical advances in one system was made regardless of the progress being made (or not) in other production systems or techniques. The corresponding
infrastructures in factories were developed with the aim to optimize one production line or one activity only, with no or very little relevance and interaction between different infrastructures and/or sectors.

However, the term “digitization of the industry” is too broad. Take, for example, how this is perceived in two articles from the open literature, *The Economist* (2012) and *Enginess* (2021). Although the articles focus on manufacturing only, a wide spectrum of professions, activities, and skills are referenced, so there is an ambiguity to which activities and/or processes the term digitization in the two articles is referring to. It may equally refer to:

- The *fabrication*, i.e., the actual process of production.
- The *conditions of production*, including but not limited to the planning, procurement, monitoring of the supply chains, accountant and logistics systems, inventory, marketing, etc.

However, digitization has a completely different meaning and application in these two categories, and it impacts production in a different way. Whenever digitization refers to the use of the advances in one or more fields of ICT to enhance coordination and to increase the productivity in the tasks associated with the conditions of production, this type of digitization does not necessarily affect the roots of fabrication. For example, the replacement of a file archiving system based on
paper with an electronic database or the replacement of postal mail with email surely increases the utility and productivity in the office, without, however, directly affecting fabrication methods. Even more, two advances in office technology can be introduced completely independent from each other. So, there is a whole range of activities where the value of digitization is limited to make better use of the available information associated with the conditions of production and/or to use digitization to eliminate any inefficiencies due to the inability of outdated technologies to process information at the interfaces between the various functions/processes of production.

Although the two categories are interlinked, the quest for a higher productivity growth rate collides with the inefficiencies arising from a long chain of interrelated professions where each of them is exploiting a different substrate of technologies and expertise. The over-specialization and the over-fragmentation of the professions manifest the limitation of the I3.0 technological framework and the over-stretching of its use to serve the purpose it is never meant to. The article from *The Economist* points out:

Today in advanced factories, the floors often seem deserted, whereas nearby office blocks are full of designers, IT specialists, accountants, logistics experts, marketing staff, customer relations managers, cooks and cleaners, all of whom in various ways contribute to the factory. (*The Economist* 2012)

Through these words, one can already observe the contradictions of this era: for one thing, it is made evident that the fields of F1 and F2 are already on the course of convergence: after all, this is what “deserted floors in factories” means—advanced factory automation via robotic machines. The other thing is that the majority of the activities are still carried out under the I3.0 framework. For example, all activities are very much “localized”: workers of different skills complete their activities by making their way to the particular building, the factory or the enterprise their work is in. Physical presence is still a necessity as it was 200 years ago.

Moreover, such an over-fragmentation of tasks turns any activity into a monotonous repetition of acts as if a worker has skills only for that particular undertaking. The acts of work are very specific and very narrow in their scope. The interaction between the different professions and activities that the workers are carrying out is rather limited, obscuring the interdependence and the interrelations of their activities. The fact that the allocation of the activities to the workforce is made by external, to them, bodies does not make things better. On the contrary, it gives them the impression of exactly the opposite, that their activities are completely decoupled. The inability to rapidly switch the working force between different tasks in a digitized industry is not due to the limited skills the workers have
but in that the whole set of the I3.0 technologies is developed in silos demanding from the worker to understand and adapt to the specificities that each technology has, not the other way around. Then, one should not be wondering why the overall productivity of society increases at very modest rates, if at all.

Under these circumstances, an alternative future, like the one presented in Part I, where a worker operates a piece of qualitatively different production machinery that makes work an abstract entity that allows him to perform the most different tasks interchangeably or to simultaneously employ a set of machines at different geographic locations, becomes impossible. Therefore, the changes should start from the very essence of the industrial age, which is the way we fabricate things. By changing the way we make things, our entire man-made civilization also changes. In the remaining part of this article, the interest is exclusively shifted to the advances and contradictions in contemporary fabrication methods aiming to trace the migration from I3.0 to I4.0.

The Ideal Single-Purpose Worker of I3.0 and Its Limitations

The starting point of industrialization is the moment when a machine is employed to carry out the activities that were previously assigned to a laborer. Before a machine is able to replace a laborer in his activities, it is necessary first to deconstruct the human activity into a number of stages and then to emulate the activities of these stages using a number of specialized tools, machines, or processes. Needless to say, a number of these industrial machines are made with the sole task of copying and replicating the movements and skills of the human hand.

Longer term, the substitution of a laborer with a machine allowed for the overcoming of the variations in productivity associated with the performance of each individual in isolation. That gave a tremendous boost to productivity, as different types of machines are deployed at different places, spreading industrialization, subject to conditions, while the laborer merely becomes the handler of the machine. Nevertheless, the handler is paired to the particular machine, and since these machines are only deployed in specific locations, and they only complete a specific task, the handler needs to collocate with the machine to adapt to the limitations and functions of the machine, not the other way around, and to concentrate his attention only to the specific machine. During this era, machines in the industrial infrastructures had no embedded intelligence of any kind, and they were inflexible as they produced only a single kind of good. So, it is undisputed that the only source of cognition is their human operator.

With the advent of I3.0 digitization, the cognitive processes necessary to operate industrial machines faced the same fate as that of a human hand, i.e., they were deconstructed into a number of consecutive implementation stages and
conceptual activities. Then, each stage was digitized, and via softwarization (primitive or advanced), these cognition functions were embedded in tools either directly or indirectly. As the final outcome, today the complete set of human abilities, i.e., the physical, especially those of a human hand, as well as the cognitive skills necessary to operate a fabrication machine apparatus, are embedded in robotic tools. Since industrial robotic machines can mimic the movements of a hand with immense accuracy and repetition, they replace a single laborer or a group of manual laborers, maximizing productivity as the corresponding industrial processes are freed from the performance variances that are inherent to manual laborers.

A closer inspection of the robotic tools used, e.g., in the automotive industry, reveals that there is a wide variety of them and that each type is tasked with a different activity. The primary reason for this is that they are equipped with a limited number of tools or with tools of a limited scope, e.g., different appliances are attached to a welding robot than on an assembly robot. As these robotic tools can carry out specific operations only, their programming supports, by design, only those corresponding activities. In the framework of I3.0, industrial robotic systems relied on proprietary hardware, operating systems, and/or middleware. In turn, a middleware with little interoperability caused fragmentation, and impeded collaboration and sharing. As a result, the functionality these platforms was able to provide is of limited scope. They were, still, only single-purpose constructions, so the flexibility they offered was limited to serving only the very specific purpose they were built for: they could not be reused or redeployed in real time to carry out new tasks, interchangeably. Therefore, one shall no wonder why the sequential assembling lines are still the dominant manufacturing process in industry.

In I3.0 fabrication, the deployment of industrial machines with single or limited-purpose tools led to applications developed in silo architectures. This was true regardless of the state of automation, i.e., in the case of fully automated machines (e.g., based on robotic arms) as well as when there was a human operator paired to a machine. These robotic apparatuses became the ideal blue-collar worker, and they could completely replace a human worker, and they are still employed today in a large number of production tasks. One cannot avoid pointing out that although these robotic apparatuses are the result of a convergence between technologies, i.e., industrial machinery (a field of F1) with the digitization and softwarization of control systems (a field of F2), this convergence is of limited applicability, leading to single-purpose implementations and silos.

Consider this: laborers can work in welding or assembly lines interchangeably. The corresponding I3.0 robotic appliances could not without a major structural modification.
The Transformation of Manufacturing

They overcome the limitations of the ideal blue-collar worker, a transformation of the production systems, based on industrial robotic platforms that are designed as general-purpose technology systems, is underway. The term general-purpose is used here in the context detailed in Part I of the article: these robotic machines are able to perform several functions interchangeably, so instead of having a collection of single-purpose robotic appliances dedicated to each step of a manufacturing process, one general-purpose robot would suffice. Below, features of these robotic systems are described both as stand-alone entities as well as when these become an integral part of NI.

General-Purpose Robotic Machines as Stand-Alone Entities

Mobility: The robotic system should sustain a six-axis movement for unrestricted functionality to support any application. Moreover, these robotic systems may also feature limited or advanced autonomous vehicle mobility.

The I4.0 End-of-Arm Tooling (EOAT): EOAT is the part of a production system that interacts with the components or the material that needs to be processed, and it is typically found at the end of a robotic arm. The development of a modular and interchangeable EOAT is what makes the qualitative difference and defines the upcoming transformation of production systems. It is exactly this feature that gives the production machine the characteristic of a general-purpose one. It is fitted to the arm with an end-effector, and it may include a variety of sensors and/or actuators. Such an EOAT is understood as a “bank” of all the historically developed tools employed in manufacturing in the previous industrial stages, which the particular machine may activate and use at will. In the most general case, there can be two approaches to implement a modular EOAT: either this is implemented by means of modular, self-configuring robotic end-parts or custom tools are tailored to a given objective with the aid of 3D printers. In particular:

Modular and self-configuring robots are able to deliberately change their own shape by rearranging the connectivity of their parts to perform new tasks (Spectrum 2002). The deployment of self-assembled, modular shaped robots has the potential to revolutionize fabrication: acting in a way similar to a “transformer,” their EOAT part can be reconfigured to become interchangeable, able provide a new functionality at will. In this case, a single general-purpose robotic platform would suffice to carry out a significant fraction of industrial activities, rendering obsolete the corresponding set of special-purpose robotic tools. An EOAT with these qualities allows the robotic machine to provide a specific functionality at one moment and then to reconfigure itself to serve a different application or even to accommodate several processes at once. In this respect,
the modularity of the general-purpose robotic production machines makes them capable of adapting to the requirements of different applications by altering at will the structural part (mechanical system).

Alternatively, a custom EOAT is implemented with the aid of a suitable 3D printer. Producing custom EOAT on-demand directly from a 3D CAD model is a promising technique for the future of robotics. Applications that require custom and interchangeable EOAT are tailored with the necessary agility, improving efficiency and effectiveness.

General-Purpose Robotic Systems as Part of the Networked Intelligence

As soon as a general-purpose robotic production machine is integrated into the Network Intelligence Ecosystem (see Part I), it immensely acquires new qualitative features. By extending the SDN/NFV framework, these machines are orchestrated and operate collectively, being part of the pool of interconnected and programmable ICT resources. This integration of resources allows to intelligently allocate a slice of these resources to the particular machine to support an application or service in a dynamic way. Moreover, it becomes an additional incentive for the proliferation of Robot-as-a-Service (RaaS) notions, as is detailed in the next section. Based on these specifications, the following challenges need to be addressed.

Performance on connectivity layer: in the context of RaaS, these general-purpose robotic production machines are not only interconnected and managed by remotely located superintendents and are linked to datacenter facilities that are dispersed over an extended geographic area. These datacenters process the vast amount of data the general-purpose robotic production systems produce, and they provide feedback to these systems. For this purpose, technology-agnostic, ultra-low-latency, and high-reliability network infrastructures are necessary to materialize these interconnections.

In turn, this postulates connections with stringent end-to-end QoS performance guarantees: the interconnection of a vast number of machines and resources that are distributed across a considerable geographic area requires proper orchestration; otherwise, it could be a source of a major bottleneck affecting the real-time performance in parameters like deadlines, availability, latency, filtering conditions, domain partitioning, etc. Therefore, tight control of the QoS performance on the connectivity layer is fundamental to ensure safety and determinism in robotic systems. The introduction of QoS guaranteed mechanisms will lead to systems that are more robust, and that can achieve better performance in time-critical loops.

Programmability and automation: The effectiveness of general-purpose robotic production machines depends on our ability to reprogram them to perform several applications and/or auxiliary functions, including the alteration of their physical structure. To orchestrate the dissimilar in purpose and heterogeneous in their
building blocks robotic production machines and systems while avoiding the I3.0 pitfalls, it is essential to adopt an Operating System (OS) that exploits open-source software based on reusable building blocks, keeping away proprietary solutions. The encapsulation of these s/w components into the machine’s OS will enhance the functionality of the robotic machine, and it will promote interoperability and composability irrespective of the robot programming language (Natale et al. 2016).

The reason why production machines should be based on an open-source OS is the same as the one used to justify the introduction of SDN (see Part I): in the context of NI, an SDN-enabled control and management framework allows to jointly orchestrate and slice the necessary ICT and robotic resources in an integrated way in order to carry out rapidly changing tasks and processes. This extension of the SDN principles across the new fields makes possible: a) the integration and orchestration of a diverse set of ICT components across a heterogeneous pool of resources; b) the build-up of low-latency communication services that interact with robotics systems in real time; and c) it will endure the introduction of machine learning techniques that foster the adaptation of temporal workflows.

So, it comes as no surprise that robotic middleware developers increasingly employ open-source controllers with the purpose of reusing robotic modules in different applications. Robotics middleware developers have proposed a number of suites like, e.g., ROS (OpenRobotics, n.d.), OROCOS (Orocos, n.d.), Player, YARP, Orca, OpenRDK, Mira, etc. with the aim of using the same OS to support a wide range of functionalities for a heterogeneous set of devices over a distributed infrastructure environment. By means of such interoperable middleware, sophisticated modularity and portability are made possible. In particular, ROS is emerging as the de facto standard, and this forces the developers of middleware to adopt the same approaches and paradigms, something that favors compatibility and code sharing.

These advances are in-line with the corresponding advances in connectivity networks in respect to the management of heterogeneous systems via SDN. Moreover, the adoption of an SDN-enabled management system will allow interconnecting the robotic machines, as well as any other type of machine, to datacenters helping the operators to extract and aggregate data that can be further used to optimize machine performance in real time or retrospectively. By connecting the robotic machines to the very extensive IT arsenal like programmable logic controllers, datacenter servers and their databases, etc., the actions of robotic production machines are coordinated and automated to an unprecedented extent. Some of these changes are already stepping up. For example, cloud robotics (Kuffner 2010) is moving in this direction. Nevertheless, the integration of robotic fabrication apparatuses to the framework of NI has far more important consequences than to merely outsource computational power to the cloud, which is the purpose of cloud robotics.
Once more, it is pointed out that it is the convergence, the interrelation of the transformations, which will define the course of I4.0. Consider this: even if open-source s/w is extensively employed to develop the corresponding OS and middleware modules—something that will make, indeed, feasible the joint orchestration of robotic, connectivity, IT, and IoT resources—the potential danger of deploying a vast number of over-fragmented, single-purpose, infrastructures still exists. Open-source s/w or not, the management of a large number of decoupled platforms developed in silo architectures, as it was done in I3.0, will make it extremely difficult to guarantee the necessary QoS performance. This is especially important when a large number of users simultaneously access the corresponding resources, which are spread over a wide geographic area across a country (let alone the possibility these resources are spread over different continent regions). For the digital economy to flourish, the transformations need to be pursued with vigor creating a wavefront of changes. Changes that are interrelated and where the progress in one sector depends on the progress being made on all others.

The Socio-Economic Consequences

From the aforementioned analysis, it is deduced that fabrication based on modular, interchangeable and reusable machines, systems, and, eventually, interconnected infrastructures create a disruption in manufacturing of such a magnitude that has not been seen since the days of Henry Ford. This transformation of the production systems not only brings a productivity leap but also it changes the essence of work in a fundamental way for, inasmuch the labor work becomes completely abstract, the laborer becomes the “regulator” of the working process. The following example gives an indication of how the general-purpose robotic production system enhances productivity in manufacturing.

To maximize the efficiency and the effectiveness of the systems and processes a regulator superintends, the regulator first starts a working process by setting the necessary agents in motion, and he defines the phases and the stages of the process as well as the corresponding operational parameters. To do so, the regulator assigns a number of identical general-purpose production machines to complete an industrial task. The regulator has the option either to plan and coordinate the machines to collaborate and execute in parallel a single task or to assign to each of the machines any of the sequential tasks a multi-step manufacturing process has. Because the general-purpose production machines are easily reconfigurable to support any of the necessary functions, the tasks are completed interchangeably from any of the machines, so in the former case the volume of products increases while in the latter, there is a speed-up of the cycle times.
The critical point here is that as soon this initial task is set, the regulator shifts his attention to other tasks in the pipeline to which he assigned a different set of general-purpose machines, until he returns back to the first engagement when/if this is needed. Through this process, the regulator delegates all repetitive and tedious tasks to the robotic machinery, and as he is freed from them he can exercise his knowledge, abilities, and ingenuity to regulate different, maybe completely different, processes. The ability the regulator of the workflow has to superintend a number of different tasks during the same timeframe and, hence, to maximize his productivity, are significantly reinforced if the robotic production machines are capable of functioning (semi)-autonomously. For this purpose, these machines are also equipped with sensor/IoT systems that provide performance diagnostics data, combined either with embedded machine learning (AI/ML) capabilities or links to datacenters with the corresponding facilities, so the machine can autonomously decide for the sequence of the necessary actions, through trial and error, instead of getting direct instructions from its user.

So far, no assumption has been made about the geographical location of the regulator as the corresponding workman is always on-site in all previous industrial stages and economic epochs. However, an even deeper transformation emerges when the production delocalization and the deployment of general-purpose manufacturing systems reinforce each other. This prospect is not only unique to the I4.0 stage but it also manifests a distinctive phase in the history of production: the production systems become remotely controlled, and they are reconfigured/upgraded with software (whatever this means) to rapidly respond to a changing environment and/or to perform new tasks without a major disruption of production or without a major reinvestment of capital. This also allows the same production systems to fabricate a wide range of products using a variety of materials, in striking contrast to their I2.0 and I3.0 counterparts that are capable of fabricating only a single product.

This framework also raises the prospect in which a collection of production systems and a number of regulators that operate from different geographic locations share the same infrastructure. In the context of RaaS, a collection of remotely controlled, general-purpose robotic production system decouples ownership from usage: since RaaS formations are universal and ubiquitous, federated production schemes take advantage of smaller or larger clusters of systems of that sort, which are formed ad-hoc in different locations, to time-share the infrastructure and to assign a slice of the collective production resources to a particular project. In this case, the production of goods is directly analogous to the number of the production systems allocated to the project, so the production, either on a local scale or across the whole digital economy, expands or contracts in a dynamic way. This feature is in striking contrast to the existing mode of manufacturing, where enterprises may
produce goods only after a certain minimum number of single-purpose machines are deployed at a specific location. This new mode of fabrication constitutes a major divergence from all previous industrial paradigms:

This rationalization of production creates the conditions under which the effect of overproduction will gradually die out while new economic models like direct production (Ejim, n.d.) are emerging, ushering in a new social entity, the prosumer. This word is a contraction of the notions “producer” and “consumer” (Toffler 1984), and its use is fully justified as the two opposite poles cease to exist as independent entities.

A prosumer with direct access to clusters of general-purpose production systems produces the goods he needs via “one-click.” This accelerates, to the maximum, the economic cycle and the rotation of capital as it cuts down the delays by means of these rapidly reconfigurable and product-diversified production systems. As a result, there is a dramatic reduction in the time between “design” and “production,” so mass-production is replaced by mass customization. Today, making a customized item often requires extensive knowledge of the order that the different processes are executed. The convergence of ICT and these robotic production machines into a single domain orchestrated via open software (s/w) allows to create personalized items without that know-how, so mass customization becomes the norm. Mass customization on that scale is not feasible under the existing centralized forms of organization in commerce.

Through mass customization, a large fraction of the existing costs in the end-to-end production chain is curbed since a whole rank of middlemen and merchants is made redundant with enormous social consequences.

The physical presence of the industrial workers in the factory and the need to have them operate in sync is no longer an essential precondition of production. The production can attain asynchronous, i.e., the regulators may operate the (remote located) production systems at different time windows and/or complete the higher and the lower priority tasks on different time cycles.

**The Impact of Technology Fusion on I4.0 Agriculture**

Changes of equal magnitude like those described in the previous section are taking place in agriculture, leading to comparable transformations in this I4.0 sector. In fact, although this might sound strange, it is argued that agriculture is one step ahead compared to manufacturing as progress in this sector is more tangible.

During the whole historical era that covered I2.0 and partly I3.0, farmers were employing electromechanical terminals like tractors, combines, etc., that feature no embedded intelligence. With no stored program control technology, there is no need for these apparatuses to be interfaced with any connectivity networks.
The farmer is tasked to carry out the necessary handling operations like steering, (de)activation, etc., by means of an electromechanical control box mounted in the cab. Following the general trend of the I2.0 and I3.0 period regarding market protectionism policies, these control boxes were tractor-vendor specific, and when new implements were to be added, new wiring and cabling were needed, so a seamless integration and the usage of heterogeneous terminals was a challenging task. Therefore, the farmer not only had to have a physical presence in the field in order to complete a specific task (that is split up into, and carried out by, a series of operations, one at a time and in a predefined order), but also an army of laborers was necessary to repeat the same activity in parallel or to carry out similar but complementary activities.

**Digitization in Agriculture: Advances and Contradictions in the Migration from I3.0 to I4.0**

Here, we adopt the distinction being made previously between the *conditions of production* and the *process of production* (farming) itself. Again, the advances in the former may not impact the latter, so the effect of digitization is considered separately for the two cases.

*Digitization of the conditions of production:* For thousands of years, including the first industrial stages, the completion of various agricultural tasks was often based on empirical decisions. Digitization reversed this trend, and an increasing number of technologies and operations exploit the advances in science to enhance the output of cultivations: networked sensors and other IoT technologies are used to collect a diverse set of data while AI-assisted expert systems, which are widely available today, process the data aiming to define the optimal course of actions in the particular agricultural field. Moreover, other applications allow for the maximization of the yield based on the field-specific application of fertilizers, pesticides, or water. Large databases are constructed worldwide to provide relevant information to the farmer for the best practices per cultivation and for economically and environmentally balanced farm management. Many of these services are already offered today, and state or private organizations assist and encourage the farmers to use them as much as they can.

*Farming automation based on robotic platforms:* The introduction of the ISOBUS standard\(^2\) is a milestone in the digitization of agriculture as it defines a paradigm shift: The ISOBUS is a standard to ensure compatibility between tractors, the control units of the machineries, and the implements of different vendors. Based on this standard, the farmer employs a tractor made from one vendor along with implements made by the same or a different vendor in a plug-and-play manner. Thanks to the universal characteristics of the ISOBUS protocol, no custom modifications of the existing firmware of the tractor or the implements are needed.
The deployment of the ISOBUS has a precondition for the availability of digital control systems based on electronic processors, which was exactly the point of departure for the digitization in manufacturing. Therefore, like in manufacturing, it is the availability of planar ICs that made possible a new material base upon which the I3.0 transformations in agriculture are built.

Furthermore, one has to point out the similarity between the reasons that led to the introduction of ISOBUS and the reasons why SDN and NFV were introduced in connectivity networks (see Part I of the article). In both cases, the objective is the same, i.e., to overcome the fingerprint the market protectionism has left on technology evolution and to ensure the interoperability between systems from different vendors. That these like-minded developments that we observe unfold in parallel in these seemingly unrelated sectors is not a coincidence. On the contrary, through them, one sees the trend, the necessity; a strong message is sent that the convergence in the fields in F1 and F2 has common roots.

In addition, deeper transformations are already underway in agriculture beyond the mere interoperability between different vendors, as automation is stepping in rapidly: brand names in the field, like John Deere (Deere, n.d.) or ASI (Asiro, n.d.), already offer products like humanless (robotic) tractors. Therefore, the analysis presented previously with respect to the new horizons the robotic platforms are opening up, as well as the related interoperability challenges, are equally applicable here. Despite these advances, the I3.0 framework still makes it mandatory for the farmer to be on-site to operate the tractors and combines in the cultivating the fields while he still has to be in the vicinity of the IoT terminals to operate them. There are still many “local” constraints, so the farmer is bound to spend a considerable fraction of his time in the field, and there is still considerably manual labor work.

**Technology Convergence in Agriculture I4.0: The Consequences**

The SDN/NFV paradigm made its debut as a solution for overcoming the barriers the proprietary technologies set and as a practical solution to the corresponding interoperability limitations in the telecommunications industrial sector. Now, this innovation has spread beyond the telecommunications networks, and become a “vehicle of change”: it serves as an overarching platform that ensures interoperability between the technologies among all industrial sectors and across the different fields.

Changes in sight in agriculture suggest that a broad spectrum of heterogeneous technologies like sensors and IoT terminals, robotic tractors and drones, network infrastructures, data processing, and storage facilities are all integrated by means of an SDN-like overarching control and management platform. Once more, one observes that technology convergence spreads in different fields, creating a wavefront of change: John Deere is promoting electric tractors based on the following
argument: “Electrification isn’t just about using batteries as the power source. It’s about using electrical drives to replace engines and hydraulics” (Deere, n.d.).

This is exactly the idea presented in an article written almost 20 years ago (Burns, McCormick, and Borroni-Bird 2002); it is argued that by switching a vehicle’s power system to electrical, one may employ a new type of engineering architecture, called “drive-by-wire technology” in the article, which with the aid of software may radically change our perception about vehicles and the role these play in modern society. As it is stated in the article, “It will allow a vehicle to be a luxury car today, a family sedan next week or a minivan next year” (Burns, McCormick, and Borroni-Bird 2002).

So, switching a vehicle’s power system from an internal combustion engine to electrical vehicles with interchangeable body modules become a reality. This is an example whereby means of SDN and adopting a new power system, F2 and F3 technologies converge to produce a radically different outcome compared to corresponding I3.0 legacy systems. Extending such notions, it is not long before the day comes when the various implements of a tractor will also adopt similar interchangeable technology, resembling the existing Black & Decker multi-head screwdrivers: with the aid of automation, the various tools will be self-assembled/modified in real time by means of modular robotic structures or otherwise.

As such, not only will a variety of agriculture robots (for, soil preparation, plant nursing, transport, etc.) appear soon, but, gradually, as new robotic series start employing interchangeable vehicle platforms with implements that adapt their functionality in real time, these robotic platforms will evolve toward a single platform that is used interchangeably on a diverse range of agricultural tasks. There will be general-purpose agricultural systems in a way similar to their counterparts in manufacturing.

Last, but not least, apart from the robotic machines that roar on land, drones are already being employed to play a special role in 14.0 agriculture. Today the availability of cheap and easy to use drones is widespread, and new generation drones will operate in future farms next to robots to support scouting, weeding, and harvesting. As tractors and drones are, effectively, agricultural robots, their connectivity requirements with respect to QoS performance discussed previously apply in this sector, too. However, precision agriculture requirements pose additional challenges: there is the additional need to guide these robotic systems with sufficiently high precision in the fields. This task is currently based on a satellite navigation positioning technique called Real-Time-Kinematic (RTK), while there are ongoing efforts to replace the existing “local” techniques with a network-centric platform (Network RTK).

It is not surprising that these advances are the necessary and sufficient conditions to put in motion the delocalization in agriculture. In many respects, the need to
transport IoT data, back and forth, from an agricultural field to datacenters and the deployment of Network RTK receivers, is already overcoming the existing framework that considers agricultural tasks as exclusively local activities: key precision agriculture functions are not only already networked but also they make necessary a robust remote connectivity network featuring high availability. As these innovations gain momentum, we reach the point where robotic agriculture apparatuses can and will be remotely operated, as an integral part of the NI ecosystem, together with their general-purpose counterpart machines used in manufacturing I4.0.

In fact, Agriculture I4.0 is going to be a highly-distributed ecosystem where the different stakeholders like farmers, robotic entities (tractors, drones, etc.), and artificial intelligence/machine learning systems are dispersed in different locations. Exploiting the advances in a number of scientific fields like the widespread availability of Cognition-as-a-Service platforms and the adoption of self-organization principles, the agricultural machines will be synchronized by adapting their position, their working speed, and function without needing constant human supervision.

Therefore, if one connects all these dots, one observes that the starting point in the process is the remote operation of robotic tractors, and the end of the line is humanless agriculture farms. After Fabrication I4.0, it is Agriculture I4.0 too that is going to employ hyper-converged technology mechanisms that exploit a general-purpose apparatus. As a result, the delocalization in agriculture will progress in parallel with agricultural machines that make use of general-purpose implements to support:

- Remote operation, monitoring and management;
- Swap between different functions in real time by means of s/w upgrades, so the same general-purpose agricultural system to support a diversified set of tasks;
- Remote asset tracking, diagnosis and repair.

Last but not least, the convergence in the fields of the factors F1, F2, and F3 to support I4.0, will leverage the convergence of these factors with F4: the availability of new methods for testing innovations like the “digital twins” and the availability of a NI ecosystem that allows to collect and process the data stemming from each and every agricultural field and to extract patterns. Overall, this will facilitate the worldwide diffusion of the knowledge and experience gained from all farmers across the globe to make biotechnology safe and efficient for humans rendering progress in one region dependent on progress in other regions.

These transformations reshape the primary sector in a way we haven’t witnessed since the Agrarian era: agriculture evolves to become a robot-intensive, data-driven process that is able to optimize the use of resources, like water, while...
it will reduce the pesticides needed so there will be a significant increase in output while using fewer resources. These changes redefine a farmer’s way of life as they are not bound to spend their entire life in the same local environment. The advances in many fields of science and technology offer them a wealth of knowledge and the best practices to overcome a number of hurdles ranging from irrigation problems to soil variation, pest and fungal infestations, differences between healthy and distressed plants, leading to improving yields and increased efficiencies. These operations can be completed asynchronously, at the convenience of the farmer adapting precision activities to the needs of the specific hour of the day. Eventually, a new landscape will emerge that transforms a muddy, low-skilled profession into a high-tech, research-lab level activity.

Conclusions

The character of the production systems is changing in a dramatic way in the context of I4.0. The catalyst for these changes is the convergence of the fields of ICT that gradually entangle with the fields of other factors into a framework of interrelated and interdependent transformations. An effort is made in this article to list the shortcomings and contradictions in the existing industrial stage, to elaborate the methods and the technologies upon which the transformation of production systems will be made possible, and to highlight the plausible socio-economic implications. In the years to come and as I4.0 progresses, the most important form of social interaction, production, will not only transform our economy but also change our way of life into something fundamentally different from what we’ve seen so far.

Notes


References


