Automation Taxonomy for Industry 4.0 based on human features: A Sensing Smart and Sustainable approach

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A Sensing Smart and Sustainable approach

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***Abstract*— The latest products and services have been designed and created under Sensing, Smart, and Sustainable (S3) and Industry 4.0 (I4.0) conceptualization. Moreover, there is a strong trend to develop more products using the S3 concept; on the other hand, I4.0 is the most advanced automation scheme implemented in manufacturing systems. Yet, a taxonomy that integrates clearness, applicability, and universality in automation systems, that drives to I4.0, is still missing. Since automation systems were conceived to substitute human operators, this paper proposes a novel taxonomy based on human operator features, as a solution for bringing a clearer perspective addressing the validity of human replacement. The suggested taxonomy not only allows to select and classify but also provides a complete structure about the human features and the S3 products that are deployed in the I4.0. The derivation of this taxonomy is presented in this paper, seeking to show its advantages and limits.**

Keywords- Industry 4.0, Product Development, Automation, Taxonomy, Sensing, Smart, Sustainable.

I. Introduction

The concept of Industry 4.0 (I4.0) arises as the integration of technologies of the last four decades, such as Cyber-Physical Systems (CPS), Internet of Things, Cloud Computing, Artificial Intelligence; among others [1]. According to [2], the estimated market value of the I4.0 in 2019 was 71.7 billion USD, and it is expected to grow at a compound annual growth rate (CAGR) of 16.9% from 2019 to 2024, due to the increasing adoption of technology trends. With those developments, challenges arrived for the future enterprises and new product developers, therefore there is a demand of reference models and taxonomies; such as the S3 taxonomy (Jonathan Miranda, et al., 2019), which seeks to integrate global trends as sustainability to the aforementioned I4.0 concepts [3].

The S^3 concept can be summarized in three elements: Sensing, Smart, and Sustainability. Where Sensing stands for the capability to detect physical or virtual variable(s) of an environment, Smart is the property that allows a system to control the state or conditions of a requirement and Sustainability pursuits to cover the current needs without compromising the future. Although S^3 taxonomy aims to be a general structure scale, the ontology of this concept rises from the query of I4.0 trends impact to the enterprise systems and yet, it does not consider how a product is created [4]. Hence, it cannot be directly applied as it is to the classification/evaluation of products, due to the compatibility lack.

Discussions around automation have reached the expansion and transformation of concepts and taxonomies known as level of automation (LOA), that started to evaluate tasks performance from manually, to fully autonomous systems, later divided in four generic functions: information acquisition, analysis, decision, and action implementation [5]. However, those functions were principally limited around the influence of human factors, and automation is not only about replacing human activities but also to enhance human-machine interaction. Luca Save et al. proposed a cognitive connected LOA taxonomy, which ended up being very complex, to apply it in a general way. Jörgen Frohm et al. proposal in [6], separates physical elements and cognitive tasks of the system, which is only reliable when evaluating an isolated arrangement. In another perspective, Jian Qin et al. [7] combined perspectives of future manufacturing visions and CPS attributes to propose a categorical framework of manufacturing, but only with Automation and Intelligence components, being unable to apply it generally.

Deficiency in the definition of taxonomy can contribute to the incorrect classification of devices, and therefore to the ambiguous application of concepts for product development. The quantitative weighting of qualitative properties is important for evaluating products; especially in the case of a feature concept such as S^3 levels.

The objective of this project is to develop and present a proper taxonomy that allows to asses products in relation to the level of S^3 reference parameters of human involvement and technology development that can be applied for the valuation of product properties; aligned with the I4.0 trends. Our proposal encompasses the different phases of technological development that start on individual devices and culminates in advanced systems set of applications.

Exploring the S^3 Taxonomy, the authors faced controversial definitions of the levels, related to enterprise allusions; therefore, this paper aims to achieve an improved taxonomy structure, with clearer and better-defined levels. Hence, Section 2 sought to find major events and properties from the Industrial Revolutions, Human Factor and Level of Automation to function as a reference of the S^3 taxonomy for Industry 4.0. Moreover, Section 3 expands the outline of the taxonomy proposal and defines its levels. Meanwhile, Section 4 presents the conclusions of this work. Finally, in Section 5 future endorsements are drawn.

II. TAXONOMY BACKGROUND

A. *Industrial Revolutions*

The fourth industrial revolution was formulated and presented in 2016 by the founder of the world economic forum Klaus Schwab, who describes it as an era of the technological revolution that is clearing off the limits between physical, digital and biological areas [8].

Technologies like CPS, Artificial Intelligence (AI), Autonomous vehicles; are becoming entwined in our day to day lives. In order to understand it better, it's important to highlight the main technological contributions that can be observed in Fig.1, as well as the impact in the human capabilities, described below as in [9].

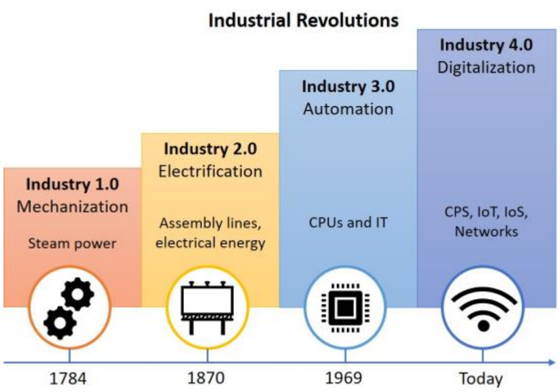

Figure 1. Main aspects of Industrial Revolutions.

The first industrial revolution started in Great Britain in the late 18th century, powered by the major invention of the steam engine in 1784; which, resulted in new manufacturing processes, the creation of factories and the upswing of the textiles industry, shifting from an agrarian economy to one based on mechanical production.

The second industrial revolution around the 1870s, was marked by mass production and some material/energy industries such as steel, oil, and electricity; deriving in some of the major technological contributions like the lightbulb, the telephone, and the internal combustion engine, ushering affordable consumer products for the mass consumption era.

The third industrial revolution, also known as the digital revolution due to the development of information and telecommunications (IT) technologies, took place on the second half of the 20th century, and within just a few decades it produced the invention of semiconductors, computers, and internet.; which impacted business, industry, products, and society, connecting people in a common environment to meet an age of optimized and automated production.

From that on, technology (CPS, IoT, Cloud Computing) happens to be merging more in human life, and the development of applications and devices have fastened more than ever. Some of the key factors of the fourth industrial revolution are shown in Fig.2.

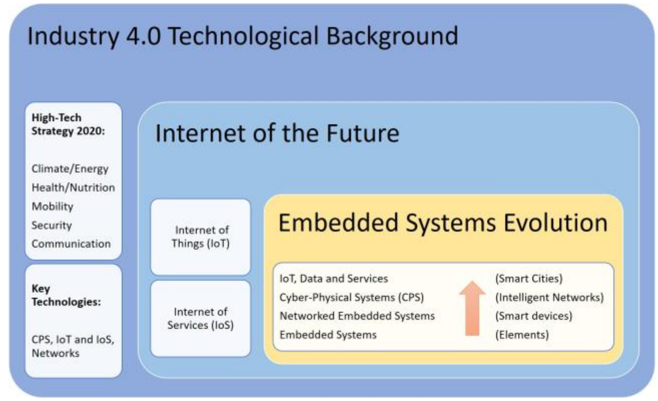

Figure 2. The fourth industrial revolution principal components (GTAI)

Embedded systems that operate to process information and control functions inside a product, interact with the exterior through sensors and actuators, interconnected between them and also to the virtual network of the internet, which gives the capability to use data to provide online services and conform CPS [9]. Thus, the evolutionary development of embedded systems culminates networking over the internet, as the Internet of Things (IoT) and the Internet of Services (IoS), breaking existing models to new service applications, production value chains and business models [10]. Additionally, decentralized control assist building networks and encourage process management independence, powered by the relation between real and virtual worlds.

B. *Human Factors*

The capabilities to support human activities have been also improved; as new tools, methods, and procedures emerged. Nevertheless, in order to talk about the technology development, it should be first discussed about the human factors of Fig.3, which are those related to the capacities to interact with, perceive and sense the environment.

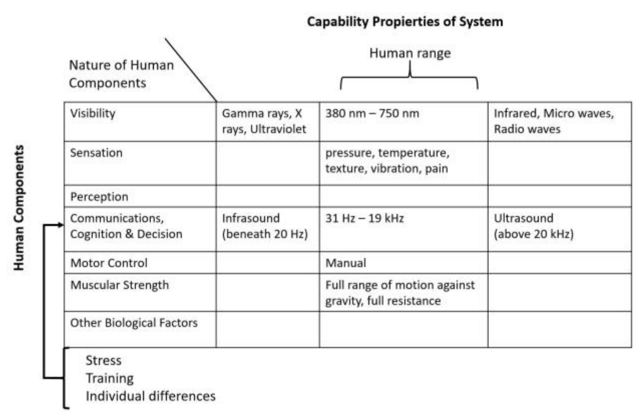

Figure 3. Human factors matrix (modified from the original of Christopher-D.-Wickens [11]).

Across the top of the matrix, there is a range that allows distinguishing the limits within which the human operates with their senses and capabilities. At the left, there are some of the system environment activities (areas), to which an operator focus; that can be affected by stress, training, and differences in skill or capability [11]. With this established, it can be postulated that there can be technological elements with wider, similar and narrow amplitude than the human element.

For individual processes, the human factors can be applied directly; but as the industrial revolutions came by, the tasks biding and the amplitude of organization grew. Therefore, the next level of human involvement was the control and administration of systems, which can be manual activities automatized, or any combination of activities and series of procedures; for instance, talking about chain production and production lines in factories. With the ability of machines to perform human activities, the concept of automation was coined in the 1950s by Diebold, to denote both automatic operation and the process of making things automatic.

C. Level of Automation, pyramid taxonomy

Many operations previously performed by humans were taken over by machines, reducing the time of production, hence increasing productivity and improving quality; due to precision and accuracy enhancement. Moreover, the role of the operator changed from manual production to supervisory activities; with the objective of improving the systems with more intellectual or cognitive tasks like planning, diagnosis and problem solving [12].

Those roles and activities, as well as the interaction between the humans and the systems, have been embodied by different taxonomies among them, the Levels of Automation (LOA) specify the automation degree of involvement as shown in Fig.4. Moreover, analyzing those automation pyramids, we realized that they mainly focus on production, which is the goal of the industry. Thus, to apply the same scheme to the products, the main core should be the principal activity of employment for which the product was developed.

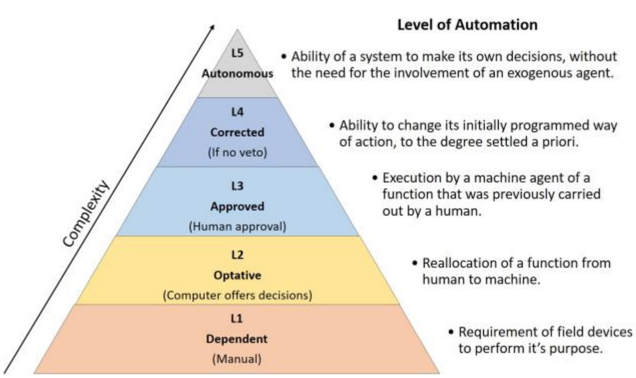

Figure 4. LOA taxonomy.

Currently, there is no taxonomy or feature evaluation scale for products that relates to industrial revolutions, therefore in the same way that the LAOs are established for production systems, the S^3 taxonomy addresses the enterprise perspective, yet none of them achieving the suitability for products.

D. Sensing, Smart, and Sustainable

Applying principles from systems and product lifecycle engineering the Sensing, Smart and Sustainable was developed to promote the integration of I4.0 trends in a model that can tackle the new century challenges [3]. One of the main characteristics of this model is that it seeks to encompass the evaluation of systems in a general way, and which can be applied not only in products development but also to production processes and manufacturing systems, even though there is a dispute around its general applicability due its seminal references, which are mainly focused on an enterprise features levels, as analyzed in Fig.5. Therefore, for the S^3 conceptualization:

- Sensing was conceived from the expected impact of the Internet of Things on businesses, and the need for transformation into organizations with the capacity to sense, analyze and seize information intelligently, supporting the decision-making process [4].
- Smart, is a control classification by LOAs, which takes into account the main characteristics of various authors [12], but still being an industry oncoming, not generally applicable for products.
- Sustainable is typically divided into three main pillars which are the social, economic and environmental impact. Looking over this impact, tools like Life Cycle Assessment (LCA), Carbon Footprint, and others are applied. Although this is a modern perspective, and the world still has ancient levels of response to this topic [13].

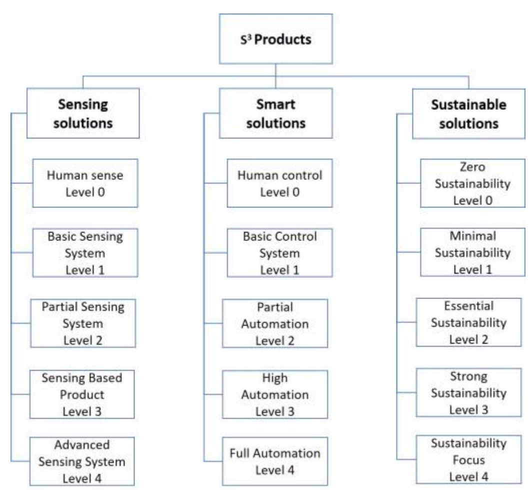

Figure 5. Sensing Smart and Sustainable Taxonomy (Jonathan Miranda, et al., 2019).

Henceforth, human senses are capable to perceive a range of physical variables as posted in the human factor's matrix of Fig. 3, the sensing characteristic ought not to be established as a human capability in the zero level because there could be devices with lower potential than the human factor. Likewise, for the smart zero levels, human capability is one of the greatest goals of automation and artificial intelligence, in order to substitute human activities to help beating challenges; furthermore, some technologies overcome the human competence, so a more robust approach could be to establish the reference baseline of human skills right inside the extremes of the taxonomy.

III. AUTOMATION TAXONOMY FOR I4.0 BASED ON S^3

A taxonomy is proposed based on the capacities, virtues, and limitations of the human, such as sensory, information processing, decision making capability, among others. Simultaneously the historical development is considered to improve the structural order from the S^3 original taxonomy. With this foundation, a reference can be achieved to weight technologies with wider, equal and/or minor capacities than those of the human being. The proposed taxonomy to define the Sensing, Smart and Sustainable levels for products is presented in Fig. 6.

Industrial Revolution	Level	Sensing	Smart	Sustainable
I0.0	0	Perception (ambiguous)	Score control	Landfill, Incineration
I1.0	1	Analog (comparable)	Analogous control (Instrumentation)	3R (product focus) reduce, reuse, recycle
I2.0	2	Digital (transduction)	Digital control (programed)	6R (manufacturing) + recover, redesign, remanufacture
I3.0	3	Multisensing (discretization)	Integrative control (composition)	Nuclear (local)
	4	Collective sensing (uncertainty reduction)	Intelligent control (autonomous)	Communal (national)
I4.0	5	Crowdsensing (collaborative)	Coordinative control (interrelation)	Global (international)

Figure 6. Levels of S^3 Taxonomy.

The proposal makes a combination of the industrial revolutions, the S^3 features, and human capabilities. At the left side in the first and second columns from Fig.6, the relation between industrial revolutions and the levels of S^3 characteristics (found in products) is presented, which comes from the historical precedents and the human involvement. Meanwhile, the indicators of the right side of the Fig.6, show how the proposal moves forward from the physical limits to the individual replacement and beyond.

Moreover, in order to clarify the proposed taxonomy levels from Fig. 6, each level is described below:

Level 0 - At the beginning of the industrial era, there was no such thing as a sensor and the measurements were made with the perception of the senses; control was carried out through scores based on intuition and accumulated experience and the waste management consisted of recollection and incineration.

Level 1 - Following, the first measurements were made in a comparative way with analogous elements, the control from devices was manual and waste problems were tackled by reducing, reusing and recycling materials.

Level 2 - Technological advances made possible to transduce from any energy to electricity, programs and manufacturing enterprises then set control commit in the residual 6r methodology to recover, redesigning and remanufacturing products that normally would pollute.

Level 3 - Discretization made possible to save data in memories; the control systems started to gather in the PLCs the minimal connections and ports to enable communications with the machines on the shop floor, residual waste programs engage people to separate its garbage at home before recollection.

Level 4 - Massive data can be merged to reduce uncertainty and improve the accuracy of measurements; artificial intelligence gave autonomous capabilities to the products and community policies promote social participation to achieve sustainability goals.

Level 5 - Nowadays, computers, smartphones, and social media applications are entwined within a global network that can be handled to provide context-aware features, control is also coordinating interrelated intelligent devices and there is a need to tackle sustainability problems on a global scale.

A. *Levels of Sensing features in Products*

Sensation has three main characteristics, transduction that changes physical energy from one type to another, an adaptation that decreases the response overexposure and a relation against perception converting information into experience.

Level 0 – Perception: Without an element to recognize and measure the environment for the system, sensing relies on human senses and its interpretation; this can be imprecise and can lead to an error (ambiguous).

Level 1 – Analog: The first way to measure anything is by comparing elements of the same physical property and establish a scale (comparison).

Level 2 – Digital: With electricity started the transduction from one type of energy to another, regularly electricity. (transduction).

Level 3 – Multisensing: With the creation of semiconductors the possibility to save data emerge and the discretization of the analogous information (discretization).

Level 4 – Collective sensing: Combining information from multiple sensors and machines increases the data quantity, which can be used to produce a statistical relation to producing a more accurate measure (uncertainty reduction).

Level 5 – Crowdsensing: With the internet, mobile systems and cloud computing, there is a capability to measure simultaneously, share data in real-time, and process the information to boost novel sensing applications in areas such as environmental monitoring, transportation and traffic planning, urban dynamics, location services and more.

B. Levels of Smart features in Products

In order to perform their tasks, technology has been developed with the aim to be autonomous, which is the capacity to be independent and self-governing. However, this capacity has different levels of smartness, going from a dependent system to an intelligent product, capable of making choices.

Level 0 –Score control: The activity or performance of the product, relays solely on human involvement, experience, and interpretation.

Level 1 – Analogous control: The device can perform certain actions, but to do so, it requires the control and operation of an individual. (Instrumentation).

Level 2 – Digital control: Elements fed with electrical power capable of performing predefined electromechanical activities. (programed).

Level 3 – Integrative control: Several components and/or devices connected to a master programmable controller, able to record instructions and execute elaborate assignments. (composition).

Level 4 – Intelligent control: Programmed to think like humans and mimic not only their actions but the decision-making process; to diminish exogenous intervention. This level requires a junction of different knowledge areas, in a common ground base such as Artificial Intelligence. (autonomous).

Level 5 – Coordinative control: Government is made virtual, simulations, and cloud computing intensify the amplitude of coordination and concepts as swarm autonomous vehicles, business analytics, data science, arise. Human interaction plays a more administrative role. (interrelation).

C. Levels of Sustainable features in Products

From the United Nations Sustainable Development Goals established in 2005 emerge the social, economic, social and environmental pillars of sustainability. Technology transactions come as an unbalanced economical exchange, which in time leads to gaps and differences between countries. Every product has its impact not only helping to solve problems or covering needs but improving the lives of the people and community in the present to preserve the future. Moreover, all of these balancing the resources to prevent the destruction of the environment [14].

Level 0 – Landfill, Incineration: When there is zero sustainability, the way the waste is managed is gathering the residuals and sometimes disposed of, for example, with fire.

Level 1 – 3R (product focus) reduce, reuse, recycle: The very first way to diminish waste, is not producing at all; so, reduction comes first. Then reuse the product, for instance, when talking about imperishable things. Furthermore, its elements, the case of a material like the metal; can be melted and remolded to recycle.

Level 2 – 6R (manufacturing) recover, redesign, remanufacture: Waste management should not be made only in the final disposal of a product; it can be recovered, redesign and remanufactured; in the case where the material does not get to be recycled yet.

Level 3 –Nuclear: It is important that the product complies with the rules and corresponds to the principles of the organization, group or family (local).

Level 4 – Communal: The business around the production can also affect workers, employers, and communities. Therefore, it is important to expand sustainability to a collective level. (national).

Level 5 – Global: From the planet, we get resources that seem to be endless, but in the long run, the way we consume and pollute is unsustainable. Meeting international sustainability standards will aid in reaching solutions in accordance to the international domain. (international).

IV. DISCUSSION

The purpose of developing a taxonomy such as the one presented is to help in providing objective information about technology related to the industrial revolutions; that can be applied not only to classify but to support the new product development. Unlike Digitization (I4.0) that seeks to virtualize, the objective of Automation (I3.0) is to relieve the activities of the human being for technology capable of doing the same with equal and/or better efficiency. With this in mind, we can establish the order and reference for the levels of our proposal; as a historical, technological evolution. The reference point requires to be universal, and human capabilities are well characterized, so are the industrial revolution timelines.

I4.0 systems require information, processing, and interrelationship capability with other applications, as well as the human being. Automation systems should be able to train at least at the same time it takes the human to acquire the ability to perform the corresponding task to be replaced. Answering what would expect from technology to be applied to the level of I4.0, at least to exceed human capabilities. Currently, there is no I4.0 taxonomy that relates human capabilities to its classification so that the proposal could fit in this requirement.

The predecessor taxonomies such as LOA and S3 were shown to be incomplete and contradictory in several aspects, mainly its inapplicability to general systems such as products or processes, due to its enterprise tackle of original characteristic definitions.

In the industry, a benchmark could be the error rate of the production system, with only the operator, without the technology being considered to improve process efficiency and compare against implementation to assess its effect. It would then be expected that, at a higher level of human factors, there would be a decrease in error; that is, it will improve efficiency. Another important aspect to consider is whether the implementation of the technology involves adapting the facilities or some part of the process for your application; if so, compare against the stage only with being human and assess whether it is appropriate to invest in such modifications or not.

V. CONCLUSION

As a synthesis in an image we can say that the taxonomy posed, provides the possibility of placing any product in its levels, aligning itself to industrial revolutions, with the characteristic and advantage of linking its assessment to the level of reference of human capacities; being in the first levels, from 0 to 2 minor capacities to the human, from 3 to 4 the transition of what an individual is capable, and from the 5 is developed the superhuman capacity, which is achieved by managing information obtained by the sensing and use of multiple it is interconnected devices and applications across the global Internet network, autonomous system master controls, and global challenge response capability in a sustainable status.

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