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TOWARDS AN OPERATOR 4.0 TYPOLOGY: A HUMAN-CENTRIC PERSPECTIVE ON THE FOURTH INDUSTRIAL REVOLUTION TECHNOLOGIES

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ABSTRACT

This paper presents early concepts and future projections of the so-called 'Operator 4.0', understood as a smart and skilled operator who performs not only cooperative work with robots but also work aided by machines as and if needed by means of human cyber-physical systems, advanced human-machine interaction technologies and adaptive automation towards achieving human-automation symbiosis work systems. This research introduces an Operator 4.0 typology as well as exploring a set of key enabling technologies that can support the development of human-automation symbiosis work systems for the Operator 4.0 in the Factory of the Future defined within the Industry 4.0 framework.

Keywords: Industry 4.0, Operator 4.0, Human Cyber-Physical Systems, Advanced Human-Machine Interaction Technologies, Adaptive Automation, Human-Automation Symbiosis, Work Systems, Socially Sustainable Manufacturing, Exoskeletons, Augmented Reality, Virtual Reality, Wearable's, Intelligent Personal Assistants, Collaborative Robots, Social Networks, Big Data Analytics.

1 INTRODUCTION

The German program Industrie 4.0 (or Industry 4.0) and corresponding international initiatives (e.g. Smart Manufacturing, USA & Smart Factory, South Korea) will continue to transform the industrial workforce and their work environment through 2025 [1]. This will have significant implications on the nature of work in industry as Industry 4.0 will transform design, manufacture, operation, and service of products and production systems [2]. At the same time, the demography is changing, especially in Europe and Japan, which brings forth additional challenges for manufacturing companies. Increasing immigration may relieve some of the effects of demographic change.

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However, integration of new migrant workers with a high variety of technical skill and educational levels and different culture is considered a great challenge. As a consequence, near-future manufacturing enterprises, and in particular 'smart factories' as socio-technical systems, will need to form and adapt a *social perspective* to be proficient in assisting ageing, disabled and apprentice operators by using advanced digital and industrial enabling technologies to help people to remain in, return to or incorporate into the modern manufacturing workforce. Meanwhile, considering the developments from a *technical perspective,* new connectivity and interaction technologies among parts (*cf*. smart products), machines (*cf*. smart machines) and humans (*cf*. smart operators) will make production systems more lean, agile, traceable, and adaptable [2] [3] [4].

To successfully embrace the Industry 4.0 paradigm in a *socially sustainable way,* manufacturing enterprises will need to accompany its technological transformations with training and development programs for their workforce, in new tools and technologies that skilled labor uses and by which the operators are directly and indirectly affected. Furthermore, new working environments such as the 'cyber-physical factory' will directly affect the operator and the nature of work, creating new interactions not only between humans and machines, but also between digital and physical worlds. Therefore, socio-technical transformation towards the factory of the future (*cf*. factory 4.0 / smart factory) will need new design and engineering philosophies for twofold 'human-centric' and 'cyber-physical' production systems where automation, robotics, and other advanced manufacturing technologies are seen as possibilities for the further enhancement and augmentation of the human's physical, sensorial and cognitive capabilities rather than for unmanned, autonomous factories [5]. This new approach requires the rethinking of simple work design, moving towards design methods similar to those used to design the working environment for aircraft pilots, process industry operators and military personnel. These would typically include human supervisory control and human situation awareness.

This paper explores early manifestations and future projections of the *Operator 4.0* [5] as a smart and skilled operator who performs not only - 'cooperative work' with robots - but also - 'work aided' by machines as and if needed - by means of *human cyber-physical systems, advanced human-machine interaction technologies* and *adaptive automation* towards "human-automation symbiosis work systems". This research work introduces an *Operator 4.0* typology as well as explores a set of key enabling technologies for supporting the development of 'human-automation symbiosis work systems' for the Operator 4.0 in the Factory of the Future.

The vision of the *Operator 4.0* aims to create trusting and interaction-based relationships between humans and machines, making possible for those smart factories to capitalize not only on smart machines' strengths and capabilities, but also empower their 'smart operators' with new skills and gadgets to fully capitalize on the opportunities being created by Industry 4.0 technologies. Hence, a *socially sustainable factory* within the Industry 4.0 framework is a workplace where work systems design and engineering uses collaborative robotics, kinematics, human-in-the-loop control systems, sensors, manipulation, navigation and adaptive automation to improve the knowledge and capabilities of operators. In this sense, a *human-centric production system* is characterized by allowing a unification of planning and implementation, expecting the operator to be in control of the work process and the technology and fostering the utilization of human competencies [6]. Furthermore, a *human cyber-physical production system (H-CPPS)* is defined as a work system that improves operators' abilities thanks to a dynamic interaction between humans and machines in the cyber- and physical-worlds by means of 'intelligent' human-machine interfaces. H-CPPS will be using human-computer interaction techniques designed to fit the operators' cognitive and physical needs, and improve human physical-, sensing- and cognitive-capabilities, by means of various enriched and enhanced technologies [5]. Moreover, these cyber-physical and human-machine interactions are supervised and controlled by adaptive control systems [7] [8] [9] within the human-in-the-loop [10] paradigm and based on sharing and trading of control strategies [11] (e.g. critical-event, measure-based and/or modeling-based) in order to allow a dynamic and seamless transition of functions (tasks) allocation between humans and machines, always aiming for the operator inclusiveness without compromising the production objectives [5].

2 TOWARDS AN OPERATOR 4.0 TYPOLOGY

This section presents an *Operator 4.0* typology that depicts how the Industry 4.0 technologies can assist operators to become ‘smarter operators’ in their future factory workplaces (see Figure 1), from a social manufacturing perspective. Furthermore, it is important to mention that these types of Operators 4.0 may exist on the shop-floor as either single- or hybrid- types. A selection of various augmentations of the original human capabilities are presented below; note however, that there might be multiple other aspects that are part of the Operator 4.0. Those augmentations do not only come in a variety of levels but also can be combined. It is also very likely that the future Operator 4.0 may only be augmented in one specific area whereas the other aspects are neglected. In some cases that will not even be possible (e.g. augmented reality functionality necessarily needs a ‘connected operator’ to perform).

Super-Strength Operator

Augmented Operator

Virtual Operator

Healthy Operator

Smarter Operator

Collaborative Operator

Social Operator

Analytical Operator

Figure 1: Operator 4.0 Typology

2.1 Operator + Exoskeleton = Super-Strength Operator [physical interaction]

Powered (Industrial) Exoskeletons are wearable lightweight, flexible and mobile, representing a type of biomechanical system where the human-robotic exoskeleton powered by a system of motors, pneumatics, levers or hydraulics works cooperatively with the operator to allow for limb movement, increased strength and endurance. The idea of wearable exoskeletons has been around for decades in industry, aiming to use powered mechanics to increase the strength of a human operator for effort-less manual functions (tasks) (e.g. [12]).

Powered exoskeletons can help to reduce the trade-offs between manual and automated operations in production systems - in other words, between flexibility and efficiency in balanced automation systems as well as to increase the social sustainability of factories in the long-term, especially with the outlook of a larger proportion of elderly workers due to changing demography.

Powered exoskeletons may allow (e.g. in an assembly area, where most manual work takes place) to have humans and technology cooperate in order to simplify the job and reduce the physical stress, thus making the overall system more efficient and productive by auxiliary processes such as safe lifting and moving of heavy items, enhancement of physical capabilities (endurance) to stay longer in a demanding position or additional strength for handling weighty tools. In general, powered exoskeletons can offer additional protection, support and strength to the operators and contribute to the social sustainability of the workforce by improving the ergonomics of manual operations (occupational health), helping to reduce injuries and accidents because of heavy work (safety), boosting productivity and quality of work by improving the operator workload-handling capabilities (e.g. decreasing the physical workload and relocating the energy to the sensorial and cognitive capabilities), and assisting to keep elder/experienced operators longer in critical positions by compensating for their loss of strength due to aging, while still capitalizing on their knowledge and experience. An additional advantage is the possibility to equip the exoskeleton with tools and (heavy) supporting equipment, which in the exoskeleton absence would reduce the humans' productivity.

An example of this type of Operator 4.0 is the *Robo-Mate* system, defined as: "a user-friendly intelligent cooperative light weight wearable human-robotic exoskeleton for manual handling work" [13].

2.2 Operator + Augmented Reality = Augmented Operator [cognitive interaction]

Augmented Reality (AR) is a technology enriching the real-world factory environment of the smart operator with digital information and media (sound, video, graphics, GPS data, etc.) that is overlaid in real-time in his/her field of view (e.g. head-gear, smart-phones, tablets or spatial AR projectors). Hence, AR can be considered a key enabling technology for improving the transfer of information from the digital to the physical world of the smart operator in a non-intrusive way.

AR technology may offer significant advantages (e.g. faster cycle times, reliability, reduced failure rate and traceability) to support the smart operator in real-time during manual operations by becoming a digital assistance system for reducing human errors and at the same time reducing the dependence on printed work instructions, computer screens and operator memory, which need to be interpreted first by a skilled worker. AR for example can enable 'digital poka-yokes systems' for work-intensive functions (tasks) in order to reduce defects, rework and redundant inspection by offering intuitive information and combining operator intelligence and flexibility with error-proofing systems to increase the efficiency of manual work steps, while improving the quality of work [14]. Moreover, AR technology can incorporate a new human-machine interface to manufacturing IT applications and assets, displaying real-time feedback about smart manufacturing processes and machines to the smart operator in order to improve decision-making [15]. This can be implemented at machine level using traditional Programmable Logic Controllers (PLCs) and Supervisory Control & Data Acquisition (SCADA) systems but also emerging Internet of Things (IoT) technologies for assets condition monitoring. AR can be implemented also at mid-level operations like Manufacturing Execution Systems (MES), novel production line simulations and big data-driven quality controls and at higher levels such as the Enterprise Resource Planning (ERP) systems.

At machine level, AR can redefine the maintenance and repair of equipment, by means of 'diagnostic intelligence' derived from real-time sensor data about a machine or part performance; at operations and enterprise levels, AR can allow production managers to view production KPIs and have an intra-factory overview of workstations and production lines in real-time for monitoring, identifying, analyzing, diagnosing and resolving problems and flaws (e.g. alerting on deviations) to keep manufacturing processes moving towards operational efficiency. Furthermore, AR technology acting as 'tag reader' may also create new human-product interactions enabled by QR codes, GPS, OCR, barcodes, RFID and NFC technologies, allowing the smart operator to retrieve current and historical information about a product and monitor and configure data and settings about it.

Presently, an early-stage example of this type of Operator 4.0 is the *Satisfactory system*, defined as “an augmented-enabled ecosystem for increasing satisfaction and working experience in smart factory environments” [16].

2.3 Operator + Virtual Reality = Virtual Operator [cognitive interaction]

Virtual Reality (VR) is an immersive interactive multimedia and computer-simulated reality that can digitally replicate a design, assembly or manufacturing environment and allow the smart operator to interact with any presence within (e.g. a blueprint, a hand-tool, a product, a machine tool, a robot, a production line, a factory), with reduced risk and real-time feedback.

VR technology can provide a combination of interactive virtual reality and advanced simulations of realistic scenarios for optimized decision-making and training for the smart operator. For example, at product design and engineering stage, VR will transform blueprints into 3D virtual models where all types of design rules, guidelines and methodologies (*cf*. Design for eXcellence) can be digitally threaded to upstream design and engineering decisions and check their impact along the product lifecycle (e.g. design for manufacturability, design for assembly, design for serviceability, design for maintainability, design for disassembly, design for repair-reuse-recyclability, etc.); at product assembly stage, CAD models of parts, hand-tools and assemblies can be transformed into interactive virtual simulations (assembly sequences) for training operators in complex assembly tasks; and at product manufacturing stage, VR brings to life the ‘virtual factory’ as an integrated simulation model of the major sub-systems of a factory in order to evaluate different factory layouts (arrangements of machinery, equipment and inventories for smooth flow of work, material and finished products), production line configurations (manufacturing processes sequences), production balance (automation vs. mechanization) and production schedules (work and workloads scheduling) in order to optimize the production master plan by means of what-if analyses, decision support systems and estimation methods.

Several commercial software tools for Virtual Product Design (VPD), Computer-Aided Design (CAD), and Computer-Aided Engineering (CAE) are available on the market. VR systems for dynamic representation of humans are also available. Some examples of software supporting the Operator 4.0 are the *VISTRA system:* “a virtual simulation and training system, which is used to train operators and test manual assembly processes” [17], and the *VFF system:* “a holistic, extensible, scalable and standard virtual factory framework and integrated simulation environment that considers the factory as a whole and provides advanced planning, decision support and validation capability features to production managers” [18].

2.4 Operator + Wearable Tracker = Healthy Operator [physical and cognitive interaction]

Wearable Trackers are devices designed to measure exercise activity, stress, heart rate and other health-related metrics as well as GPS location and other personal data (e.g. biometrics). With the dawn of commercially available solutions like the Apple Watch, Fit-bit and Android wear, many people all over the world are already using aspects of this envisioned system. Military applications are going a step further and employ data analytics on bio-data to predict potentially problematic situations before they emerge, e.g., for Special Forces combat divers during missions. Currently there are already first steps being made to take this to the next level, with the potential to track the complex nature of the human brain during different activities. While this might take decades to be applicable in industry, it gives an indication of the potential this might offer.

Without entering into data privacy issues, rules and employment as well as law implications, wearable trackers (bio-data sensors) can drive positive change via improved productivity, well-being and proactive safety measures for the workforce. Different application levels are possible, e.g. both at the individual and collective level, with the system boundaries for the collective level being flexible.

A smart operator for example can use 'personal analytics' to plan and schedule his/her work-shifts, rest-breaks and overtime based on health-related metrics, can monitor his/her physical workload (exercise activity) and cognitive workload (mental effort) during the work-shift and set alerts and warnings to manage proper levels of occupational effort and stress. Using advanced data analytics on bio-data might allow for utilizing subconscious cognitive states and thus allow for a warning mechanism for imminent danger and/or potential harm to the worker him-/her-self and/or others.

As an aggregation of operators' personal analytics, 'workforce analytics' can prevent urgent threats to operators' safety and also production quality by monitoring health-related metrics and workloads and alert decision-makers (e.g. production line supervisors and factory managers) for example if the stress levels are or workload is too high, which may lead to human errors (e.g. accidents or poor quality of labor) or on the contrary if energy levels of operators are high, controlled aggressive production targets can be set and pushed to the workforce. Moreover, operators' location inside a big factory or warehouse can improve internal logistics (e.g. response time) and help to locate and allocate the closest operator to an urgent function (task) in-hand.

A present example of this type of Operator 4.0 includes the use of smart-watches to leverage awareness of biometrics, so a smart operator can make better decisions in regards to his/her occupational health care self-management (e.g. fitness, wellness, medical). In this basic example, however, the required technology is available today and the advanced data analytics capability needed is progressing fast.

2.5 Operator + Intelligent Personal Assistant = Smarter Operator [cognitive interaction]

An *Intelligent Personal Assistant (IPA)* is a software agent or artificial intelligence that has been developed to help a smart operator in interfacing with machines, computers, databases and other information systems as well as managing time commitments and performing tasks or services in a human-like interaction [19].

One of the main features of IPAs is their capability to offer a voice-interaction technology (a natural language interface) to the smart operator, which induces productivity and operational efficiency by allowing the operator to go hands-free to complete certain tasks. Some scenarios where IPAs can create advantages for the smart operator and offer personal assistance are: in searching and retrieving from a digital library, based on a voice request, the repair or maintenance manual of a machine tool or part and reading the instructions to the operator while he/she performs the task; in scheduling and setting reminders for actions or critical events in operations, inventory or assets management (e.g. re-certifications, check stocks, preventive maintenance); planning activities, where human creativity can be applied to solve problems of routing or staffing while utilizing the IPA to store and visualize the underlying planning data; in providing mobility and location assistance for logistics (e.g. GPS-based geographical navigation) and warehouse stocks whereabouts (e.g. IPS-indoor positing system); interfacing with connected devices through voice commands (e.g. voice user interfaces); detecting and diagnosing errors and problems and suggesting troubleshooting tools and strategies in smart, connected machines and systems; and building predictive models by tracking operator or machine behavior and alerting for proactive actions.

A present example of this type of Operator 4.0 are Apple's Siri, Android's 'Hey Google' and especially Amazon's Alexa. Especially Amazon's Alexa allows external developers to access the API and build additional apps and services using the existing functionalities and infrastructure. Alexa can already perform tasks like 'finding suitable recipes' and writing a shopping list – tasks that translate easily in a shop-floor environment.

2.6 Operator + Collaborative Robot = Collaborative Operator [physical interaction]

Collaborative Robots (CoBots) are industrial robots (*cf*. humanoid, robotic arm or SCARA configurations) capable of performing a variety of repetitive and non-ergonomic tasks and that have been specially designed to work in direct cooperation with the smart operator by means of safety (e.g. force sensing and collision) and intuitive interaction technologies, including easy shop-floor programming. Popular examples are Rethink-Robotics' Baxter & Sawyer, which promise low-cost and easy to use collaborative robots.

CoBots will allow co-working spaces and interaction with their human counterparts without the need for traditional safety barriers. These possibilities will create benefits such as recovering shop-floor space normally lost due to safety barriers (*cf*. safety cage) and savings for the costs associated to their implementation; increasing the smart operator productivity and job satisfaction by augmenting him/her to accomplish a task more effectively and relieving him/her from tedious, non-ergonomic and vulnerable tasks (e.g. difficult placement of parts, "third-hand" functionality for assembly, heavy and repetitive lifting, loading and handling of hazardous materials). Another societal positive effect emerging from close collaboration of humans and robots in the workplace may be the increasing acceptance of robotic help in the healthcare domain, again, being estimated to being highly relevant due to demographic change in some areas.

A present example of this type of Operator 4.0 is the LIAA CoBot system: "a hybrid assembly systems combining manual and automatic workstations in symbiotic human-robot collaborations to achieve a balance between investment costs, batch size and flexibility in the assembly line" [20]. The INSA project is another example of applied research leveraging advanced image recognition to create safe collaborative workspaces for close human robot interaction [21].

2.7 Operator + Social Networks = Social Operator [cognitive interaction]

Enterprise Social Networking Services (E-SNS) focus on the use of mobile and social collaborative methods to connect the smart operators at the shop-floor with the smart factory resources. Such connections include 'social relations' among the workforce (*cf*. social network services) and between operators and smart things (*cf*. social Internet of Industrial Things [22]) to interact, share and create information for decision-making support.

Social networking between smart operators, enabled by real-time mobile communication capabilities, can empower the workforce to contribute their expertise across the production line and to the shop-floor, can accelerate ideas generation for product and processes innovation and can facilitate problems-solving by bringing together the right people with the right information and especially knowledge management and knowledge creation within the enterprise. Knowledge creation and management is (and always has been) challenging as there is still no 'ideal way' to proceed. Research and industrial practice (e.g. Airbus) suggests that a personal approach to sharing, communicating and managing knowledge within the enterprise (e.g. deriving knowledge from a future retiree) is more successful than a technical and highly structured approach. Social networks embedded in the companies' knowledge system might present a chance to utilize the 'social' component and still allow for storing and accessing collective knowledge. Meanwhile, the social IoIT can connect, through 'interactive machine learning', smart operators with smart things (*cf*. intelligent assets) in social networks for sharing information and exchanging messages about their location, condition, operation status and availability for improving (for example) at machine level the asset reliability (e.g. intelligent maintenance) and at production line level the material flows and resources productivity (e.g. spotting bottle-necks) towards social problems-solving and optimization of the production system.

In both cases, the final aim of enterprise social networking is to communicate and enable cooperation between smart operators and smart machines via social relations to accomplish production goals.

An example of this type of Operator 4.0 can be considered the internal (intranet) forums and wikis (such as e.g. used at VW). However, this only utilizes parts of what is ultimately envisioned for the Operator 4.0. Some companies and their employees make use of existing Social Network Services (e.g. Facebook or LinkedIn) to communicate and connect. This is risky however, as the data is then in the hand of private entities outside of the company and thus should be accompanied by an in-depth risk analysis.

2.8 Operator + Big Data Analytics = Analytical Operator [cognitive interaction]

Big Data Analytics is the process of collecting, organizing and analyzing large sets of data (big data) to discover useful information and predict relevant events. Its application to the smart factory has given birth to manufacturing real-time analytics at the shop-floor, also known as 'smart manufacturing'.

Big Data analytics may help smart operators (e.g. production managers) to achieve better forecasts, understand the smart factory performance (shop-floor control), fuel continuous improvement (Six Sigma), provide greater visibility of KPIs (data visualization and interactive dashboard) and real-time alerts based on predictive analytics (fault detection and quality improvement) in order to leverage real-time information for driving the right response to prevent mistakes, quickly identify problems and call for the right decisions to improve operational efficiency.

Data analytics and machine learning have several applications in manufacturing and are already fairly widely employed [23]. However, the increase in available data through cheap sensors and the Industrial IoT (connected devices) and also fast progress in unsupervised methods like deep learning will bring forth even more powerful and applicable solutions in the near future.

The 'analytical operator' is somewhat connected to several other applications as many of them rely on advanced data analytics. So does the 'collaborative operator', who often utilizes image recognition to allow working in close proximity to CoBots, the 'healthy operator' who relies on the analytics of the bio-data collected and the 'smarter operator' using Artificial Intelligence embedded in a virtual assistant.

This type of Operator 4.0 is illustrated by the variety of monitoring and control tools currently using machine learning and data mining algorithms to improve quality, lead time, etc. [24].

3 RELATED SYSTEMS, STRATEGIES AND ENABLING TECHNOLOGIES TO/FOR THE OPERATOR 4.0

This section briefly introduces related systems, strategies and enabling technologies to/for the *Operator 4.0*. Thus, Figure 2 presents a generic *human cyber-physical system control loop* depicting the interactions between humans and machines and cyber and physical worlds.

3.1 Towards Human Cyber-Physical Systems

Human Cyber-Physical Systems (H-CPS) are the new frontier of human-machine interactions and physical-digital worlds interfacing for the augmentation or enhancement of human performance.

For the case of the Operator 4.0, H-CPS aim to become safety (fault tolerance) engineered systems of systems with the human-in-the-loop, using context-sensitive, advanced communication and adaptive control technologies to support inter-agent systems of humans, machines and software to interface in the virtual and physical worlds towards a sustainable and human-centric production system (see Figure 2).

H-CPS will be deployed in the near future at the shop-floor to optimise the outcome of a production system considering the social sustainability of the manufacturing.

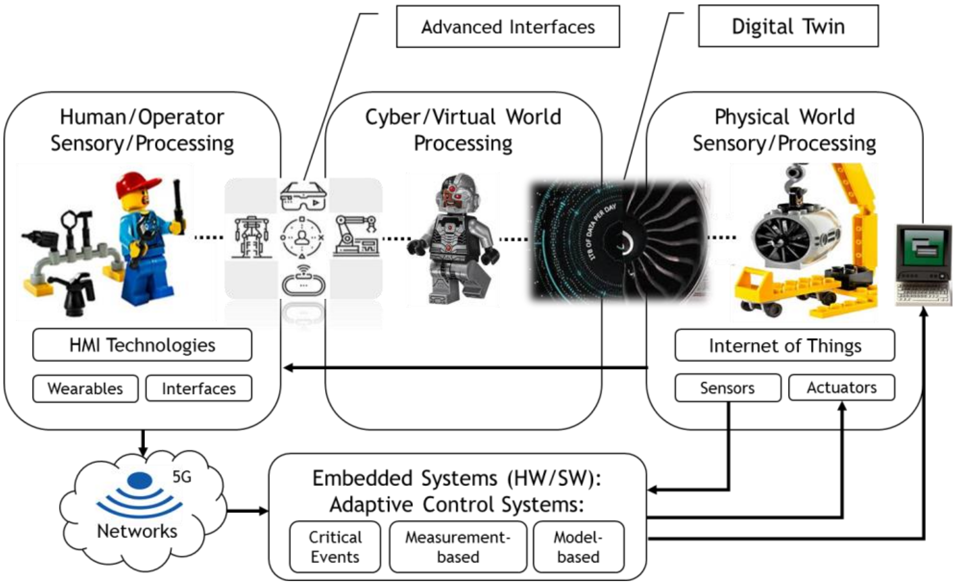

Figure 2: Generic Human Cyber-Physical System Control Loop

3.2 Adaptive Automation Control Systems Strategies

Adaptive Automation Control Systems rely on three main strategies for adaptive function and task allocation in human-machine interactions towards supporting the Operator 4.0 [11]: (1) based on ‘critical event(s)’ that will trigger the sharing or trading of control between human-machine agents in order to guarantee the completion of a critical to task by one or the other or by a hybrid or emergent agent, or when the functioning of the overall system is endangered by the action(s) of an agent; (2) ‘measurement-based’ as human and machine agents are continuously monitored in order to detect deviations from their tasks or ideal performance and trigger the proper countermeasures; and (3) ‘model-based’ on cognitive human and machine models for handling effective and efficient distribution of workload.

3.3 Human-Machine Interaction Technologies

Some relevant HMI technologies that will support the Operator 4.0 are: *Dialogue Systems* – handling the dialogue between humans and machines (e.g. using natural language interface); *Control Devices* – physical (e.g. keyboards, mouse, joystick, trackball, steering wheel, pedals, knobs and switches) and digital ones (e.g. buttons, sliders and menu buttons) enhanced with haptics technology; *Multimedia-Multimodal Displays* – providing the smart operator multiple modes of interacting with a system; and *Adaptive Interfaces* - which adapt their layout and elements to the needs of the smart operator and/or context.

4 CONCLUSIONS AND FUTURE WORK

Human-centric manufacturing has been a core topic for most previous manufacturing paradigms; that same is true for Industry 4.0. Computer-based manufacturing control requires the human to handle complexity emerging beyond the imagination of manufacturing system designers. Therefore, the full potential of Industry 4.0 and the achievement of a socially sustainable manufacturing industry will only be realized if the Operator 4.0 is at its heart (*cf.* human-centric) and interacting with the machines through physical and cognitive means. As mentioned by [25], *human-automation symbiosis* [3] [5], manifested as the Operator 4.0 vision, is necessary for achieving sustainable development in human society. However, it can only be secured through the use of intelligent (smart) automation systems and human-machine interfacing technologies. There, the assumed 'intelligence' allows inclusion of the explicit representation of human goals and plans (e.g. productivity, occupational health, safety, job inclusion and job satisfaction, etc.), thus constituting the basis of human-machine interaction and 'social' interaction with technology. The Operator 4.0 typology is useful in order to increase the understanding of the future roles of humans and machines in the factories of Human Cyber-Physical Systems. By creating a typology and a transcript of available assets and skills, traditional manufacturing companies can easily adopt the future contributions of humans in Industry 4.0. Future work will identify and address the specific challenges of the Operator 4.0 typology types.

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