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The Intelligent Factory Space – A Concept for Observing, Learning and Communicating in the Digitalized Factory

JAN REIMANN[1] AND GABOR SZIEBIG[2], (Senior Member, IEEE)
[1]Department Digitalisation in Production, Fraunhofer Institute for Machine Tools and Forming Technology IWU, 09126 Chemnitz, Germany
[2]Department of Production Technology, SINTEF Manufacturing, 7031 Trondheim, Norway

Corresponding author: Jan Reimann (jan.reimann@iwu.fraunhofer.de)

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ABSTRACT The current and most important request for industrial automation is from Small and Medium-sized Enterprisess (SMEs). This is due to the fact that the SMEs need to increase their competitiveness to withstand the trend of outsourcing to low-cost countries. However, there are good examples of the strong competitiveness of the European SMEs, when they are able to utilize industrial automation for repetitive work, while utilizing the human labor for tasks requiring human skills, like sensing, flexibility, and cognitive skills. The Intelligent Factory Space (IFS) concept represents a framework for interaction between human and an automated system (digital factory). The IFS is composed of multiple layers (representing different services for the human user) and many modular components, which can be extended to the users' requirements. The IFS relies on industrial standards to communicate with existing machines while using novel two-way communication possibilities to feedback to the human user. In this paper, the general concept for the IFS is presented along with a reference implementation, where the concept is implemented in the situation of the human–robot collaboration.

INDEX TERMS Cyber-physical systems, industrial cyber-physical systems, flexible manufacturing systems, intelligent shopfloor, connectivity, interoperability.

I. INTRODUCTION

Intelligence can be interpreted on many levels in a factory. A single piece of equipment could be called intelligent, because it solves a task in an efficient way. On the other hand, a set of machines could also be called intelligent, as the machines can share the work related information with each other and complete the task flexibly. However, when someone calls a factory intelligent it is usually due to its' logistics or production variety capabilities [1].

For the future, an *intelligent factory* denotes the synergy of the skills of machines (such as robots) and humans in order to increase productivity and quality, while still maintaining sustainable working conditions and environment, health, safety for humans. This will clearly motivate manufacturing scenarios, where humans and machines are operating within the same working space mutually, utilizing the capabilities of each other. By connecting the machine even closer to the human, in terms of direct collaboration or task sharing within the same working area, there is important potential for a strong synergy between the machines' and the humans' capability; thus, a very productive, user-friendly, yet rapidly changeable system.

However, connecting machine and human closer within the same working space requires the essential aspect of safety for increasing trust for the human in working together with a machine. Thus, the following key features must be provided by an intelligent factory infrastructure in order to be able to adapt flexibly when the context in the working space changes: *Observing*, *Learning* and *Communication*.

In this paper the authors propose the *Intelligent Factory Space (IFS)*, an architecture which covers all of these requirements. The IFS concept describes a novel approach toward the challenges in Human-Machine Interaction (HMI) in the era of Industry 4.0. IFS addresses the intelligence in multiple levels, supported by Artificial Intelligence (AI).

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The presented concept addresses the trend in an ever closer human-machine interaction and makes the factory more observing, learning and communicating by expanding intelligence from logistics and production variety capabilities to the functional aspects of a factory.

The remainder is structured as follows. The related work in Sect. II shows that, currently, no comparable approaches exist. In Sect. III the general architecture of the IFS is explained. A reference implementation is presented in Sect. IV, before the paper is summarized in Sect. V. A discussion of future work is presented in Sect. VI.

II. RELATED WORK

Manufacturing equipment for small and medium scale production is often arranged in a setup of a Flexible Manufacturing Cell (FMC) [2]. The flexibility provides efficient use of resources but makes the control of these systems more difficult. Normally, such cell members are from various manufacturers and each has their own specific capabilities when it comes to human-machine and inter-machine interaction.

The FMC concept appeared well before Industry 4.0 in which researchers and industry identified the solution for interoperability and higher efficiency on the Factory Space with equipment connected to local area networks and which use of hierarchical computer integrated manufacturing (CIM) [3], [4].

Along with the development in electronics, computer systems and control technologies the CIM concept became outdated and with the appearing of software based solutions like [5], [6], today's Industry 4.0 was established.

Industry 4.0 has also been the enabling technology for most of the (Industrial) Cyber-Physical Systems (CPSs) related research. CPSs have matured and have been implemented in the last 5 years [7], [8]. CPS related research is focused around three major topics:

1) *Interoperability:*
    - Creating a Layer based architecture for efficient communication between components [9]–[11].
    - Software-based abstraction by Plug&Play solution [12], [13] or Java implementation [14].
    - Agent-based interoperability, in which the agent's are software implementations [15].
2) *Cloud-Based Solutions:*
    - Service-Oriented Architecture (SOA) solutions for controlling Industrial Internet-of-Things (IIoT) [16]–[19].
    - Cloud and Fog integrated [20], [21]
3) *Data Analytics:*
    - Manufacturing inspection with the usage of CPSs, supported by either fog computing [22] or some kind of decision system [23], [24].
    - Challenges with networked based control [25].

As previously described, the focus is on the abstraction, software-based interoperability and storing/processing historical/soft real-time data in cloud based solutions.

TABLE 1. IFS concept properties and its services.

	IFS layer services	Layer 1	Layer 2	Layer 3
Cyber-Physical System properties	Real-time sensor data processing	•		
	Processed sensor data fusion		•	
	Soft real-time sensor data processing			•
	Edge/Fog architecture	•	•	
	HMI	•		
Artificial Intelligence properties	HMI task transformation		•	
	HMI task abstraction			•
	Cloud services, data storage			•
	Big Data analytics (machine learning and deep learning)			•
	AI algorithms deployed	•	•	
	Standardized software interfaces for communication and data exchange	•	•	•

In addition, it could also be identified, that AI, such as machine learning and deep learning, is not yet a topic in CPS as there is a lack of common architecture, which is a prerequisite for any AI-related research [26], [27].

An early attempt at establishing a framework for distributed sensory intelligence [28] (various sensors, such as cameras and microphones with intelligence, haptic devices to manipulate in the space), a platform on which of the communication is based [6] was not as successful as it was originally planned. The lessons learned from [28] is actually implemented and further developed in IFS concept's Layer 2.

In Table 1 IFS concept properties are highlighted and compared to the previously introduced various solutions.

To address this missing link between CPSs and AI, the IFS concept is contributed and introduced in the following section.

III. GENERAL ARCHITECTURE OF THE IFS

The IFS represents an open and extensible system enabling automatic transition between multiple safety modes in order to support sharing the same working space between human and machine (e.g. a robot). This enables an environment where the machine can seamlessly adapt, i.e. switch from full automation, to safe task sharing and direct collaboration within the shared working area. As mentioned in the previous section, such an architecture requires to support observing, learning and communicating to achieve such a flexible system.

The *learning* part of IFS continuously monitors the tasks and the humans to establish a *task database*. This database is intended to be the reference for the machine when a human enters the working area. Then, instantly, the machine can prepare its setup for the expected task, making (statistically) a very simple, fast and smooth, reconfiguration of the working cell.

The *observation* capability of IFS is intended to detect the human and the human's condition, and through a cognitive analysis, prepare automatically for his/her expected working tasks. This considers the human's condition by adapting the machine to his/her expected working performance. The cognitive analysis is performed through modern, psychological methods and cognitive human development.

Hence, the IFS provides an open, collaborative arena without fences, optimizing the human's and machine's skills in a close to perfect synergy, and even more important harmony; where the human feels comfortable without any stress next to a machine. Continuous adaption of the working task is done through the capability to *communicate* back via multiple human senses in parallel. This creates an adaptive, easy configurable system.

The general architecture of the IFS consists of three hierarchical layers illustrated in Fig. 1. These layers represent multiple scales which improve the ability to automatically make decisions with different constraints, such as timing or granularity [29]. All together they compose the *Intelligent Factory Space*. Every layer offers particular services in order to improve the work environment and comfort for collaboration between human and machine:

Layer 1: local environment
Layer 2: work cell environment
Layer 3: global factory environment

Depending on the required data processing capability each layer offers services which have to be realized in the overall system. In the following subsections the offered services and the contained parts of every environmental layer are explained.

A. LAYER 1: LOCAL ENVIRONMENT

The local environment is considered an immediate area inside the shared working space of human and machine. It is a subspace of the whole working area and several local environments compose the entire working space. In order to construct a complete image of the reality – a current scenario between human and machine – all local environments are required to contribute to compute the overall global environment. Therefore, similar to [28], a physical device is associated with a local environment being able to observe and to communicate. *Observing something* can be considered as *sensing with a specific purpose* because generally a sensor just produces data. Processing such data can only be done by interpreting it in a particular context, following a specific purpose. Thus, the IFS overall purpose to enable perfect synergy between human and machine, needs to be divided into multiple services which have to be realized at this layer of the IFS architecture. Altogether, the services at this layer of the IFS aim to recognize the local environment (observe) and to inform about the current state (communicate). Therefore, the physical device being associated to the local environment is called *Local Observing and Communication Device (LOCDev)* and must realize the following services:

1) HUMAN RECOGNITION

To establish perfect synergy between human and machine both must be detected and identified. Therefore, this service's purpose is to recognize the human in the working area. This is a complex task in itself since the sensed data must be processed in order to generate with a human model which stands out from the surrounding. This service returns the worker's location inside the work cell at any point.

2) OBJECT RECOGNITION

As indicated before knowing where the machine is located at is essential for being able to adapt to changing context in the work cell. Therefore, this service's purpose is to detect objects in the working area. Particularly, the machine is such an object, but also obstacles must be detected in order to prevent collisions. One might raise the objection that the machine should be known per se, but it can be argued that in general the dimensions of the machine must be detected, too, in order to be able to prevent collisions between human and machine automatically.

3) AUDIO RECORDING

This service's purpose is to monitor the work cell by means of audio. Possible contexts which might appear are categorized into *known scenarios* and *unknown scenarios*. A scenario where the worker instructs a machine (e.g. by voice) can be considered as *known* because communication between both must be started explicitly at a specific point in time. A scenario where sudden sounds or noises may allow a conclusion to be drawn about a, e.g., dangerous situation is considered *unknown* because it is not known explicitly, when it will happen. To automatically make decisions for both categories this service contributes continuous data which can be processed further.

4) AUDIO SPEAKING

Perfect synergy of human and machine also means communicating without stopping or interrupting the current task. Therefore, this service's purpose is to communicate to the worker by voice synthetization. As a result, the human does not need to look at a screen but gets audio information and/or instructions. The worker is not being distracted physically from the current task to be accomplished and potentially does not need to release a tool holding in their hand.

5) INFORMATION PRESENTATION

As previously indicated distraction-free communication is the goal. This is also the way humans can communicate to other humans. Decentralized communication, where communication is not bound to a specific location (such as e.g. a terminal or a screen), has the very valuable advantage that communication can continue within changing contexts. Thus, this service's purpose is to present relevant information in a decentralized distraction-free manner.

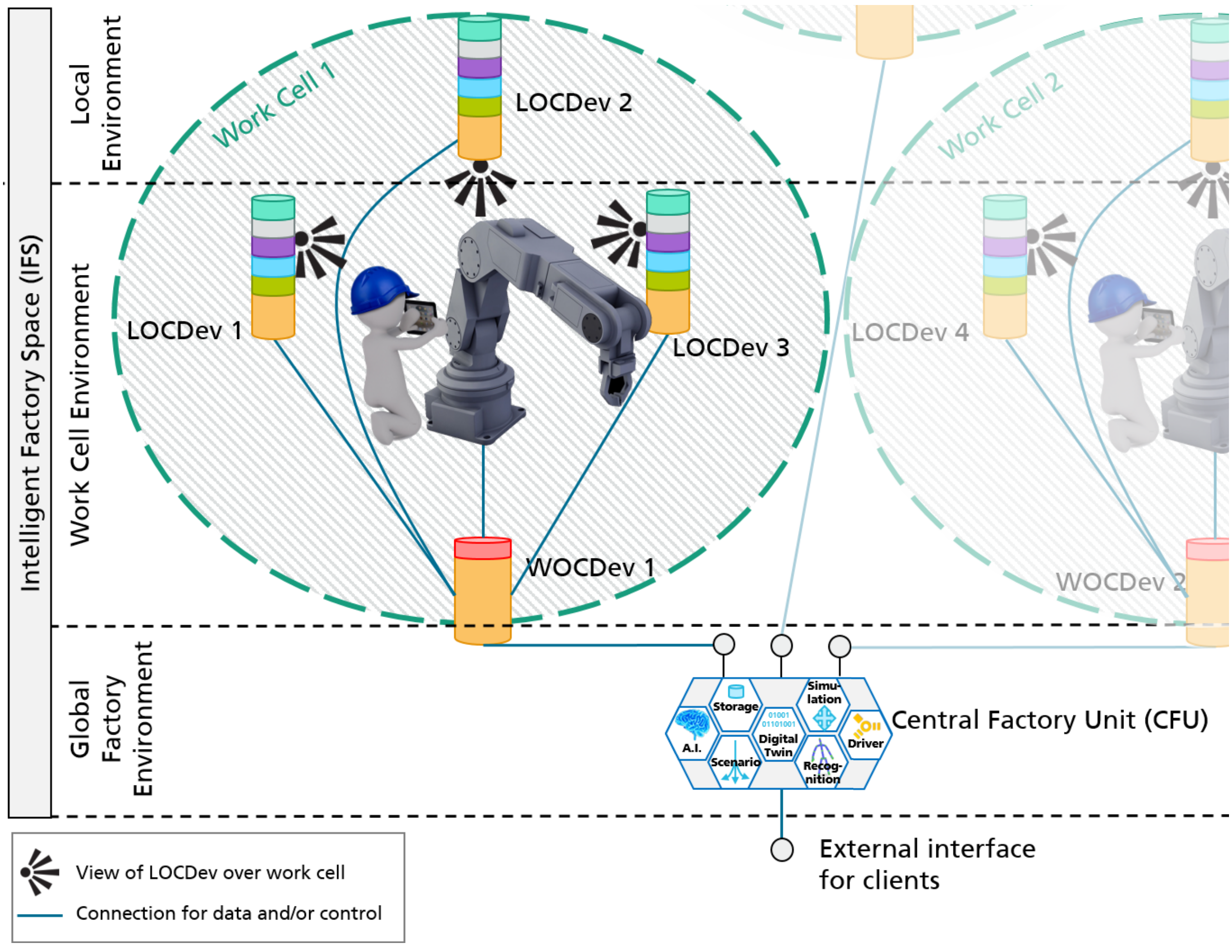

FIGURE 1. General architecture of the IFS.

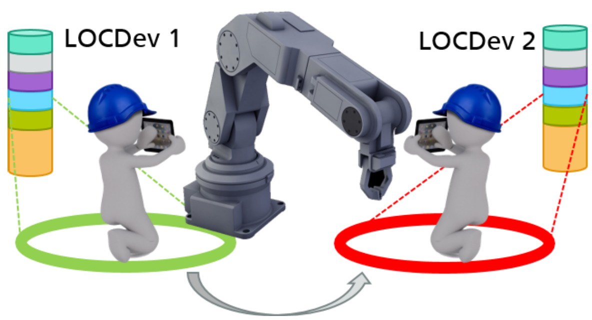

FIGURE 2. Projection of critical zones.

Fig. 2 shows an example for such a communication. When starting a task, the worker is located in a safe zone, which is currently unreachable by the robot and a green circle is projected on the ground. When the worker moves outside this zone, this circle turns red. The projected circles improve the comfort for the human, when they are inside the physical working space of the machine.

6) POSITIONING

To take up the previous example of projecting information on the ground, the LOCDev must know more than just the location of the worker (cf. III-A1 Human recognition). In order to adequately project the information it must also know where LOCDev itself is located at. Therefore, this service's purpose is to continuously monitor the position of itself (LOCDev).

Fig. 3 shows the construction of a LOCDev in conjunction with the realized services. Multiple modules can be attached to a LOCDev, whereas every module consists of a sensor or actuator in connection with a dedicated processor by means of an integrated computer which is dedicated to progress the specific data (sensor and/or actuator). Such module then collects the data gathered from the sensor or actuator, processes it and sends the results to a Base Module (BM). The fact that every module contains a integrated computer ensures modularity. This means that additional modules can be attached in the future. Every module is physically connected to the BM, either over Ethernet, USB or any other stable data connection.

All the previously described services of the LOCDev develop to their full value when they are not considered in isolation. It is not sufficient to know where the human is, where the machine is and where potential obstacles are. Only when this information is put together can real added value be achieved and automatic decisions be made. Correct projection

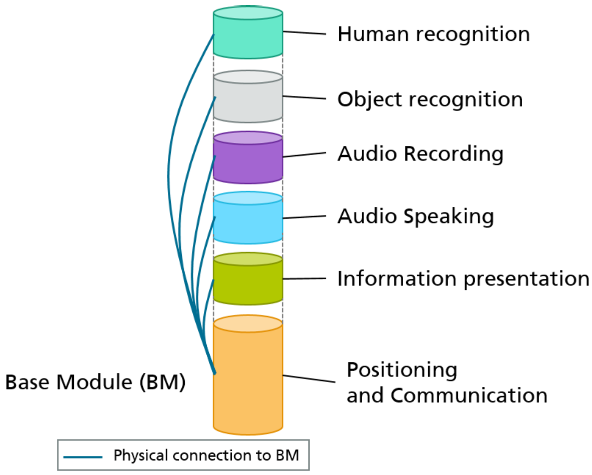

FIGURE 3. Modular composition of the Local Observing and Communication Device components.

of relevant information on the ground can only be achieved when the location of the human and the LOCDev are known.

Detected sounds or noises from the audio recognition are only useful when their meaning and reason are known. Thus, this information must be inferred with AI and machine learning (ML) techniques.

Furthermore, one single LOCDev is not sufficient to compute an image of the overall global environment in which human and machine are located. One LOCDev might have a limited viewpoint because of obstacles. The worker must not be restricted in their movement because the human is in focus and not the machine. As a consequence, redundancy in the working area is required which means that multiple LOCDevs are located inside (see Fig. 1 and Fig. 2). Furthermore, the gathered information must be processed at different layers. First, sensed data is processed directly at the LOCDev where it is produced. Thus, the LOCDev can be considered an edge device and the whole IFS realizes a Fog-architecture [30]. Second, relevant data being for making automatic decisions must be processed in a layer where more extensive information is available. This will be achieved either in the following Layer 2 of the whole work cell environment or in the Layer 3 of the whole factory (see Sect. III-C).

B. LAYER 2: WORK CELL ENVIRONMENT

The area of the shared working space of human and machine is considered the work cell environment. As explained before, this environment is composed of multiple local environments and is the next layer where new data is collected, processed and where automatic decisions are made. The requirements of the LOCDev at Layer 1 also apply for this layer: observe and communicate to contribute to the purpose of enabling perfect synergy between human and machine. This means that specific services need to be realized in the work cell where multiple LOCDevs are contained in. In particular, the information retrieved by the LOCDevs and forwarded to this layer is put into context, aggregated, interpreted, linked and processed here. Thus, the services at this layer of the IFS aim to recognize the work cell environment (observe) and to inform about the current state (communicate). Therefore, another physical device is required which is associated to the work cell environment. It is called *Work Cell Observing and Communication Device (WOCDev)* and must realize the following services:

1) MAKE SAFETY DECISIONS

As explained previously, audio speaking and information presentation are used to communicate with the worker in a location-independent manner. In order to project critical zones on the ground of the work cell, the corresponding information is required. Such information is not binary (yes or no), but it must be derived from multiple other information. It might be dependent on the particular task being worked on or from the level of interaction between human and machine [31]. It may also depend on the experience of a worker (novice or advanced), the mood, physical conditions or even other properties, such as the worker's age. As a consequence, this service's purpose is to make context-aware safety decisions. Therefore, the WOCDev takes all relevant information from the LOCDevs into account and computes safety states on which base automatic decisions can be made.

2) COMPLEX EVENT PROCESSING

Making safety decisions is about analyzing a complex series of interrelated events [32]. In order to achieve this, a stream of events needs to be analyzed and new safety-relevant decisions have to be made upon the analysis' results. In general, the events are perceived and analyzed from different perspectives (data of various LOCDevs having different purposes). In the case that safety-relevant decisions have to be made it is directly processed by the aforementioned service in the WOCDev. Otherwise it is forwarded to the next layer.

3) FAST COMMUNICATION TO LAYER 1

When complex events are being processed and the analysis detects a safety-relevant event, the respectively derived decision must be communicated immediately to the relevant LOCDev in the Layer 1. This demands an almost real-time, low latency and high quality communication network. As a consequence, the underlying LOCDevs are directly connected to the WOCDev on Layer 2. Whether this is achieved through physical network connections or mobile 5G connections does not play role, but rather it is important that fast communication from Layer 1 to Layer 2 is realized. Connecting various LOCDevs within a work cell to their WOCDev is not enough. More important is a communication channel to the machine. In safety-critical situations it is not sufficient to inform the worker but the machine must be controlled immediately (e.g. decreasing speed or stopping the machine). In order to achieve this, the purpose of this service is fast communication to the connected machines and the Local Observing and Communication Devices on the underlying Layer 1.

The previously described services are interrelated and depend on each other. While the Complex Event Processing (CEP) service processes all the incoming events and signals originating from various LOCDev, the safety decision service progresses safety-relevant events from the CEP. In order to keep latency small and ensure fast communication the Layer 2 is regarded as the next hierarchical fog level after the previous edge layer in the IFS architecture [30].

Furthermore, it is obvious that the decision making service in conjunction with the CEP service depend on a mature knowledge base. Such a knowledge base must evolve over time in terms of storing all actions, tasks and processes in combination with the sensed properties of the workers and machines and all other relevant data from the factory. Context-based decisions to be made automatically can only be realized with AI and ML techniques. Thus, services in the WOCDev compute immediate decisions whereas decisions of longer terms are processed at the next layer: Layer 3. This means that data from layer 2 will also be forwarded to layer 3.

C. LAYER 3: GLOBAL FACTORY ENVIRONMENT

Analogous to the work cell environment in Layer 2, which consists of multiple local environments of Layer 1, the global factory environment of Layer 3 comprises various work cell environments. Since time-critical decisions are made by the WOCDevs in the underlying layer, all high-level decisions (e.g. task assignment, information projection) can be realized in this layer. All WOCDevs of the work cells forward information to the topmost fog-level where everything can be linked together. As a consequence, nothing is regarded in isolation and all data can be linked semantically (by their meaning). Linking data has the advantage that new relationships are established by which new knowledge can be derived automatically [29]. The layered and hierarchical organization spans a tree by means of a fog-based architecture and has the advantage that only relevant information is processed at every layer and required results can be communicated back fast when needed. Thus, the services at this layer of the IFS have the purpose to recognize the global factory environment (observe) and to inform about the current state (communicate). Furthermore, the *learning* component of the IFS is achieved here. The central device at this layer of the IFS is the *Central Factory Unit (CFU)* and is unique inside the factory. The CFU realizes the following main services:

1) DATA STORAGE

The CFU is the central entity inside the factory where all relevant data is collected. This comprises required information not being volatile but which is essential for being reused for deriving new knowledge, or from which future decision will be based. Thus, the CFU's purpose is storing high-level user interaction scenarios which are parameterized and reused in particular concrete tasks inside the mentioned task database. Planned and unplanned scenarios are also persisted in the task database. The data storage service is the central source for subsequent computations. Therefore, various different kinds of storages are contained inside this service:

- task database
- test database
- cognitive database
- timeseries (e.g. machine data from a sensor)
- etc.

As a concrete solution it can be argued to use an ontological model [33] since it is highly flexible. An ontology stores both the conceptual part (schema) and the concrete entities (instances) which allows easy reasoning by means of the types. Furthermore, every constituent of an ontology can adopt arbitrary types which results in the fact that data from different domains (such as, e.g., process data, machine data, worker's data) can be interrelated easily. As an example, consider the linking between an executed process, a specific order and the particular worker who accomplished the whole task. In general, the IFS architecture is independent from particular solutions, provided that they have an interface for querying. But, using ontologies as the formal grounding results in perfect interplay with AI and ML techniques for exposing new knowledge.

2) PROVISION OF AI AND ML ALGORITHMS

Based on the collected data AI and ML algorithms are applied for gathering new knowledge. This new information might expose additional relations between particular entities in the factory. Therefore, this service' purpose is knowledge retrieval by using aforementioned databases (e.g. the task database). Deliberately created data (e.g. teaching a robot or simulations) can be considered as training data against which test data is to be evaluated. This way unknown/unplanned scenarios can be detected and be made explicit. Supervised learning algorithms are able to detect a known category for such scenarios. Predicting context changes in a work cell is, e.g., a feasible use case. On the other side, unsupervised learning can be perfectly applied for understanding completely new data.

3) DIGITAL TWIN AND SIMULATION OF RELEVANT ENTITIES

The collected data and additional simulations of scenarios represent an abstract picture of relevant entities inside the factory under specific viewpoints. The data of a particular viewpoint can be considered a digital twin for the entity for a specific context. Therefore, this service's purpose is to capture digital twins of the real factory. There might be various viewpoints in the factory. As a consequence the summation of all digital twins results in a completely digital factory. Simulations abstract the real behavior into explicit data which can be, e.g., target of ML algorithms.

4) SCENARIO DEFINITIONS RECORDED FROM TEACHING

As mentioned in the AI and ML service, when teaching processes are executed the CFU has the responsibility to capture the scenarios and to make them available as training data. Therefore, this service's purpose is to extract a scenario definition from a specific teaching scenario. Such definitions are used to learn from the operator in the work cell and to be reused for future scenarios and to detect context changes. A scenario definition can be regarded as an abstraction from the real scenario. From a software technology and ML point of view such abstractions have great potential to be connected to other feasible abstractions, such as an abstract task description. This way the IFS is independent from the concrete formalism which stores a scenario and can be used as target for information retrieval queries. A possibility would be to design a sophisticated Domain-Specific Language (DSL) [34].

5) COGNITIVE MODELING

A very important service being realized by the CFU is cognitive modeling [35]. This service comprises the detection of specific physical states, such as tiredness of the worker. Similar to sleep detection in modern cars the eyes and the facial expressions are to be observed and analyzed. Other cognitive properties, such as the level of attention, are also taken into account. Therefore, this service's purpose is to extract a cognitive model of workers in order to contribute to the cognitive database which can be queried for retrieving new knowledge. The main target of this service is to gather information related to the worker's brain in order to ease collaboration with the machine.

6) EXTERNAL INTERFACE

The CFU is also regarded as the access point to external clients. On the one hand, an external client can be infrastructure of the same company but from another location. On the other hand, an external client may also be interested institutions from the public, such as scientific networks. In the former case the client may obtain deeper access to the available data, whereas in the latter case the client may only get pseudonymised/anonymised access. In either case the provided endpoints must conform to the General Data Protection Regulation (EU) 2016/679 of the European Parliament.

Also in this layer the previously described services interrelate and depend on each other. The CFU has a strong focus on knowledge retrieval based on ML techniques in order to support and strengthen automatic decision making. Every service provided must be backed up with specific storage solution. As a result the CFU at Layer 1 of the IFS is the topmost node in the fog-based architecture having access to all underlying information systems. This general architecture establishes a first framework for collecting purpose-based data (observe), for deriving new knowledge (learn) and for informing the human and instructing the machine (communicate). The IFS contributes various hooks, endpoints and extension points where it can be customized to the specific requirements of a particular digital factory.

IV. REFERENCE IMPLEMENTATION

One of the most complex tasks in Human-Machine Interaction is the Human-Robot Collaboration (HRC). In these

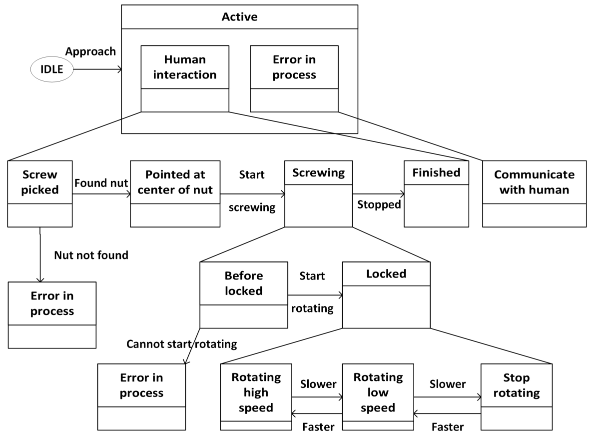

FIGURE 4. Flowchart of nut screwing operation.

situations robot and human are working together and interact in close proximity, within the same working space. This requires an essential aspect of safety for increasing trust for the human in working together with a robot. Until now, these approaches have usually been custom made, sensor-integrated solutions, where the robot's safety controller ensures the safety of the human worker. Such solutions are according to todayâĂŹs rules and standards. With the IFS concept the necessary infrastructure can be created for these HRC situations, where the adaptability to context is crucial in the working space changes. The IFS will provide the flexibility in order to provide the following services: *Observation*, *Learning* and *Communication*.

To demonstrate a cooperation between human and a machine, in this section a reference implementation of IFS will be introduced, which will include a human and an industrial robot. A simple nut screwing operation is presented from the viewpoint of the IFS concept and its AI capabilities, while the actual detailed implementation can be found in [36].

On Fig. 4 the decision flowchart can be seen, which describes the abstract task for the human and robot together, with stages, actions and decision points. This abstract task is stored in IFS Layer 3 in a form of an abstract command sequence. When the actual Human-Robot Collaboration takes place, this abstract task is translated to actual command sequence, based on the participating human and robot. This transformation is happening from a DSL to a concrete command sequence, specific for the given Industrial Robot specific command language, as shown on Fig. 5. The participating human is detected multiple ways: voice recognition (as introduced in Sect. III-A3), human and object recognition (as introduced in Sect. III-A1).

In the case of the nut screwing operation the IFS Layers are configured the following way:

- **Layer 1**: Camera, Audio and Projection modules
- **Layer 2**: Industrial Robot (NACHI MZ-07 with high-speed interface for Force/Torque control), Schunk PSH32, pneumatic gripper with two finger jaws

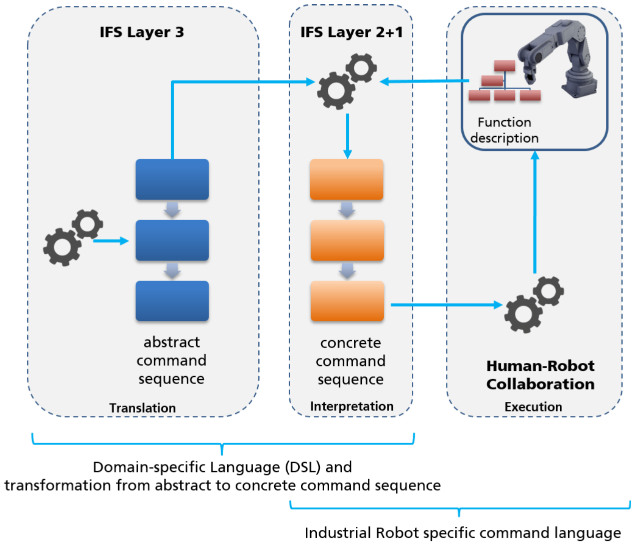

FIGURE 5. **Context-Sensitive (Robot|Machine)-Control.**

- **Layer 3**: Robot Operating System connected with cloud service

The goal with the nut screwing scenario is to help the human to put the nut on the screw and rotate the screw. All the human worker needs to do is to move a nut close to the industrial robot (no matter which direction and orientation) and communicate with the robot (through the IFS), then work together with the robot to finish the rest of the task, while holding the nut in the hand, as shown on Fig. 6.

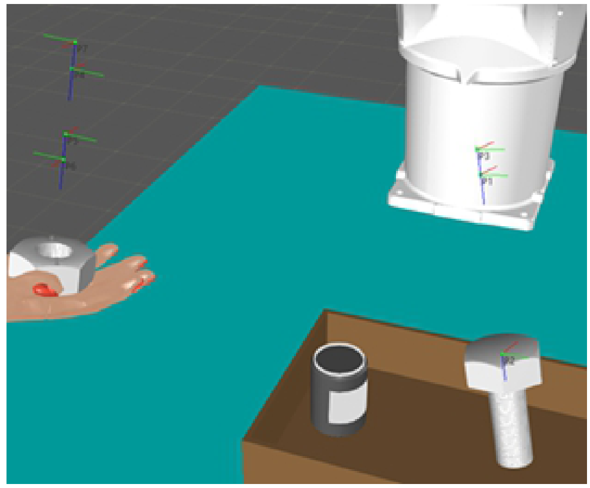

FIGURE 6. **Scenario overview for nut screwing operation.**

The nut screwing scenario involves many of the services, which were already introduced in Sect. III. More specifically the AI related parts are highlighted in the following:

All sensor data processing is happening in Layer 1, closest to the sensory data generation. This allows the IFS to have real-time data processing capabilities. The type of data and the algorithms for data processing is decided in Layer 3, which allows fine-tuning and fast changes in processing parameters. Only processed data is than forwarded to Layer 2 and 3, which decides the usage and storage of this high-level information. This could be interpreted as an Edge

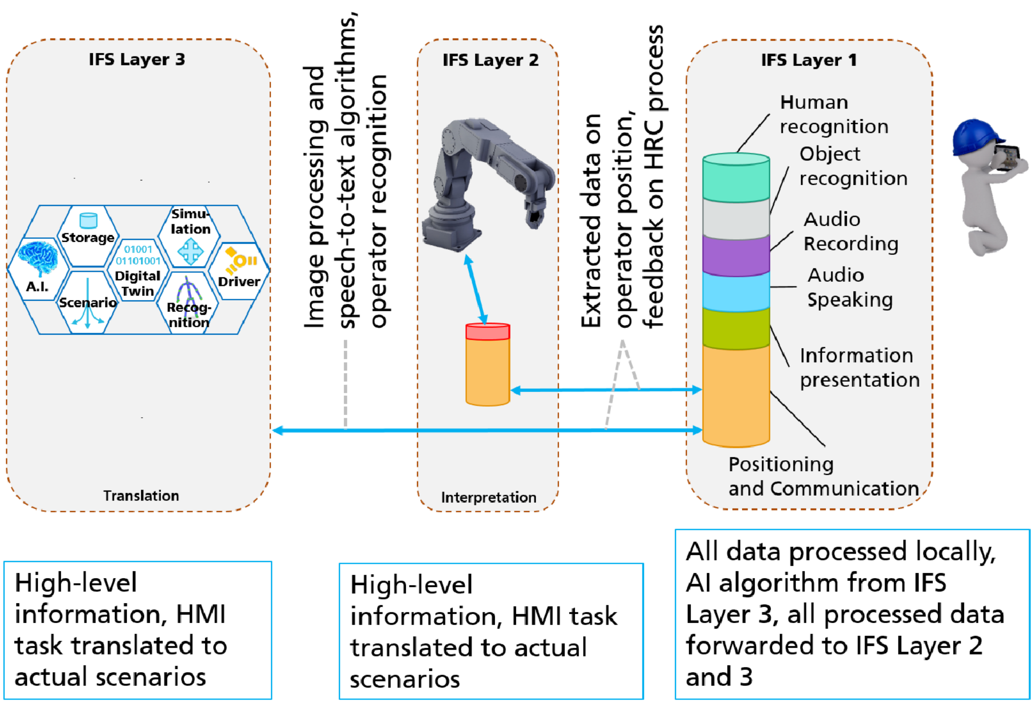

FIGURE 7. **Overview of data processing in nut screwing operation.**

computing scenario, with a support of a cloud-based learning environment. The main benefit with the Layer 3-based algorithm supervision is that the resource-dependent e.g. deep learning or machine learning algorithms can be executed in the cloud and only the parameters for the data processing need to be deployed to the Layer 1 module. This makes the Layer 1 a very robust and flexible setup.

Layer 2 processes high-level information (like human-position from Layer 1) and abstract task descriptions from Layer 3. The main benefit from the merging of the information on Layer 2 is that the human machine interaction tasks can be highly customized: the co-operation could be based on the given participant, the mood and the experience level of that person, which is unique in such scenarios.

This information flow in case of the nut screwing scenario is shown on Fig. 7.

V. CONCLUSION

The concept of Intelligent Factory Space was introduced, which focuses on Observing, Learning and Communicating in the Digitalized Factory. The IFS concept represents a framework for interaction between human and an automated system. It is also demonstrated that the IFS concept is a unique and novel solution in the era of Industry 4.0 and Cyber-Physical Systems.

First, the general concept was introduced with all the 3 layers of the IFS and the corresponding services. Later on, this is followed by a reference implementation of the IFS concept, where the whole concept is demonstrated through a scenario of HRC: a nut screwing scenario. The reference implementation describes a simple setup of the IFS and emphasizes the two-way communication between the human and the robot, with a special focus on the AI processing part.

VI. FUTURE WORK

IFS is meant to be the core concept for the Digital Factory. A Proof of Concept implementation is shown in Sect. IV, which has its limitations and is still on a lower Technical Readiness Level (TRL). The next step will be further development of the concept with modularized software and hardware components. As a result, a generalization of the reference implementation can be expected which will be manifested into a methodology on how to apply IFS principles for making a factory intelligent. For improving the TRL of the IFS framework R&D projects are under preparation.

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JAN REIMANN is currently a Computer Scientist and has been with the Department Digitalisation in Production, Fraunhofer Institute for Machine Tools and Forming Technology IWU, Chemnitz, since 2016. Since 2017, he has been leading the group Data and Information Management. Prior to that, he was a researcher in model-driven software development, software evolution, and software quality, a field where he also received the Ph.D. degree from the Technische Universität Dresden, in 2015. In his Ph.D., he developed a generic approach for increasing quality of software models in heterogeneous environments, such as cyber-physical systems by refactoring. His research was published in numerous scientific papers and journals. He has been involved in many national and international projects from research and industry.

GABOR SZIEBIG (M'06–SM'18) received the M.Sc. degree in computer science from the Budapest University of Technology and Economics, Budapest, Hungary, in 2007, and the Ph.D. degree in production engineering from the Norwegian University of Science (NTNU), Trondheim, Norway, in 2013. He is currently a Senior Research Scientist with SINTEF Manufacturing. From 2013 to 2019, he was an Associate Professor with the Department of Industrial Engineering, Faculty of Engineering Science and Technology UiT, The Arctic University of Norway. His research fields are automation, robotics, computer vision, and control theory. During his Ph.D. studies, he was focusing on novel programming methods for Flexible Manufacturing Systems and have developed a concept called small-scale intelligent manufacturing systems (SIMS). He is an active contributor/organizer of the conference on this topic, which was arranged for the 2nd time in Ireland, in 2018, called Symposium on Small-Scale Intelligent Manufacturing Systems, which is technically co-sponsored by the IEEE. He is the Vice-Chair of the IEEE IES-Technical Committee on Control, Robotics and Mechatronics, and the Secretary of the IFAC TC on Robotics.