A Service-Oriented Middleware Framework for Manufacturing Industry 4.0

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ABSTRACT

The advantages of the Internet of things (IoT) initiated the vision of Industry 4.0 in Europe and smart manufacturing in USA. Both visions aim to implement the smart factory to achieve similar objectives by utilizing new technologies. These technologies include cloud computing, fog computing, cyber-physical systems (CPS), and data analytics. Together they help automate and autonomize the manufacturing processes and controls to optimize the productivity, reliability, quality, cost-effeteness, and safety of these processes. While both visions are promising, developing and operating Industry 4.0 applications are extremely challenging. This is due to the complexity of the manufacturing processes as well as their management, controls, and integration dynamics. This paper introduces Man4Ware, a service-oriented middleware for Industry 4.0. Man4Ware can help facilitate the development and operations of cloud and fog-integrated smart manufacturing applications. Man4Ware offers many advantages through service level interfaces to enable easy utilization of new technologies and integration of different services to relax many of the challenges facing the development and operations of such applications[1].

Keywords

IoT; Smart Manufacturing; Industry 4.0; Fog Computing; Cloud Computing; Cyber-Physical Systems; Middleware

1 Introduction

Due to the increasing business costs of manufacturing and the rising competitiveness among manufacturing countries and companies, there is a pressing need for applying more intelligent approaches to make smart decisions to optimize the diverse manufacturing processes. These smart decisions aim to enhance automation to achieve higher productivity, accuracy, reliability, cost-effectiveness, quality, and flexibility of the manufacturing processes. This vision has been supported by initiatives like Industry 4.0 in Europe [1] and smart manufacturing in USA [2].

The basic principle of Manufacturing Industry 4.0 is that by connecting different manufacturing machines, facilities, units, and companies as well as other manufacturing related and supporting industries we create a smart manufacturing network along the entire manufacturing value chain. This will benefit all by automating, autonomizing and optimizing operations. This smart manufacturing network, as shown in Figure 1, changes the manufacturing business models and enables the interactions across the value chain and within its components. Industry 4.0 is enabled by several ICT advancements in fields like:

1. Industrial Internet of Things (IoT), to enable connecting different manufacturing machines and devices in a network [3].
2. Internet of Service (IoS), to enable providing services for different manufacturing-related systems and organizations via the Internet. These services can be used by their owners and by other manufacturing systems that may need them [4].
3. Manufacturing Cyber-Physical Systems (CPS), to facilitate useful interactions between the cyber world and the physical manufacturing world such as machines and robots, by providing continuous monitoring and control services [5].
4. Cloud Manufacturing: to provide on demand scalable computation, data storage, and advanced smart services for different manufacturing-related applications [6].
5. Fog Manufacturing: to provide low latency support, real-time control, location awareness, better mobility and security support, and streaming support for manufacturing applications [7].
6. Manufacturing Data Analytics, to offer intelligent decisions based on gathered manufacturing data for enhancing manufacturing processes [8].

Although, Industry 4.0 can provide many advantages in manufacturing, building smart manufacturing processes to achieve the concept of Industry 4.0 is not trivial. Issues like increased design complexity, verity of architectural choices, capabilities to support different services including control, connectivity and security mechanisms create many obstacles.

This paper proposes Man4Ware, a service-oriented middleware (SOM) [9][10] for building and operating Industry 4.0 applications. Man4Ware addresses some of the issues and challenges of building and operating Industry 4.0 applications. It enables the utilization, integration and operating of new technologies like the cloud, edge/fog computing, IoT, CPS and data analytics to deliver value added Industry 4.0 applications.

This paper is organized as follows. Section 2 provides background information about Industry 4.0. Section 3 introduces Man4Ware. An example of how to use Man4Ware for building and operating an Industry 4.0 application is discussed in Section 4. Section 5 provides some discussion, while Section 6 covers the related work. Section 7 concludes the paper.

[1] AIoTaS, June 2018, Los Angeles, CA, United States

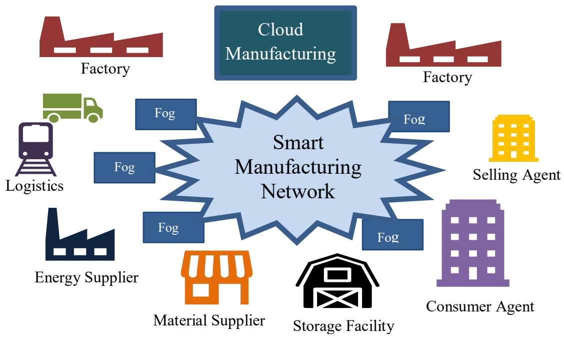

Figure 1. A smart manufacturing network utilizes technologies like manufacturing CPS, industrial IoT, cloud manufacturing, fog manufacturing, manufacturing data analytics, and communication.

2 Manufacturing Industry 4.0

Industry 4.0 or as it also sometimes called smart manufacturing or Industrial IoT aims to facilitate better performance, lower costs, and higher quality in various fields of industry. In some context, it is also referred to as the creation of the smart factory. To achieve Industry 4.0, various components and systems such as CPS, IoT, the cloud and cognitive computing must be integrated to collaborate towards a common goal [11]. It is also considered the fourth generation of industry in terms of the evolution of mechanization and automation of manufacturing. The concept is promising; however, there are pressing issues that currently impede its effective development such as integration and flexibility [2]. To consider a factory or system as Industry 4.0 it must include interoperability, technical assistance, information transparency, and decentralized decision making [12]. Putting it all together, with Industry 4.0 we allow humans, advanced manufacturing hardware, and sophisticated software, to collaborate effectively to autonomize manufacturing processes and offer various capabilities to:

1. Automate more tasks using customizable and adaptive devices and machines.
2. Incorporate new manufacturing processes and technologies.
3. Reduce human interaction with the machines via digital sensing, controls and automated decisions.
4. Improve measurement and monitoring procedures using precision devices.
5. Enhance response times for more accurate control of processes.
6. Collect and store real-time data across all areas of the manufacturing plant continuously.
7. Elevate analysis capabilities using the collected data and advanced data analytics models.
8. Introduce intelligent algorithms using available data to allow the system to make autonomous decisions.
9. Reduce the reliance on humans for monitoring and decision making.
10. Provide better maintenance and repair operations based on predictive analysis of operational data.
11. Create safer and more comfortable working environments.
12. Enable the creation and utilization of new business models in manufacturing.
13. Facilitate the integration of different technologies, models, sectors, and organizations in the manufacturing industry.

As a result, we can better meet the need to reduce costs and the reliance on human workers to enhance operations and to improve the quality of the products. A closer look at the manufacturing execution system (MES) of the future as a result of following the Industry 4.0 evolution reveal that the key movement is the transition from centralized processes locally controlled at the factory to a decentralized approach distributed across all entities involved in the manufacturing process. This move however, may not so easy. Challenges in interoperability, integration, real-time requirements, and compliance are present and must be dealt with to ensure the success of such ventures [13]. Another important aspect in Industry 4.0 is the tight relationships between CPS and IoT with the physical environment that creates specific requirements directly linked to the sector or area these are used in.

In terms of technology, Industry 4.0 must have specific components that are connected and integrated to achieve the “smart factory” and “intelligent production.” These components are: Cyber physical systems (CPS), Cyber Physical Production Systems (CPPS), Cloud computing, and big data and data analytics [14]. Others further extend this list by including smart connections, cognition and configuration [15]. Another aspect that is also critical for Industry 4.0 applications is real-time support such that decisions are made within the required time frame and control signals are generated in a timely manner. Therefore, some very recent work started investigating the inclusion of an additional component, namely fog/edge computing. Fog or edge nodes can bridge the difference in response times between the cloud and the local CPS/CPPS by providing cloud-like capabilities closer to the operational units [16].

One example applying Industry 4.0 is done at the China Petroleum and Chemical Corporation (Sinopec). The effort targeted four areas: smart petrochemical pilot units, an integrated business-management platform, an information technology shared-service center, and a mobile application. The goal is to create an integrated smart manufacturing environment to enhance production and operations. Currently 90% of these four areas have advanced controls leading to 10% higher production levels and the utilization of integrated online optimizations. The integration incorporated available models such as MES, ERP (Enterprise Resource Planning), LIMS (Laboratory Information Management System, flowsheet optimization, planning, and scheduling models [17].

The concept of Industry 4.0 is generally based on six design principles. These principles offer a general framework to the main requirements of Industry 4.0 and are discussed here with specific references to manufacturing.

1. Interoperability: the ability of different manufacturing CPS, machines, robots, workers to connect and communicate via a network such as IoT and IoS.
2. Service Oriented: the ability to present the functions of the manufacturing processes as a set of services. These services should be accessible over the IoS by other systems. These services can be provided both internally within the same manufacturing unit and across manufacturing unit borders.
3. Decentralization: the ability of different manufacturing systems to make decisions on their own. This requires avoiding the use of centralized controls. Although, manufacturing systems can

benefit from other facility systems like cloud manufacturing and fog manufacturing, they still need to be able to make their own decisions locally to effectively continue their operations.

4. Real-time Capability: the ability to immediately collect and analyze manufacturing data such that the right actions can be effectively conducted. This enables the discovery of erroneous observations including possible manufacturing machine faults, wrong worker-machines interactions, and declines in production quality and reliability.
5. Modularity: the flexibility of changing, expanding, and enhancing individual modules to fit new requirements in existing manufacturing processes or build new processes.
6. Virtualization: the ability to monitor manufacturing processes such that virtual copies can be created for these processes. These virtual copies can be utilized for future enhancements of some manufacturing processes. One example is to virtualize a specific manufacturing procedure to examine new or enhanced automation for that procedure.

3 Man4Ware

Man4Ware is a service-oriented middleware (SOM) platform designed to enable development and execution of Manufacturing Industry 4.0 applications. This middleware platform enables connecting multiple manufacturing machines, manufacturing robots, other manufacturing-related devices, fog manufacturing, and cloud manufacturing in one virtual environment. This virtual environment provides services representing or serving the connected components that can integrated to build and operate Manufacturing Industry 4.0 applications. Man4Ware is introduced to support the design principles of Manufacturing Industry 4.0 applications discussed earlier (see Table 1).

Man4Ware consists of a set of services that can be divided into essential services and component or domain-specific services. Essential services are those designed specifically to support the fundamental functions of Man4Ware, such as broker services, remote service invocation, fog manufacturing services, and security services. These services enable the operations and control of other systems services and different manufacturing industry 4.0 applications that operate in the environment. Component and domain-specific services provide uniform interfaces to access services provided by the environment's components such as cloud manufacturing services, fog manufacturing services that support specific applications, and manufacturing machines, robots, and devices services (see Figure 2). These services are directly associated with the components and applications using them, thus their implementation is left to the application developers. However, they all have to provision for the same set of standard web services interfaces to facilitate their integration with basic services and other applications services. The manufacturing machines, robots, and devices services provide interfaces to remotely and securely monitor manufacturing processes' status, monitor individual machine and robot status, adjust operational processes, and capture and create virtual copies of manufacturing operations.

Cloud manufacturing services come in various forms: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), Software a Service (SaaS), manufacturing data analytic as a service, manufacturing data mining as a service, manufacturing diagnostics as a service, manufacturing simulation as a service, etc. Component services offer direct interfaces to utilize the original services offered by cloud manufacturing or add new features for these services like adding reliability and safety enhancements.

Table 1. Man4Ware Support for Industry 4.0 Design Principles.

Design Principle	Man4Ware Supports
Interoperability	Enables interoperability by following web services standards allowing different services to interact using well defined interfaces and execution mechanisms.
Service Oriented	Views all aspects of the manufacturing functions and components as services.
Decentralization	Supports developing and distributing different services to provide decentralized controls for various aspects of manufacturing processes.
Real-time Capability	Provides fog services supporting real-time functionality for decisions and controls.
Modularity	Provides a modular view of services, where services can be easily changed, enhanced, extended and reused in addition to creating and including new services based on applications requirements.
Virtualization	Utilizes the capabilities of fog computing in monitoring different manufacturing processes and the capabilities of cloud computing in data storage and analysis to create a virtual copy of any manufacturing process.

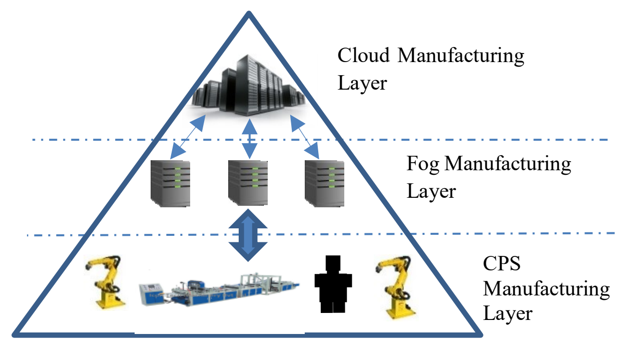

Figure 2. Layers of manufacturing industry 4.0 through integrating manufacturing machines, manufacturing robots, manufacturing workers, fog manufacturing, and cloud manufacturing.

The Man4Ware services are distributed among multiple manufacturing CPS/CPPS, cloud manufacturing, and fog manufacturing nodes (see Figure 3). These services define standard interfaces that make them available to other services and applications in the environment. Using SOM approaches for Man4Ware offers useful mechanisms to connect and integrate existing manufacturing services to create new and more advanced services and applications. It is possible to utilize and integrate a specific subset of the offered distributed services in Man4Ware for building sophisticated manufacturing industry 4.0 applications. Moreover, the offered services can function as clients that utilize other available services building on top of their functionality. The needed services for a manufacturing application are connected by Man4Ware utilizing loose coupling amongst the available services. Man4Ware includes several essential services supporting its basic operations and supporting applications services. Among these essential services there are a few that are key to guarantee the effective use of other offered services and enable the main tasks that Man4Ware provides.

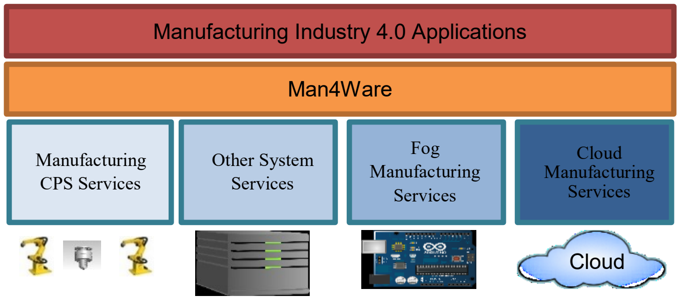

Figure 3. Man4Ware integrates and utilizes different technologies and services to enable manufacturing industry 4.0 applications.

3.1 Broker Services

Broker services are responsible for advertising, discovering, and registering the services provided by different components in the manufacturing environment. All services in all contributing components in the manufacturing network are advertised, registered, and discovered using the Man4Ware brokers. Multiple brokers can be used in the environment, where each broker has a different role and owner. These brokers keep definition information about offered services including the typical information defined in the Web Service Description Language (WSDL). For each service definition, there is also information about the functions this service does, the types and formats of the messages the service uses, and the locations of the service on the network.

There are two broker ownership types: private brokers and public brokers. A private broker is owned and controlled by one manufacturing company and used internally to hold information about services available privately for the applications in this company. In addition, a private broker can hold information about other services provided by other manufacturing companies and other related companies, if made available by the others. Public brokers are publicly owned and operate across all participating manufacturing and related companies. Public brokers hold information about publicly available services provided by the different companies. Any company wanting its services to be known and used by others needs to register them on a public broker.

There are also two broker scale types: a global broker, usually located on a cloud manufacturing or on a powerful server on the network, and local brokers provided to mainly serve local applications within close proximity to the services. The local brokers can be part of local machines or available on fog nodes that serve application's components. While the global broker keeps information about all offered manufacturing services in the network, the local brokers only maintain information about the current available manufacturing services within that area or provided by a local fog. This method is adopted to allow manufacturing applications and services within a manufacturing facility to deploy available local services and resources and deliver fast responses. The local brokers periodically update the global broker about the accessibility and status of their services. This two-broker-level approach provides better scalability for large-scale systems for manufacturing industry 4.0 applications.

Local brokers can be private or public brokers depending on their setup and ownership. A global broker may also be a private global broker serving a large manufacturing organization that operates across large geographic areas. Yet, we can also have public brokers available to connect services across multiple manufacturing and manufacturing related industries.

Multiple brokers can be used in different ways based on the manufacturing company size, manufacturing applications, and integration requirements. A small manufacturing company can use one private local broker for all its manufacturing applications while a large manufacturing company with multiple distributed branches can use the two-broker-level approach deploying a private global broker and several private local brokers for the branches. In addition, multiple manufacturing companies can be integrated using a private local broker for each company and a public global broker for the whole environment. Furthermore, for environments with multiple manufacturing companies and fog manufacturing nodes available publicly, one public global broker, several pubic local brokers, and several private local brokers can be used. In such environment, each fog node will have a public local broker to serve different local manufacturing applications, while each company will have a private local broker to serve its own applications. In this case, it is very likely that the global public broker will reside on the cloud manufacturing to enable access to all the components and services in the environment.

3.2 Invocation Services

Man4Ware offers facilities to enable local and remote service invocation for services available on different components of the manufacturing network. For example, Man4Ware supports remote service calls between manufacturing CPS services and fog manufacturing services. Here the manufacturing CPS can easily utilize services and resources provided by the fog manufacturing. Man4Ware also supports remote service calls between fog manufacturing services and manufacturing CPS services. In this case, the fog manufacturing service can check the status or configure manufacturing CPS devices. Other examples of remote service calls are between: fog manufacturing services across multiple fog manufacturing nodes; fog manufacturing services and cloud manufacturing services; or cloud manufacturing services and fog manufacturing services. Man4Ware provides several functions to support remote service calls including proper addressing and connection between clients' services and servers' services, data marshaling and demarshalling, managing the flow of requests and responses, and performing the actual service calls.

3.3 Fog Manufacturing Services

These services are designed to support the use of fog nodes as part of manufacturing industry 4.0 applications. They provide real-time capabilities through efficient utilization of fog manufacturing nodes at the edge of the network close to the manufacturing units, CPS, and other components. Man4Ware provides several fog manufacturing services to support real-time capabilities:

- Offloading computation service: allows manufacturing CPS components with limited processing capability to utilize the fog node for its computational needs.

- Caching service: provides a data caching service for specific manufacturing records to provide fast access to these records.
- Temporary storage service: allows the temporary use of storage available in a local fog node to support specific manufacturing applications storage needs.
- Manufacturing data analysis services: provide low latency data analysis for specific manufacturing situation.
- Manufacturing monitoring and control services: provide low latency monitoring and control of manufacturing components.
- Communication services: establish value added communication channels between the fog nodes and other components in the environment including the cloud manufacturing. These channels provide special features such as stream communication, data filtering, data compression, encrypted communication, and data fusion.

3.4 Security Services

Manufacturing services and data in industry 4.0 are distributed across multiple facilities, units, platforms and systems, possibly spanning multiple cloud manufacturing platforms, multiple fog manufacturing platforms, and multiple manufacturing CPS. These services may also be owned by different companies. Applications integrating multiple services owned by multiple entities will create multiple access points and flow paths across all components. Thus raising issues of security and privacy. These manufacturing services should only be accessed and shared by the right people, companies, and other services based on proper authorization and authentication models. Several security mechanisms can be utilized for manufacturing industry 4.0 applications. The main roles of the security services in Man4Ware are to incorporate different security features and mechanisms among all connected manufacturing components and confirm that the mandatory security measures are functioning properly to secure the applications and the systems. The security services involve authorization, authentication, and access control services for the components. These services can be offered with variable protection levels, such that diverse manufacturing industry applications can apply the appropriate set of security services at the desired protection levels.

As Man4Ware views all functions as services, it can utilize other developed security and privacy architectures to provide security and privacy solutions for manufacturing industry 4.0 applications. Man4Ware can be integrated with these solutions while their functions can be represented by services available for the manufacturing industry 4.0 applications. As service calls that can initiate transactions or information updates can be used among multiple authorized parities in Manufacturing Industry 4.0, Blockchain technology [18][19] can be used to log the updates. This facilitates maintaining a trustable audit trail using a distributed ledger that can provide step by step records of all updates. This process can be done with the support of Man4Ware at the level of service calls, where Man4Ware can ensure that the calls are recorded and timestamped.

3.5 Other Advanced Services

In addition to the discussed essential services, more services can be added to offer advanced features. One example is a virtualization service for manufacturing CPS and processes. For example, if a fog manufacturing node provides a monitoring service for a specific manufacturing CPS, it can also capture different operational status information of this CPS and store it on a cloud manufacturing node. Later, another cloud manufacturing service can be used to analyze this data and create a virtual copy of the manufacturing CPS. At the same time, a tuning fog manufacturing service can be used to adjust the monitoring process at the fog node to collect more detailed information about certain situations and conditions of the manufacturing CPS, which then lead to a more accurate virtual copy of the manufacturing CPS.

4 Application Example

Man4Ware services are distributed among multiple manufacturing CPS, Industry IoT systems, the cloud and fog nodes. Using the services standard interfaces, it is possible to connect, integrate and deploy various services to create advanced and smart manufacturing applications for Industry 4.0. It can also support different types and levels of integration as needed. To illustrate how this is done, we first describe a generic (imaginary) manufacturing industry. Suppose we have a frozen meals manufacturer that owns multiple factories in different locations around the world. Many components, organizations, and systems are involved in this industry like raw material producers and suppliers, transportation and logistics systems, plant management systems, operational systems and components, shop floor CPS and CPPS, distribution systems and consumers. In addition, other organizations may get involved such as the health department, regulatory and certification bodies, financial institutions and tax systems. Man4Ware can support the integration of these different components and the addition of advanced services and smart analytics to enhance performance, improve quality and reduce costs.

Horizontal Integration allows us to consolidate resources within the same level across different entities and organizations. It helps provide cross cutting services to streamline operations involving these different entities. For example, services to optimize measurement and quality control within each plant can be integrated together and with regulatory bodies to streamline testing and approvals of the products. In addition, it becomes possible to link specific areas in production across multiple plants for monitoring, control and optimization purposes. Integrating these services will allow for collecting more data about each locations of operations and consolidate it through intelligent services and predictive analytics to further identify optimization possibilities and reduce problems and failures in any of these services. A simple example is using collected data to compare operational parameters for a specific process in different plants to find out discrepancies or indicators of problems. In all these cases, CPS components, fog-based localized services, and global cloud-based services will be integrated to build such applications. Since most horizontal integration services occur within the same company, it is easy to rely on private brokers (several private brokers within the plants and a global broker on the cloud or privately-owned computing facility). Application specific services are developed and registered with these brokers and then utilized as needed. In some cases, there may be some need to access and use some public services through available public brokers like when measurement information need to be transferred to another company or organization.

Vertical Integration is more concerned with the value chain of the production process. This includes managing the acquisition and storage of raw material, shop floor operations, and storage and distribution of the final product. This in some way represents the core of the manufacturing operations. This integration will utilize services available in every stage of the manufacturing process to collect and utilize data for best possible results. For example, CPS components in the shop floor collect data on the performance of the different machines used and provide instantaneous controls to manage the operations of these machines and monitor process flows and material/resources utilization. This data can also be collected at fog-based services to aggregate each plant data into useable sets. More data is also collected from warehouse, logistics and transportation companies to support the application and help derive usable decisions on how to manage these resources and optimize operations. Furthermore, the data from each plant, producers, suppliers and distributors can be then transferred to a cloud-based service for advanced analysis. Data mining, predictive analytics, and smart algorithms can be used on the cloud to provide high level optimizations for the whole manufacturing value chain. Here services are accessed through almost all types of brokers. Within the company some relevant services will use their local private brokers to operate, while several will have to connect with services provided throughout the value chain. For example, to create an optimized raw material delivery schedule, services from the manufacturer, suppliers and transportation systems must be integrated using the public local and global brokers.

End-to-End Integration enables building and deploying applications involving a specific type of product using available services at all levels. For example, quality tests for the raw material obtained, monitoring of the manufacturing process of a particular food product, quality controls for the produced meal, and storage and transportation requirements for the final product can be collected through different services. These services exist within the plant CPS, the fog nodes serving all entities involved and the cloud. Several local brokers wil be involved across the different plants and the private broker will help coordinate the globa efforts for this type of application. In addition, some use of public brokers will be needed to integrate services necessary for the application from other entities like logistics, labs, government bodies and retail stores. This type of application allows for better management of specific products, enhanced product processing timeline and discover faults or problems in the production process early.

5 Discussion

Addressing the Industry 4.0 issues and challenges to fully realize its potential has proven to be a complex endeavor. However, a lot of effort is being made to address the complexity and provide guidelines and standards to help organize these efforts. One of the major aspects to consider is the need for standardization across the field to facilitate multi-party utilization, collaborations and integration [20]. The authors discuss various issues such as electro-mechanical and communication standards. In addition, they discuss some key aspects to be considered such as production line and process, plug and produce, smart infrastructures, control architectures and vertical integration. The NIST report [21] offers a glimpse into some relevant standards the future smart manufacturing should rely on. It also discusses opportunities and challenges for new standards to be developed. An SMLC (Smart Manufacturing Leadership Coalition) report discusses a framework to move towards smart manufacturing and identifies several priority areas [22]. It also proposes several goals and outcomes for the future of smart manufacturing such as: 1) Reduce the cost of applying relevant functionalities such as advanced data analysis and modeling in manufacturing processes; 2) Establish a shared platform to provide access to customizable open-access software and serves as an applications or “apps” store and clearinghouse; and 3) Create and provide broad access to next-generation sensing technologies and the digital infrastructure.

These examples emphasize the need for uniform approaches that will allow different manufacturing Industry 4.0 systems and applications to seamlessly work together and achieve the perceived goals. Our proposed Man4Ware offers one possible direction towards this goal. As a SOM, Man4Ware utilizes standardized interfaces that allow applications to view everything as a service. Within manufacturing Industry 4.0, we can treat every component and device in the CPSs or IoTs as services and every fog, edge and cloud node as a provider of additional services supporting the whole industry. These services, can be registered, looked up and integrated within any application serving the manufacturing purposes, creating a virtual services store. The availability of the service brokers at different levels facilitate these activates and help create a seamless integration across all platforms. Other work utilizing SOM and other methods in integrating fog and cloud computing (to be discussed next), show the viability of this approach and confirms the validity of our approach.

Man4Ware’s integration across different platforms and service providers creates an environment where the benefits of each platform can be maximized. Cloud computing has the capacity to offer advanced, compute- and storage- intensive services like data analytics and intelligent decision making. However, it lacks the capability to support real-time responses due to the inherent delays in communication. Fog nodes can bridge this gap as they can offer some level of compute and storage capabilities, while being located very close to the CPSs and IoTs. Therefore, many time critical and location sensitive services can be placed on fog nodes. As a result, the smart manufacturing system will benefit from both and further enhance its operations. Table 2 summarizes some of possible support fog and cloud computing can offer each at their level.

6 Related Work

Implementing Industry 4.0 to its full potential requires various sectors, components and systems to be integrated for effective use. However, this is not easy due to the complexity of achieving this integration. In addition, many challenges like the dynamicity, heterogeneity make the process even harder. Various research groups and professionals in the industry approached these issues and many possible solutions were proposed. The following is a summary of some of the research efforts invested in this topic.

Table 2. Fog and Cloud Support for Industry 4.0 Applications.

Factor	Fog Manufacturing	Cloud Manufacturing
Comm. Latency	Low and stable for low loads	Relatively high and unstable
Processing power	Limited	Powerful and scalable
Data storage	Small to medium, mostly for temporary storage	Large and scalable, suitable for long-term storage.
Suitable services	• Monitoring and control • Data fusion and filtering • Mobility support • Data streaming • Coordination • Data caching • Quality control • Integration with local subsystems • Small-scale local resource management • Rescheduling	• Building manufacturing knowledgebase systems • Long term planning • Optimizations • Large-scale scheduling • Large-scale data mining • Resource management • Unknown faults detection • Global application monitoring • Integration with other systems • High computational analysis • Coordination of multiple fogs

Cilia [23] is an integration middleware that uses service-oriented components to provide dynamic and autonomic features to support CPS data collection and sharing. The main concern here is the connectivity across all components local, and remote for better data sharing. Another architecture for the Industrial IoT (IIoT) is proposed as a middleware based on the Data Distribution Service for Real Time systems (DDS) protocol and uses a multilayer approach [24]. A smart factory framework is introduced in [25] to incorporate industrial network, cloud, and supervisory control terminals with smart shop floor objects. Agents are devised to represent the different smart objects in the system and assigned a coordinator on the cloud. A framework to address communication and comprehension challenges of Industry 4.0 and represent data and meta data in a semantic model that allows for standardized access model and administrative shell is proposed in [26]. Another architecture is proposed to address the issue of finding and utilizing services within the Industry 4.0 environment. This approach organizes services in a hierarchical structure and provides mechanisms to identify, find and use the needed services [27].

A service-oriented architecture (SOA) based middleware was introduced with services like dynamic spectrum management, distributed control logic, object virtualization, a SCADA (Supervisory control and data acquisition) gateway service, and data fusion transport capability. These services enable the integration of heterogeneous smart objects, sensors, actuators, legacy devices and sub-systems towards holistic management capabilities [28]. SOCRADES (Service-oriented cross-layer infrastructure for distributed smart embedded devices) is a European research project using SOA to facilitate developing Industry 4.0 applications [29]. Another example is SStreaMWare, a SOM for heterogeneous sensor data management [30]. Similarly, the authors of [31] propose a SOM for data quality management in Industry 4.0 applications. In a different direction [32] focuses on the trends of manufacturing service transformation in big data environments and predictive analysis to enhance transparency and productivity. Similarly, [33] discusses implementation requirements for maintenance applications and propose an information system for scalable fault tolerant big data pipeline to support collecting and analyzing data about the machines conditions and operations.

A vertical integration model for a reconfigurable smart factory is supported through a framework integrating industrial WSN (wireless sensor networks), the cloud and shop floor equipment [34]. The framework focuses on operational mechanisms and control engineering with the support of the cloud. Similarly, CCIoT-CMfg (Cloud Computing and IoT-based manufacturing) service system is proposed [35] to facilitate the integration of the manufacturing IoT systems with the cloud. In [36] another model for integrating multiple manufacturing CPSs with the cloud is proposed to leverage data integration across all platforms. Fog computing very recently was introduced to offer more localized and low latency services. For example, an approach to move functionalities closer to the devices through fog or edge nodes is introduced in [37]. This approach aims to enable CPS components to be programmable, autonomous, and capable of peer-to-peer communication. Similarly, in [16] an extension to the MQTT (the defacto IoT) communication protocol is offered allowing low latency services between the IoT and the Cloud.

Most of the work we identified focus on one or a few of the issues involved. Many of the solutions are feasible and provide useful features, yet each alone is limited. For example, Cilia [23] is very functional and useful for data related features, but does not address challenges like integration, real-time requirements or processing variety. In [24] the IIoT middleware architecture ignores the processing needs and does not incorporate the cloud and fog nodes. The multi-agent design [25] integrates CPS and smart objects with the cloud, yet it does not address real-time concerns as decisions have to go through the cloud-based coordinator. In [26] some challenges were addressed, yet the current proposal focuses on the administrative shell and does not discuss how this will integrate with other systems. The approaches discussed in [28] thru [31] offer some promising directions based on SOM. However, each has a different focus and does not offer a holistic approach. The remaining works discussed here focus on specific components of the manufacturing Industry 4.0 environment such as big data analytics, CPS, IoT, cloud computing or fog computing. Some integration efforts are underway, yet we have a long way to go before achieving complete solution environments. Man4Ware, combines many of the benefits of some of the approaches discussed here. However, it offers a more comprehensive and inclusive framework to design and build Industry 4.0 applications.

7 Conclusion

Manufacturing Industry 4.0 is a promising concept that, if implemented well, will transform the manufacturing world. Around the world, the costs of manufacturing are increasing and the major contributors to these increases are the human workers and rising energy costs. Just as lean manufacturing managed to optimize and reduce manufacturing costs earlier by eliminating non-value adding processes and optimizing workflow; Manufacturing Industry 4.0 aims to drive that goal a lot further. It envisions fully connected, automated and in many areas autonimized manufacturing environments, where human involvement is minimized, processes are lean and energy efficient, thus minimizing costs.

To achieve the vision, effective and efficient integration of technologies and processes is necessary. Industrial IoT, CPS, CPPS, shop floor equipment, information systems, and any other relevant systems (internal and external) must be integrated. Services supporting this integration and providing value-added features to the manufacturing process are created. And to further strengthen the environment, fog and edge computing and cloud computing will be needed. Fog nodes will support the components services locally and provide real-time control and monitoring services among others. The cloud, given its vast capabilities, will provide advantages in terms of supporting data storage, analytics, and provide high level intelligent methods and smart decision making and planning services.

Man4Ware, using the SOM approach can provide the right framework to achieve the integration among all these components and services. It represents every manufacturing component (IoT and CPS devices, robotic components, shop floor machines, etc.) as services with standard interfaces. It also provides a wide range of basic services on fog and cloud nodes using the same interface standards. As a result, seamless integration of multiple services at all levels can be accomplished leading to building and operating effective manufacturing industry 4.0 applications. In addition, along with the basic support services, developers can build and introduce new industry specific services and enhance current services to match their applications needs. The main advantage of Man4Ware is the SOM base and the support framework of key essential services enabling the use and integration of services across all levels and utilizing all available technologies to achieve the goals of manufacturing Industry 4.0.

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