Architecture of a Software Platform for Affordable Artificial Intelligence in Manufacturing

Vincenzo Cutrona, Giuseppe Landolfi, Rubén Alonso, Elias Montini, Andrea Falconi, and Andrea Bettoni

1 Introduction

The huge transformation brought by the fourth industrial revolution into the manufacturing world has forced any company to take on the digitalization journey, regardless of its size, sector, or location. In this context, Artificial Intelligence (AI) technologies are ready to take off as a new approach to solve business issues, and, recently, AI tools are proliferating [1]. Forward-thinking results can be obtained by analyzing huge amounts of data from a wide range of sources in the production system and by identifying deviations and trends in real time for making decisions [2]. The greater intelligence brought by AI embedded in production systems can not only bring advantages for large companies but also support Small-Medium Enterprises (SMEs) and mid-caps in achieving better operational performance. Yet

V. Cutrona · G. Landolfi · A. Bettoni
University of Applied Science of Southern Switzerland, Viganello, Switzerland
e-mail: vincenzo.cutrona@supsi.ch; giuseppe.landolfi@supsi.ch; andrea.bettoni@supsi.ch

R. Alonso
R2M Solution s.r.l., Pavia, Italy

Programa de Doctorado, Centro de Automática y Robótica, Universidad Politécnica de Madrid-CSIC, Madrid, Spain
e-mail: ruben.alonso@r2msolution.com

E. Montini (✉)
University of Applied Science of Southern Switzerland, Viganello, Switzerland

Politecnico di Milano, Milan, Italy
e-mail: elias.montini@supsi.ch

A. Falconi
Martel Innovate, Zurich, Switzerland
e-mail: andrea.falconi@martel-innovate.com

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several challenges are still preventing them from embracing AI on a large scale. To reduce the barriers, two conditions have to be satisfied: the technology has to be affordable and accessible enough for mass use, and the level of awareness of individuals and companies should be high enough to be able to understand how and where to use it.

The first condition can be tackled by democratizing AI tools: by exploiting the "as-a-service-model," technologies can be made available to SMEs at an affordable price and on-demand, thus reducing the financial gap with large companies and avoiding SMEs getting lost in the hype around AI [3]. This is the best solution since, on the one hand, the adoption of ad hoc solutions for specific company requirements leads to integration problems, long implementation times, and flexibility limits. On the other hand, adopting an all-in-one solution requires big investments for complex systems, which exceed the effective needs and strictly depend on legacy providers.

The second condition is more difficult to be satisfied at the level of single companies since, often, SMEs lack the skills and knowledge needed to turn AI into a major boost for their business, thus lagging behind larger organizations in the uptake level [4]. Successful implementation of AI requires identifying the right tools to be chosen among a plethora of solutions and their harmonization with existing IT systems and processes from both a technical and a strategic point of view so that they can become real enablers for performance improvement. Upskilling workers is essential to both empower a mutually supportive human–machine interaction and lower adoption barriers, but building internal competences requires time. Support is needed now to accompany European SMEs in their digitization journey so that they can keep the pace with their larger counterparts and be key players in their value chains. An innovation ecosystem should be created around SMEs so that they can easily find locally the needed support to draw customized AI adoption plans and be immersed in a vibrant and stimulating environment that makes them progress across the digital innovation flow.

At the European level, initiatives have been launched to promote the development of platforms that could support SMEs in the digital uptake, and the creation of local Digital Innovation Hubs (DIHs) is promoted to create an innovation ecosystem providing services to lower the entry barriers for SMEs. The AI uptake has to pivot on digital platforms that act as one-stop shop for SMEs, showcasing advances brought forward by synergistic efforts of DIHs, research centers, and technologies providers and offering services to smooth the adoption. Being able to offer to SMEs solutions tailored to their specific needs, built on modular kits, at a reasonable cost, easy and fast to implement is a must to strengthen the European economy's competitiveness.

KITT4SME recognizes that SMEs are among the companies that could benefit the most from the opportunities brought by AI solutions while, at the same time, being the ones with the least capabilities and resources to embrace them. KITT4SME specifically targets European SMEs and mid-caps to provide them with scope-tailored and industry-ready hardware, software, and organizational kits, delivered as a modularly customizable digital platform that seamlessly introduces AI in their production systems. Uptake of the resulting packages and of the provided services is strongly supported by the clear characterization and market readiness of the individual components and by the platform grounding on the already established RAMP marketplace. Seamless adoption of the customized kits is made possible by a Powered by FIWARE infrastructure,[1] which flawlessly combine factory systems (such as Manufacturing Execution System (MES) and Enterprise Resource Planning (ERP)), Internet of Things (IoT) sensors and wearable devices, robots, collaborative robots, and other factory data sources with functional modules capable of triggering data-driven value creation.

The rest of the chapter is structured as follows: Sect. 2 examines existing platforms and alternative methods for delivering AI services to manufacturing SMEs; Sect. 3 introduces the concept underlying the proposed platform, its architecture, and the provided functionalities for supporting AI developers; in Sect. 4, a real-world use case illustrating the advantages of the proposed platform for an SME is presented; and Sect. 5 concludes with a discussion of limitations and related future work.

2 Platforms in the AI Ecosystem

The KITT4SME platform aims to assist SMEs in adopting AI-based solutions by offering various services. These services, ranging from analyzing clients' requirements and implementing technical solutions to developing AI applications and training AI algorithms, coexist in an environment with platforms providing AI solutions, technology providers, AI consulting firms, and DIHs.

Platform-based services and aPaas are cloud computing services that allow customers to provide, instantiate, run, and manage modular software solutions comprising a core infrastructure and one or more applications without the complexity of building and maintaining the whole system, typically associated with developing and launching the applications [5]. These solutions allow also developers to create, develop, and package such software bundles. Gartner sees AI Platform as a Service (AI PaaS) as a set of separate AI services. However, it is possible to consider the concept of AI PaaS from the perspective of the classic Platform as a Service (PaaS) model. Such an environment usually includes two main components required for application development: hardware infrastructure (computing power, data storage, networking infrastructure, and virtual machines) and software solutions (tools and services).

The key hurdle to generalize a similar scheme for the AI PaaS architecture is that there is no general model for AI PaaS yet. The market is still forming, and different vendors offer completely different services under the same umbrella term. Yet many elements are common to the majority of today's AI PaaS and AI service

[1] https://www.fiware.org/.

platforms: infrastructure, data storage, pre-trained AI models, and Application Program Interfaces (APIs).

AI as a Service (AIaaS) allows individuals and companies to experiment with AI for various purposes without a large initial investment and with lower risk [6]. In this market, different AI providers offer several styles of Machine Learning (ML) and AI. These variations can be more or less suited to an organization's AI needs since organizations must evaluate features and pricing to see what works for them. To date, there are two kinds of platforms, depending on how they offer the service:

- *Platforms to develop code to build AI programs*: comparable to an open-source solution that allows users to create and configure applications through a graphical user interface instead of a traditional hand-coding computer program
- *Platforms providing already developed applications*: similarly to KITT4SME, these platforms allow users to deploy and implement ready-to-use solutions that do not require users to have advanced technology and IT skills.

Since KITT4SME addresses SMEs, and very few of them have in-house competencies (data scientists, analysts, and developers) or a specialized team able to develop AI models and applications [4], the following paragraphs focus on the platforms providing already developed applications.

Acumos AI Acumos AI[2] is an open-source platform that enables the training, integration, and deployment of AI models. It was launched in 2018 by the LF AI Foundation,[3] which supports open-source innovation in AI, ML, and Deep Learning (DL), making these technologies available to developers and data scientists. The platform provides a marketplace for AI solutions that are not tied to any specific infrastructure or cloud service. It aims to create a flexible mechanism for packaging, sharing, licensing, and deploying AI models securely through a distributed catalog among peer systems. Acumos AI aims to make AI and machine learning accessible to a broad audience by creating a marketplace of reusable solutions from various AI toolkits and languages. This way, ordinary developers who are not machine learning experts or data scientists can easily create their applications [7].

Bonseyes Bonseyes[4] was a H2020 project that ended in 2020. It was led by NVISO SA,[5] based in Lausanne, and aimed to create a platform with a Data Marketplace, DL Toolbox, and Developer Reference Platforms. The platform was designed for organizations that wanted to implement AI in low-power IoT devices, embedded computing systems, or data center servers. The platform had an engagement strategy where platform experts published challenges and requests for AI solutions that met specific technical requirements based on real industrial problems faced by companies. Data scientists proposed their own AI applications to be deployed on the

[2] https://www.acumos.org/.

[3] https://lfaidata.foundation/.

[4] https://www.bonseyes.eu/.

[5] https://www.nviso.ai.

platform. Companies evaluated and paid the winners after the call ended. Bonseyes used a collaborative AI Marketplace to provide real-world solutions to the industry, supporting scenarios where data must remain on the data provider's premises and online learning with distributed Cyber-Physical Systems (CPSs). The platform allowed continuous feedback from human actors to evaluate model performance and obtain metadata about context and users' perspectives [8, 9].

GRACE AI Grace AI[6] is an AI platform launched by 2021.AI in 2018, with the mission to help customers in realizing their vision of AI by identifying innovative business opportunities in key processes and functions. Grace AI Platform and the AIaaS portfolio are the company's main assets. The Grace platform is built for both organizations at the beginning of their AI and ML journey and organizations that have already established a data science team but are looking for ways to infuse continuous intelligence into their business.

Grace AI aims to provide any organization access to AI implementation, including automated documentation, validation, and certification through data exploration, AI development, deployment, and operation.

PTC Inc. PTC Inc.[7] is a software and services company founded in 1985, based in Boston. It offers a range of products and services that support innovation and Industry 4.0. It is a platform for developing IoT and Augmented Reality (AR) solutions. PTC Marketplace is a digital space where customers and partners can access IoT apps, market-ready solutions, and innovative technologies. PTC has made recent enhancements to its marketplace, making it easier for solution builders to find market-ready solutions and customized accelerators. It also provides a platform for PTC partners to showcase their technologies, solutions, services, and industry expertise to customers and prospects.

The platform offers a rich set of capabilities that enable solutions for design, manufacturing, service, and industrial operations and incorporates modular functionality that simplifies development. These include pre-built applications for the fast, easy implementation of Industrial Internet of Things (IIoT) solutions for common use cases in various industries.

3 KITT4SME: A Platform Delivering AI to SMEs

The KITT4SME project aims to provide AI solutions to SMEs in the manufacturing domain through a five-step workflow. This workflow consists of interconnected activities designed to facilitate the adoption of AI technologies on the shop floor. The activities are detailed as follows:

[6] https://2021.ai/offerings/grace-ai-platform/.

[7] https://www.ptc.com/.

- *Diagnose*: In this step, the KITT4SME platform utilizes a smart questionnaire to identify how AI can be beneficial in transitioning the shop floor. The questionnaire helps assess the specific needs and challenges of the SMEs, enabling a better understanding of where AI technologies can be applied effectively.
- *Compose*: The platform recommends a minimal set of AI tools from a marketplace catalog based on the diagnosis obtained in the previous step. It considers the unique requirements and constraints of each SME, aiming to maximize the benefits derived from the AI technologies. The platform provides guidance on the wiring and configuration of these AI tools, ensuring their seamless integration into the existing workflow.
- *Sense*: This activity focuses on establishing the connection between the shop floor and the cloud platform. By enabling this connection, new data become available to AI services. The KITT4SME platform provides a tailor-made kit that can output insights about the status of the shop floor (e.g., to detect and explain anomalies). Additionally, it offers visualization of Key Performance Indicators (KPIs), allowing SMEs to gain valuable insights into their operations.
- *Intervene*: In this step, the platform suggests corrective actions to address ongoing issues and anomalies identified on the shop floor. Leveraging the power of AI, the platform provides recommendations for resolving problems and improving the overall performance of the manufacturing processes.
- *Evolve*: The final step involves analyzing the outcomes and feedback generated from the previous steps. The platform uses this information to continuously improve the *Diagnose* and *Compose* steps. It also provides personalized staff training recommendations to further enhance the adoption and utilization of AI technologies within the SME.

The underlying concepts of the KITT4SME platform revolve around understanding the specific needs of SMEs, recommending tailored AI solutions, establishing seamless connections between the shop floor and the cloud platform, providing real-time analyses and KPI visualization, offering intervention recommendations, and continuously improving the overall workflow based on feedback and outcomes.

By following this five-step workflow, the KITT4SME platform aims to empower SMEs in the manufacturing domain to harness the potential of AI technologies, enhance their operational efficiency, and drive growth and innovation in their businesses. This section reports on the basic concepts underlying the platform and explains its main functionalities.

3.1 High-Level Concept and Architecture

The KITT4SME architecture is designed to address the challenges associated with deploying and utilizing AI models developed by data scientists or AI developers in SMEs. One of the key challenges is the discrepancy between the pace of AI model

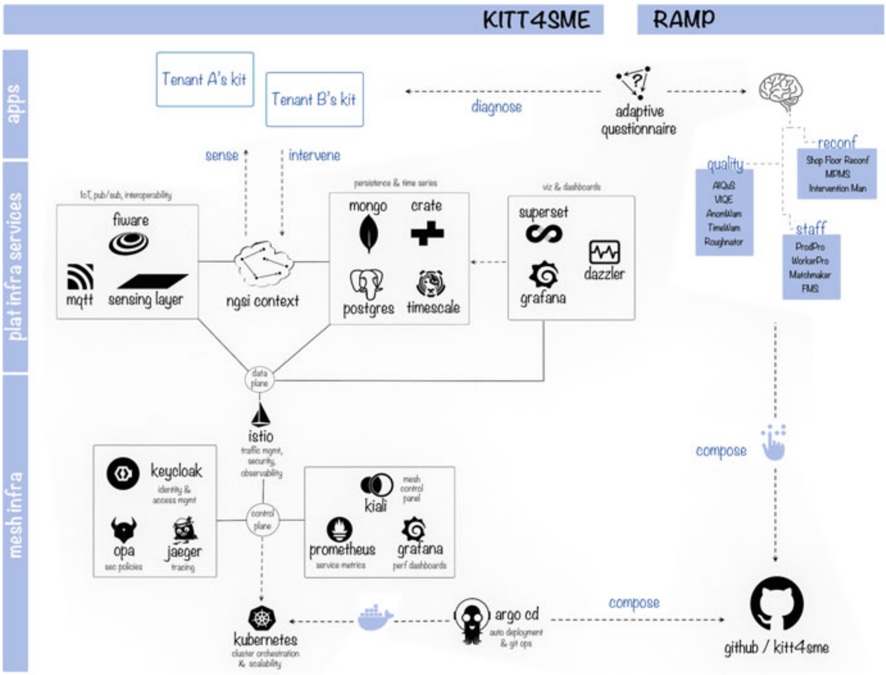

Fig. 1 KITT4SME platform three-tier architecture

development and the capabilities of SMEs' IT systems. This often leads to situations where models are not deployed or where the deployment and update process is time-consuming.

To tackle these challenges, KITT4SME proposes a conceptual pipeline consisting of six steps, which cover the process from data preparation to the practical use of the model. The steps (presented in Fig. 1) are as follows:

1. *Prepare data*: This step involves collecting and preparing the data required for training the AI model. It includes tasks such as data cleaning, transformation, and feature engineering to ensure the data are suitable for model development.
2. *Develop the model*: In this step, AI researchers and developers focus on building and training the AI model using the prepared data. This is where the core value of the AI solution is generated.
3. *Package the model*: Once the model is developed, it needs to be packaged in a way that it can be easily deployed and integrated into the existing systems of the SME. Packaging involves encapsulating the model and its associated dependencies into a deployable form.
4. *Validate the model*: Before deployment, it is crucial to validate the model to ensure its accuracy, reliability, and suitability for the intended use. Validation may involve testing the model's performance on a separate dataset or using techniques like cross-validation.

5. *Deploy the model*: This step focuses on deploying the validated model into the SME's IT infrastructure. It involves integrating the model with the existing systems, ensuring compatibility, and addressing any technical requirements or constraints.
6. *Use the model*: The final step is when the SME can actively utilize the deployed model in its operations. This includes making predictions, generating insights, and incorporating the model's outputs into decision-making processes.

The three intermediate steps, namely packaging, validating, and deploying the model, are often complex and time-consuming. KITT4SME aims to simplify and automate these steps, reducing the overall time and effort required to deploy and update the AI model. By streamlining these processes, the platform enhances the repeatability and efficiency of the entire pipeline, making it easier for SMEs to leverage AI technologies effectively.

The software platform implementing the KITT4SME workflow is based on a service mesh, multi-tenant cloud architecture. It provides a means to assemble various AI components from a marketplace and facilitates their connection to the shop floor while ensuring interoperability, security, and privacy-preserving data exchange. The platform consists of loosely coupled web services running in a cluster environment and relies on a dedicated cluster software infrastructure. Several key concepts and guiding principles underpin the architecture of the KITT4SME platform:

- *Leveraging state-of-the-art technology and standards*: The platform utilizes a dedicated cluster software infrastructure, referred to as *mesh infrastructure*. This infrastructure is built on industry-standard technologies such as Kubernetes[8] and Istio[9]. The platform reuses open communication and data standards as much as possible to foster service interoperability (e.g., REST principles for services interaction and NGSI standard for data exchange).
- *Platform services*: The platform comprises two types of services: *application services*, which are integral to the KITT4SME workflow and provide the functionality required for the platform's core activities, and *infrastructure services*, which consist of a network of intermediaries within the mesh infrastructure. These intermediaries handle essential operational aspects such as routing, security, and monitoring. By separating these concerns, AI developers can focus on implementing service-specific features while relying on the platform for operational support.
- *Multi-tenancy*: The platform is designed to support multiple SMEs sharing the same instance. Each company is associated with a security protection domain, referred to as a *tenant*, which isolates its data and users from other tenants. The platform also allows for explicit sharing policies that enable companies to selectively share data and resources if desired.

[8] https://kubernetes.io/.

[9] https://istio.io/.

- *Containerized deployment and orchestration*: The platform adopts a container-based virtualization approach for service deployment and orchestration. Services are packaged and executed within containers, enabling independent development using appropriate technology stacks. This containerization allows for the decoupling of services and facilitates their independent deployment, potentially through automated release processes such as Continuous Integration (CI) and Continuous Delivery (CD).

By adhering to these principles and utilizing modern technologies, the KITT4SME platform ensures efficient and scalable execution of the AI workflow. It promotes service interoperability, simplifies deployment and management, and provides a secure and isolated environment for SMEs to leverage AI capabilities within their manufacturing processes. The KITT4SME high-level architecture provides the ecosystem enabling the streamlined AI packaging, validation, and deployment while also fostering and facilitating the composability and integration of AI solutions.

As depicted in Fig. 1, the architecture is organized into a three-tier structure on top of the hardware layer. Each layer comes with a set of components dealing with certain operational functionalities, as follows:

1. *Mesh Infrastructure Layer*: This layer, depicted as "mesh infra" in Fig. 1, is responsible for managing computational resources, network proxies, and interconnection networks. It utilizes Kubernetes for containerized workloads and services, while Istio acts as a service mesh for traffic management, observability, and security. The tasks performed by the mesh infrastructure layer include:
   - Managing computational resources (e.g., CPU, memory, storage) and allocating them to processes in the upper layers, acting as the *Cluster Orchestration Plane*
   - Handling the network of proxies for transparent routing, load balancing, and securing communication, which represents the *Control Plane*
   - Managing proxies and interconnection networks for capturing and processing application traffic, serving as the *Data Plane* of the mesh infrastructure
2. *Platform Services Infrastructure Layer*: This layer, labeled as "plat infra services" in Fig. 1, comprises processes that support the operation of application services in the upper layer. It includes components such as IoT sensor connectors, context brokers, databases, and software for creating dashboards and visualizations. These components rely on well-known software and IoT middlewares like FIWARE [10]. Each component exposes interfaces for use by higher layers while utilizing the lower layer for interconnection.
3. *Application Layer*: This layer, represented as "apps" in Fig. 1, hosts services and components that provide functionality to the manufacturing SME. Examples include anomaly detection, data augmentation components, and dashboards. The application layer focuses on application-specific concerns while leveraging

the security, traceability, scalability, integration, and communication mechanisms provided by the lower layers.

Additionally, the KITT4SME platform benefits from its connection to an application marketplace. This marketplace, facilitated by discovery solutions like adaptive questionnaires, enables the identification of new applications and components, supporting the *Compose* activity in the KITT4SME workflow. A detailed description of the components and their functionality in each layer is provided in Sect. 3.2.

3.2 Functionalities and Component Description

Pursuing the idea of an open-source platform for the uptake of AI solutions in manufacturing SME, KITT4SME has chosen FIWARE[10] as the underlying open-source platform for its AI solutions in manufacturing SMEs. FIWARE is renowned as a top-quality open-source platform for IoT [10]. By leveraging FIWARE, the KITT4SME platform, branded as "Powered by FIWARE," inherits a range of capabilities that are beneficial for managing context information and data in the manufacturing domain. These capabilities include:

- *Handling and managing context information*: The KITT4SME platform can efficiently handle and manage context information from diverse data sources. This allows for the collection and aggregation of data from various sensors, machines, and other sources in the manufacturing environment.
- *Distributing and streaming data*: The platform is equipped with mechanisms for distributing and streaming data to external components. This enables the seamless transfer of data to external systems for various purposes, such as persistence or AI-based processing.
- *Integration with AI-based processing*: The KITT4SME platform can integrate with AI-based processing components, leveraging the capabilities of FIWARE. This integration facilitates the application of AI algorithms and techniques to analyze and derive insights from manufacturing data. The results obtained from AI processing can be seamlessly integrated back into the platform, enriching the current context and enabling data-driven decision-making.

Overall, by utilizing FIWARE as the foundation, the KITT4SME platform gains powerful tools and features that are instrumental in the management of IoT data and seamless integration of AI-based processing capabilities. Figure 2 depicts the logical architecture of the platform, illustrating the hierarchical layout in which intelligent services and AI applications are placed on top of the FIWARE ecosystem. In the subsequent discussion, we present a comprehensive overview of the platform's functionalities, accentuating the advantages derived from harnessing FIWARE as the bedrock of its technological infrastructure.

[10] https://www.fiware.org/.

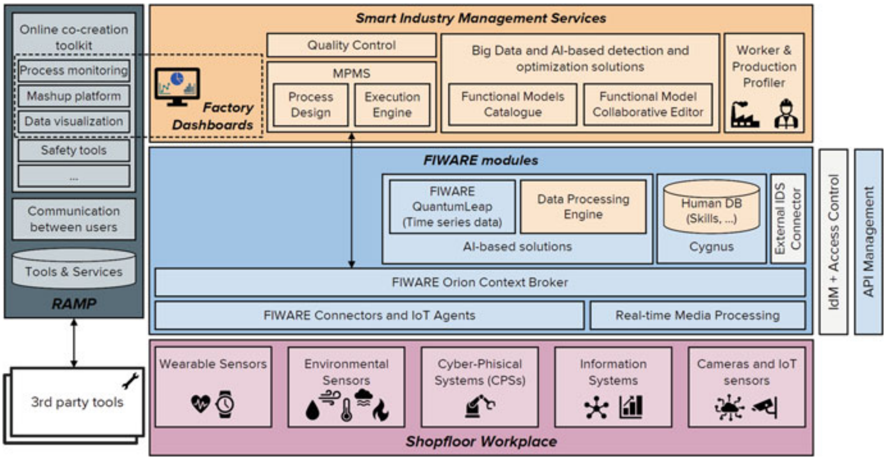

Fig. 2 Powered by FIWARE KITT4SME architecture. Components represented as blue boxes are from the FIWARE reference architecture [10, 11]

Data Gathering The data gathering aspect of the KITT4SME architecture encompasses the collection of data from diverse devices, situated at the lowest layer of the architecture (as depicted in Fig. 2). These devices, deployed within the factory, serve to enrich the system's knowledge base with both raw and preprocessed data. The following categories of devices contribute to the data gathering process:

- *Wearable Sensors*: These sensors are specifically designed to monitor the health and well-being of workers within the factory setting. They provide valuable insights into various physiological parameters and indicators.
- *Environmental Sensors*: Scattered throughout the factory, environmental sensors play a vital role in monitoring and capturing data related to the prevailing environmental conditions. This includes parameters such as air pollution levels, temperature, and humidity.
- *CPSs*: The architecture also incorporates CPSs, with a particular emphasis on those commonly involved in the manufacturing processes, such as machining equipment and collaborative robots. These CPSs facilitate the capture of relevant data pertaining to the operational aspects of the production line.
- *Information Systems*: Information systems represent a valuable source of raw and value-added data, which contribute to update the contextual information of the platform also with aggregated data.
- *Cameras and IoT sensors*: Together with environmental sensors, cameras and IoT sensors are needed to monitor the production, usually requiring a real-time processing to extract valuable knowledge from data streams.

Communication Interfaces In the subsequent layer, the FIWARE framework encompasses a collection of Generic Enablers (GEs) that serve as interfaces between devices, enabling the retrieval of contextual information and the initiation of actuations in response to context updates. Examples of FIWARE GEs available in the catalog[11] include:

- *Connectors and IoT agents*: These modules facilitate the interaction with devices utilizing widely adopted IoT protocols, including LWM2M over CoaP, OneM2M, and OPC-UA. It provides a standardized approach to interface and communicate with diverse IoT devices. Also, connector supporting FAST Real-Time Publish–Subscribe (RTPS) for efficient and real-time processing of data streams is provided, based on the ROS 2 [12] framework.
- *Real-Time Media Processing*: These GEs are designed to support real-time processing and manipulation of media streams (e.g., to transform video cameras into sensor-like devices) to extract valuable information from visual data streams.

Data Broker In the layer above, the FIWARE Orion Context Broker represents the fundamental component of any solution powered by FIWARE. This context broker facilitates the decentralized and scalable management of context information, allowing data to be accessed through a RESTful API. Serving as the authoritative source of information, the Context Broker stores the latest update status of all devices, components, and processes that contribute data to the platform.

However, for the purpose of training and fine-tuning AI tools, it is often necessary to access historical data. To address this requirement, FIWARE offers dedicated GEs called QuantumLeap that automatically generate time series data from the evolving context information, enabling AI tools to leverage the valuable insights gained from historical data analysis.

Smart Industry Management Services The topmost layer of the architecture encompasses analytical services and profilers that leverage the knowledge base within the system. These services include Big Data applications and components utilizing AI-based detection and optimization tools. It is in this layer that AI developers and researchers can greatly benefit from the historical data and up-to-date context information made available by the Powered by FIWARE platform. Additionally, the KITT4SME architecture incorporates utility components in this layer to extract additional knowledge from persistent information and provide insights to human actors regarding the factory's status. These components include:

- *Human Description Database*, which stores a comprehensive representation of factory workers derived from physiological parameters, worker information, machine parameters, and environmental data
- *External IDS Connector*, a component from the IDSA reference architecture[12] that ensures a trustworthy interface between internal data sources and external data consumers. This connector plays a critical role in enabling the integration

[11] https://www.fiware.org/catalogue/.

[12] https://docs.internationaldataspaces.org/ids-ram-4/.

of external value-added services, where data exchange is governed by IDS policies

The outputs of analytical models, such as anomaly detection, can be fed back into the FIWARE Context Broker. This triggers decision-making mechanisms, whose logic can be modeled and managed during execution by decision support systems, such as the Manufacturing Process Management System (MPMS). The activation processes of the platform can involve human-in-the-loop interactions, such as collective intelligence, or rely on behavioral updates for groups of involved CPSs. The decisions thus triggered must be identified by IDAS IoT Agents through the FIWARE Context Broker to effectively enable feedback to the CPSs.

Marketplace and Identity Management and Access Control To facilitate the widespread adoption of AI applications and enhance their discoverability, the KITT4SME platform leverages an existing marketplace called Robotics and Automation MarketPlace (RAMP). RAMP enables the Software as a Service (SaaS) provision of these applications, making them easily accessible to users. By incorporating FIWARE-compatible equipment (e.g., robots, machines, sensors) on the production floor, businesses can directly utilize the various tools offered by KITT4SME without the need for complex software deployments and extensive IT expertise. This allows manufacturing SMEs to focus on their core business activities and adds value to their operations.

Furthermore, the distributed nature of the architecture promotes collaborative usage of tools and production data between manufacturing SMEs and technology providers. It facilitates online co-creation and minimizes the necessity for continuous on-site inspections and system installations. Access to platform resources is facilitated by an IDentity Management and Access Control (IDM) GE. This IDM GE provides robust support for secure and private OAuth2-based authentication of users and devices. It also offers features such as user profile management, privacy-preserving handling of personal data, Single Sign-On (SSO), and Identity Federation across multiple administrative domains. These capabilities ensure secure access to the platform's resources while maintaining user privacy and data protection.

4 KITT4SME to Bring AI to an Injection Molding Use Case

The KITT4SME platform has been applied in 4 use cases within the KITT4SME project and 18 external demonstrators made via Open Calls.[13]

In this section, we discuss how the KITT4SME platform has been exploited to create an AI kit supporting one of the internal use cases. This use case is from the injection molding industry, and it aims at facilitating an assembly task mainly composed of screwdriving operations. The assembly task starts with a molding

[13] https://kitt4sme.eu/open-call/.

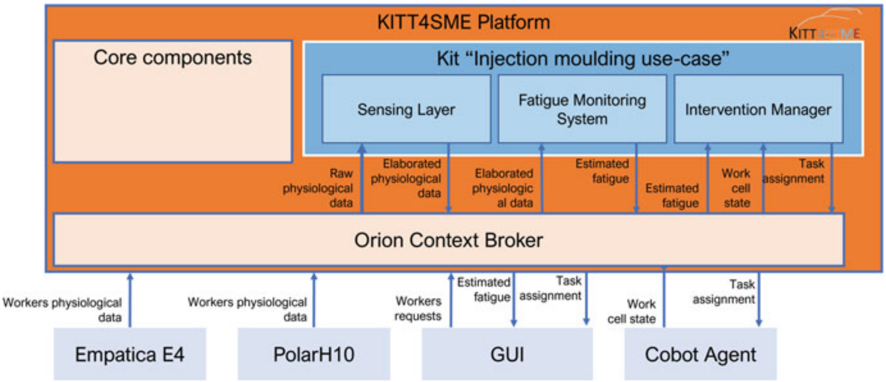

Fig. 3 The KITT4SME solution for the use case in the injection molding sector

press producing a molded piece every 90 seconds. Then, the task foresees a gantry robot that automatically extracts the molded piece from the injection molding machine and places it onto a conveyor belt. Subsequently, a human operator works at a designated workstation to perform the assembly operations while also being responsible for periodic quality checks on the molded pieces or quick maintenance operations on the injection molding machine.

The KITT4SME platform has introduced an AI solution to mitigate workers' physical stress caused by heavy workloads and the injection molding machine's demanding pace during operations. In particular, the use case relies on the concept of human digital twin [13]. A dynamic task assignment between the collaborative robot and the operator is performed by creating a digital representation of the operator and the production system.

The Kit used for this use case, represented with its whole architecture in Fig. 3, includes:

- *Sensing Layer*: This module supports the collection and use of IoT sensor data to be used by data analysis and decision-making modules to take decisions or to be visualized on dashboards. It provides a solution including the interoperability elements (APIs and broker client) for bidirectional data exchange between sensors and the KITT4SME's Orion Context Broker. Data are also preprocessed if needed.
- *Fatigue Monitoring System*: It is an AI model that estimates the perceived fatigue of the workers based on physiological data (e.g., heart rate) from wearable devices and on quasi-static characteristics (e.g., age). The estimation is made using physiological data collected from wearable devices selected by applying an Analytic Hierarchy Process (AHP)-based methodology [14] and operator's characteristics, including age, sex, handedness, exercise/healthy habits, and routines, collected via interviews.
- *Intervention Manager*: It monitors the real-time status of the worker–factory ecosystem, elaborating data from sensors, machines, workers monitoring sys-

tems, and ERP, and it knows what interventions can be applied and which are the rules to decide which is the best one given a particular situation. It applies AI models specifically developed to support decision-making.

The kit has been deployed to the platform to support the task assignment in a screwdriving process in the following process:

1. The operator retrieves two molded parts from a conveyor belt and positions them on the working bench.
2. The operator inserts six nuts into each part, flips one part, and places it on top of the other.
3. The operator positions nine screws on one side of the assembled parts.
4. The Intervention Manager assigns each screw to the operator or the cobot. The operator and a cobot simultaneously perform the screwdriving process. Depending on the number of screws assigned to the operator, they may also engage in other support activities, such as monitoring other machines, conducting short maintenance operations, or removing the pallet.
5. The operator flips the assembled parts and repeats steps 3 and 4.
6. The assembled parts are stacked on a pallet.

The task assignment, performed by the Intervention Manager and confirmed by the operator, consists of the allocation of the screwing operations (9x2 for each assembled part), and it is made considering the following parameters:

- Current perceived fatigue of the operator as estimated by the Fatigue Monitoring System.
- Work In Progress level.
- Cobot state (idle, current operation, and error).

Discussion The above use case exemplifies how the KITT4SME platform can actually ease AI adoption by SMEs, compared to other platforms in the AI ecosystems. Indeed, compared to platforms to develop AI solutions, the SME from the use case did not spend any effort on developing AI, given that they exploited the existing application available on the platform. Also, the platform helped the company compose the best kit to solve a real need, i.e., to facilitate an assembly task mainly composed of screwdriving operations. The proposed kit already included all the components needed to be implemented in the factory, i.e., data acquisition (Sensing Layer), AI solution to derive data-driven knowledge (Fatigue Monitoring System), and a reasoning engine (Intervention Manager), relieving the company from extra development activities needed to connect the shop floor to the platform. Instead, by considering platforms providing already developed applications, a similar use case has been successfully tested in a laboratory environment [15], exploiting a different IIoT platform [16]. This kind of platform enables the handling of third-party applications, with no guarantees about the interoperability of components in terms of application interfaces and data models, which are covered within the KITT4SME platform by the FIWARE components. Also, while this kind of platform comes with a ready-to-use solution, integrating and deploying such solutions is often a burden solely on the developers. Again, the KITT4SME platform offers a distinct advantage since it effortlessly facilitated the integration and deployment of three distinct modules, two of which leverage AI, resulting in a smooth and reliable operation.

5 Conclusion

In this chapter, we discussed the potential of AI solutions in increasing the profitability of SMEs (e.g., by improving product quality or optimizing production line configurations), and we presented a new platform, namely the KITT4SME platform, intended to deliver affordable, tailor-made AI kits to the manufacturing industry. The cloud platform presented in this chapter supports the KITT4SME workflow by relying on widely adopted platforms, e.g., FIWARE, in such a way to ease the development of new AI services, as well as their deployment in real industrial settings.

Specifically, the platform is capable of composing AI components from a marketplace (i.e., the RAMP marketplace) into a tailor-made service offering for a factory, a functionality that is not provided by any of the existing AI platforms. Once the factory shop floor is connected to the AI services, the platform enables data storage and exchange in an interoperable, secure, privacy-preserving, and scalable way. The architecture has been designed by leveraging state-of-the-art technology and standards, reusing open-source software and technologies whenever possible, thus promoting both its adoption by small manufacturing companies on a budget and further extensions by other researchers and practitioners in the reference community. The exploitation of the platform has been demonstrated with real-world use cases, which have been conducted as part of the KITT4SME project thanks to a platform prototype publicly available in the KITT4SME online repository.[14]

Future work will be focused on further increasing the interoperability of platform services, also relying on semantic data interoperability, to better define the composability of different AI components, possibly available in different marketplaces, enabling cross-platform service composition.

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References

1. Wu, S.-Y.: Key technology enablers of innovations in the ai and 5g era. In: 2019 IEEE International Electron Devices Meeting (IEDM), pp. 36–3. IEEE (2019)
2. Alexopoulos, K., Nikolakis, N., Chryssolouris, G.: Digital twin-driven supervised machine learning for the development of artificial intelligence applications in manufacturing. Int. J. Comput. Integr. Manuf. **33**(5), 429–439 (2020)

[14] https://github.com/c0c0n3/kitt4sme.

3. Elger, P., Shanaghy, E.: AI as a Service: Serverless Machine Learning with AWS. Manning Publications (2020)
4. Bettoni, A., Matteri, D., Montini, E., Gladysz, B., Carpanzano, E.: An ai adoption model for SMEs: a conceptual framework. IFAC-PapersOnLine **54**(1), 702–708 (2021). 17th IFAC Symposium on Information Control Problems in Manufacturing INCOM 2021
5. IBM: What is platform-as-a-service (PaaS)? https://www.ibm.com/topics/paas (2021). Accessed 08 Aug 2023
6. Lins, S., Pandl, K.D., Teigeler, H., Thiebes, S., Bayer, C., Sunyaev, A.: Artificial intelligence as a service. Bus. Inf. Syst. Eng. **63**(4), 441–456 (2021)
7. Zhao, S., Talasila, M., Jacobson, G., Borcea, C., Aftab, S.A., Murray, J.F.: Packaging and sharing machine learning models via the Acumos AI open platform. In: 2018 17th IEEE International Conference on Machine Learning and Applications (ICMLA), pp. 841–846. IEEE (2018)
8. Llewellynn, T., Fernández-Carrobles, M.M., Deniz, O., Fricker, S., Storkey, A., Pazos, N., Velikic, G., Leufgen, K., Dahyot, R., Koller, S., et al.: Bonseyes: platform for open development of systems of artificial intelligence. In: Proceedings of the Computing Frontiers Conference, pp. 299–304, 2017
9. Prado, M.D., Su, J., Saeed, R., Keller, L., Vallez, N., Anderson, A., Gregg, D., Benini, L., Llewellynn, T., Ouerhani, N., et al.: Bonseyes ai pipeline—bringing ai to you: End-to-end integration of data, algorithms, and deployment tools. ACM Trans. Internet Things **1**(4), 1–25 (2020)
10. Ahle, U., Hierro, J.J.: Fiware for data spaces. In: Otto, B., ten Hompel, M., Wrobel, S. (eds.), Designing Data Spaces: The Ecosystem Approach to Competitive Advantage, pp. 395–417. Springer International Publishing (2022)
11. Fiware Smart Industry Reference Architecture: https://www.fiware.org/about-us/smart-industry/ (2022). Access 08 Aug 2023
12. Macenski, S., Foote, T., Gerkey, B., Lalancette, C., Woodall, W.: Robot operating system 2: Design, architecture, and uses in the wild. Sci. Robot. **7**(66), eabm6074 (2022)
13. Montini, E., Bettoni, A., Ciavotta, M., Carpanzano, E., Pedrazzoli, P.: A meta-model for modular composition of tailored human digital twins in production. Procedia CIRP **104**, 689–695 (2021)
14. Montini, E., Cutrona, V., Gladysz, B., Dell'Oca, S., Landolfi, G., Bettoni, A.: A methodology to select wearable devices for industry 5.0 applications. In: 2022 IEEE 27th International Conference on Emerging Technologies and Factory Automation (ETFA), pp. 1–4. IEEE (2022)
15. Montini, E., Cutrona, V., Dell'Oca, S., Landolfi, G., Bettoni, A., Rocco, P., Carpanzano, E.: A framework for human-aware collaborative robotics systems development. Procedia CIRP **120**, 1083–1088 (2023). 56th CIRP Conference on Manufacturing Systems 2023. https://doi.org/10.1016/j.procir.2023.09.129. https://www.sciencedirect.com/science/article/pii/S2212827123008612
16. Montini, E., Cutrona, V., Bonomi, N., Landolfi, G., Bettoni, A., Rocco, P., Carpanzano, E.: An IIoT platform for human-aware factory digital twins. Procedia CIRP **107**, 661–667 (2022)