Micro Service based Sensor Integration Efficiency and Feasibility in the Semiconductor Industry

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Abstract—**The semiconductor industry is strongly increasing the production capacities and the product portfolio for a wide range of applications that are needed in the worldwide supply chains e.g. the automotive, computer and security industry. The complex manufacturing processes require more automation, dig- italisation and IoT frameworks, especially for highly automated semiconductor manufacturing plants. Over the last years, this industry spent much effort to control highly sensitive materials in production by product monitoring using advanced process control by various sensors in production. Nevertheless, until today, sensor integration, especially for such sensors that are not supported by the equipment vendors, is time-consuming and complicated. This article aims to use a micro-service-based approach by Eclipse Arrowhead as an open-source microservice architecture and implementation platform [1]. This architecture is an easy and powerful framework that can be used for multiple sensor applications to control the manufacturing material flow in a modern semiconductor plant with a high product mix. The article describes how the engineering process was designed, the architecture of the use case and the main benefits in the operational business are shown.**

Index Terms—**Eclipse Arrowhead, IoT Frameworks, Sensor-integration, Micro Services, Engineering Process, Digitalisation, Industry4.0**

I. MOTIVATION

Semiconductor manufacturing has become increasingly complex in recent years. A variety of new IC facilities manufacturing products according to More Moore or More than Moore have started production based on 200 and 300mm wafers. Wafer facilities that follow both the one and the other strategy have to adapt their production to the diverse requirements of the respective technologies and customer requirements. The Time2Market factor is enormously important to deliver the products in an optimal quality to the customers at the right time. Monitoring the supply chain is one of the most important points to achieve the mentioned goals. Sensors for monitoring the material flow and hundreds of different process steps play an increasingly important role in highly automated manufacturing plants. Over the last ten years, Infineon Technologies Dresden (IFD) has almost completely automated the 200 mm production line and established the world´s first fully automated 300 mm line for power semiconductors. IFD worked over the last 15 years already on the automation of its 200 mm line with hundreds of different products in the same line. The challenges in the field were described by Heinrich et al. [2]. The influence of automation on the production in the semiconductor industry was already researched [3]–[5] by different teams from IFD in the front end and the wafer test area [6]. The results of this work showed that the controlling and monitoring of a high mix product portfolio requires advanced automation and factory integration concepts compared to high volume production with a low product mix. In 2010, IFD started the first worldwide production line for power semiconductors based on 300 mm wafers and thin wafer technologies. This kind of manufacturing required special manufacturing concepts again. The use of more automation, especially digitalization, has been the main enabler to overcome the challenges by the new requirements of power semiconductor manufacturing described by G. Schneider et al. [7]. Both production lines at IFD follow the More than Moore strategy and produce hundreds of different products in different technology nodes with the highest quality requirements e.g. products in the medical sector or automotive applications. Besides modern production plants, which already have a large number of integrated sensors, additional sensors or IoT devices and external, chemical and physical sensors are increasingly needed for real-time monitoring and controlling hundreds of individual process steps. The number of sensor data per day has now increased to more than 1 billion per day, which stresses the manufacturing facility's server capacities and IT performance. Due to the introduction of automation by means of robots or fully automated, hybrid transportation systems, only a few humans remain in the production area who can sense deviations with their sensory organs. Therefore, it has become increasingly important to online monitor the different machines, processes and, above all, maintain the

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entire systems such as the different machines, processes and the whole cleanroom. In this context, sensor fusion [8] and IoT [9] play an important role in ensuring the link between the different participant members inside the production line. The IoT offers many new methods to easily integrate these kinds of IoT devices and process and visualize the resulting data while sensor fusion is more focusing on the perception of a dynamic environment including humans with the advantage of a spatial and temporal coverage extension and improvement of the global system resolution [10], [11]. Hence, IIoT can be understood as the connection of smart assets, which are part of a larger system of systems (SoS) in industrial environments to optimize the value of production [12]. A SoS can be described as a set of systems working together to achieve a more complex target or a higher purpose [13], whereas each system can act independently and have its own purpose. Furthermore, the individual systems of the set are organized independently to fulfill their purposes. The combination of systems provides results that cannot be achieved by individual systems [14]. Five characteristics of SoS can be used to define and differentiate it from other complex, but monolithic systems: operational independence of its systems, management independence of the systems, evolutionary development, emergent behaviour, and geographic distribution [15], [16]. In comparison to consumer applications, the specifications and requirements in industrial environments are more restrictive. Their focus is commonly on security requirements, device interoperability, quality of service, and communication technologies, and protocols [17]. The right IoT framework for the entire system is chosen based on the System of System approach and remains a big challenge There are already many different products offering so-called IoT frameworks on the market, but only a few of those frameworks offers real capabilities in terms of SoS and real-time capability. Panigua and Delsing [18] compared different IoT frameworks and emphasized the Arrowhead framework, an open source software that provides various important tools and applications. This article gives a nice overview about the features of the most famous IoT frameworks like AUTOSAR, FIWARE.. which show the advantages of the Arrowhead framework compared to the other frameworks. In general, besides being an open source framework and supporting security and interoperability features, Arrowhead Eclipse Framework has the following big advantages [18]:

- The different functionalities and core services are distributed into the different core systems instead of having a unique middleware that reduces the scalability.
- The orchestration system is capable of computing new orchestration patterns in runtime and providing dynamic orchestration and authorization.
- It supports and manage applications with real-time constraints.
- It supports different data transmission protocols (TCP/UDP, DTLS/TLS) as well as communication protocols (HTTP, CoAP, MQTT, OPC-UA).

This contribution shows a new approach using the framework of Eclipse Arrowhead, which can overcome the challenges for easy sensor integration and the interoperability of many different use cases in semiconductor wafer facilities. The framework is based on a service-oriented architecture and provides automation capabilities [19]. While enabling device interoperability and IIoT at a service level, it meets the demands in terms of real-time control, engineering simplicity, security and scalability. Furthermore, the framework enables simple sensor integration and consists of the following three core services: authorization system, a service registry unit, and the orchestration system (see Figure 1 below).

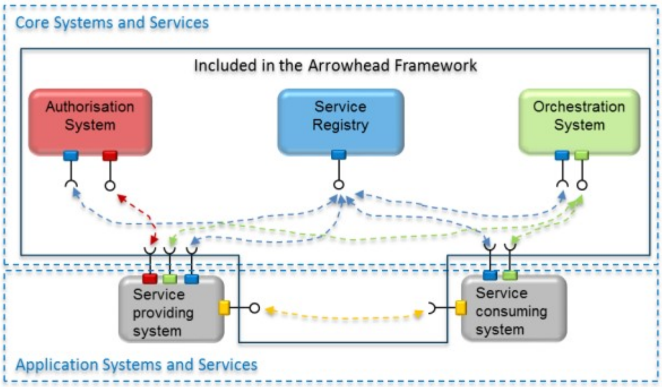

Fig. 1. Core System and Services

In the different applications, the provided information is sent to a service consuming system that can be used in many different use cases. This architecture offers a simple method of interoperability for hundreds of sensors that can be than easily connected to internal clouds in the IT environment of the wafer facilities. The Arrowhead framework has been used in various IoT automation scenarios [19], e.g. for programmable logic controller (PLC) device monitoring, energy optimization, replacement devices, maintenance, and as for the efficient deployment of a large number of of IoT sensors [18]. A first use case of the implementation of sensors in the cleanroom of IFD based on the architecture for automatic integration of sensor with the IO-link standard into a system of systems was already published by Patolla [20]

II. DESCRIPTION

Infineon Dresden has been working for over 20 years to improve process monitoring using statistical process control (SPC) and advanced process control (APC) to better monitor increasingly complex manufacturing processes. In addition to the classical fault detection and control system (FDC), internal and external sensor data has been used for many years at different points in the process, the system, or the cleanroom where the respective process data cannot be generated the wafer producing tool itself. The integration of suchlike sensor data, which are installed outside of the equipment and not supported by the vendors, is very time consuming and requires extremely resource-intensive engineering. The integration of the sensors in the respective manufacturing execution system of the fab requires coordination of different departments in the fields of IT, individual process technology and production. This is associated with a high expenditure of time and money. Furthermore, the responsibility of such sensors is not always given especially if they are not directly assigned to a tool owner. Another problem is that the respective sensor data can be found and orchestrated in the system, and the certainty must be given that it is really sensor data and that it can be managed in a safe factory environment. Today, various software companies offer countless software solutions to manage sensors and visualize sensor data in so-called IoT frameworks. Therefore, it is not easy for the respective users to select the right application not to have to go from one software solution to the next. This article provides an overview of how IFD found a way to integrate external sensors using the Eclipse Arrowhead framework easily.

III. INNOVATION

The innovation of the project lies in the integration, management and visualization of external sensors in a semiconductor facility using a state-of-the-art IoT framework based on Eclipse Arrowhead: the Arrowhead-Framework shows the potential of how to easily implement any sensor into the manufacturing execution system (MES) of existing semiconductor production in the future and what advantages such integration and orchestration of the data means for the future semiconductor manufacturing. The respective architectures and interoperability are discussed in particular. The use of the Eclipse Arrowhead Framework offers a lot of opportunities in case of interoperability and security. If one use case is implemented, many other use cases can be easily implemented using similar processes. This open-source application offers the possibility to the industry to enhance the automation and digitalisation level with the lowest engineering efforts.

IV. RESULTS

For the implementation of sensors in the cleanroom, the sensor team of IFD worked to get out the main requirements for the future integration of sensors to enable them to be compatible with a variety of different applications in the factories. The main goal was to reduce the engineering efforts and the engineering costs. In a first step, a possible architecture was described based on the requirements, which should comply with the Eclipse Arrowhead IoT Framework. The first use cases are implemented after the functional design was finished and the applications tested and validated, which were important steps before starting the operation of the sensors in the manufacturing area. Figure 2 shows the engineering process with all interfaces needed to obtain compliance. This engineering process was defined by G. Urgese et al. [21]. IFD strongly followed this engineering process in implementing the different use cases in production. In a second step, the architecture with all interfaces of the most important stakeholders are established, see Figure 3 underneath Figure 2.

The architecture results show the most important interfaces of the individual areas and stakeholders, which are required for later implementation. The stakeholders are engineers from the field of the IT department, of the process and product engineering groups and by specialist working on big data applications. As shown in this 3, seven main stakeholder functions were needed in the specific use cases involved to establish and run the operational concepts. The end-users, typical process or manufacturing engineers, needed support from different IT experts with deep knowledge of the IT infrastructure and the IT network. In addition, other IT specialists are needed to maintain the sensor applications in the MES afterwards. For data controlling, stakeholders with knowledge on advanced process control and data scientists for visualization of complex data evaluation must also be involved in the process. An overview is provided in Figures 4 and 5 of how the IoT framework from Eclipse Arrowhead will enable significantly simplified sensor integration in the future while drastically reducing engineering efforts. As already mentioned, the Arrowhead Framework provides a variety of tools that can be important not only for the semiconductor industry but also for a variety of other industries such as the automotive, energy, building or building or a variety of other industries such as the automotive, energy, building or building metal industry to achieve overall compliance. Important attributes of this framework are security characteristics, a high level of interoperability and high saving potentials to reduce engineering costs. Furthermore, such IoT solutions can greatly improve current automation and digitalization levels in the respective fabs and, therefore, enhance the plant's KPIs, time to market, and the overall competitiveness of the company. We can show in this article, based on the example in the Infineon Dresden fab, how sensor integration can be realized with Eclipse Arrowhead and what benefits can be achieved now and in the future in the various applications.

Figure 4 shows how many stakeholders had been involved in a classical sensor integration in the fab without using an IoT framework. Six main stakeholders were needed in the past, which had to configure multiple applications. Three different specialists from the IT department in the fields of network applications, MES and factory integration were needed to implement hardware and software in the IT system of the fab. Furthermore, engineers in the production and unit product development (UPD), as well as data scientists, had to work on the implementation and visualization of the data. Figure 5 shows that the stakeholders could be reduced to only three main stakeholders using the Eclipse Arrowhead integration. The main work is saved within the IT department reducing the efforts for different alignments and waiting times from one expert to the other experts. Therefore, the work from three stakeholders could be reduced to only one main stakeholder for the MES integration. Figure 6 illustrates the reduction of time from 3 months down to around one day and the reduction from 6 main stakeholders to at least only two main stakeholders. The engineering efforts for only one sensor application have been estimated at three months. Security

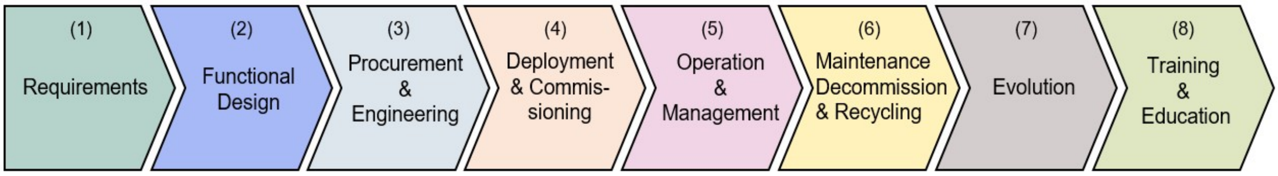

Fig. 2. Engineering Process

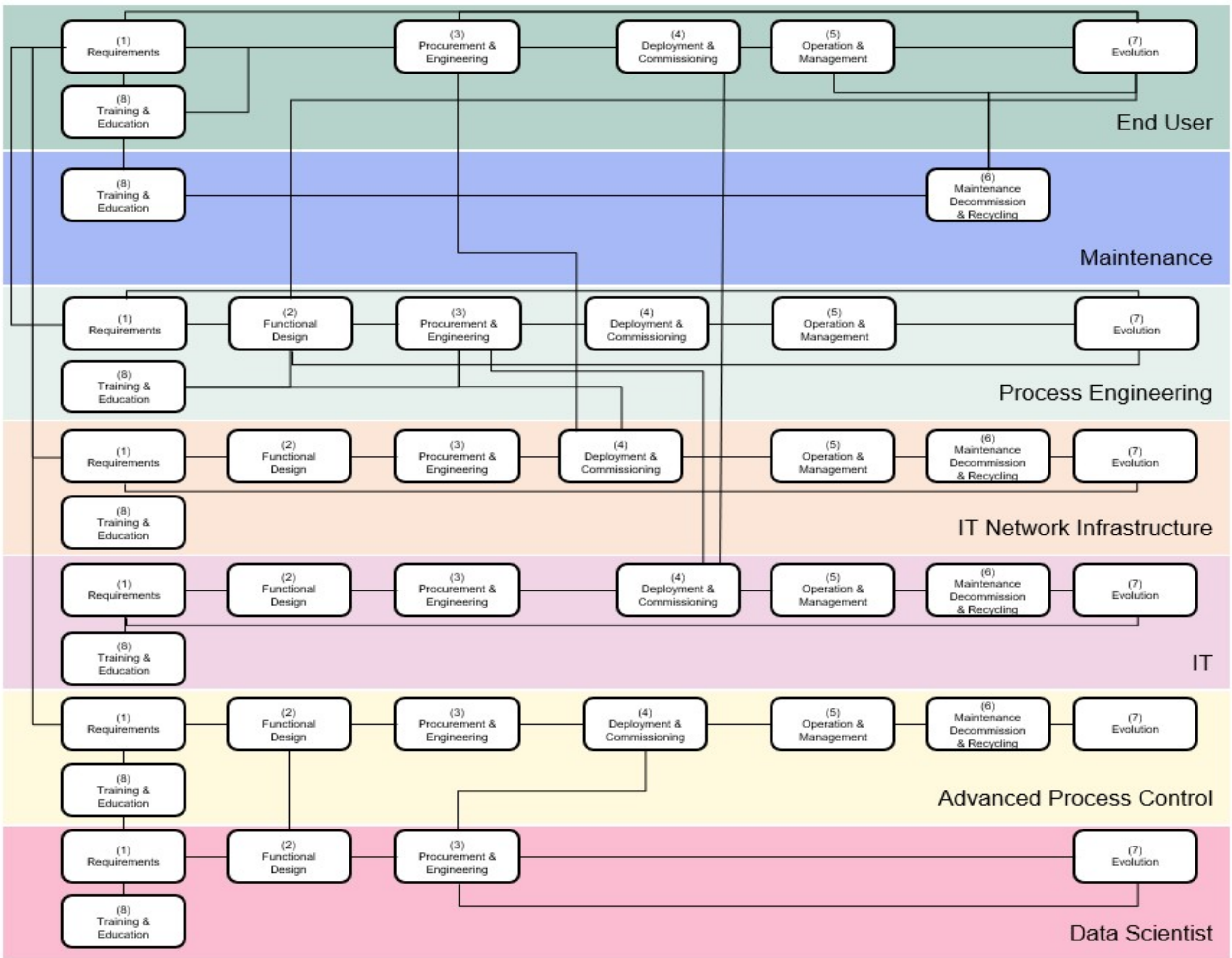

Fig. 3. Ownership of digitalization engineering process including stakeholders

is important in the semiconductor industry and open source applications are in general forbidden due those restrictions. Therefore, the applications were performed on only internal cloud solutions.

We showed that Eclipse Arrowhead Framework improved use cases for applications with one sensor to reduce the engineering time and efforts and sensor integration of external sensors for complex semiconductor equipment will be as easy as to plug and play an USB stick. Furthermore, for processes e.g. external sensor systems e.g. on on automated guided robots need more than one sensor system. For those use cases sensor fusion and the use of a multiple sensor integration is needed. We showed the architecture for such a use case with two different sensors delivering two output signals. Figure 7 below shows an overview of how the signals from two sensor systems, ToF and radar sensors, can be combined and create value out of the fused data for obstacles detection (more general details about the ToF/radar fusion system itself was already described in the papers [22] and [23]). An MQTT broker acts as the main information node.

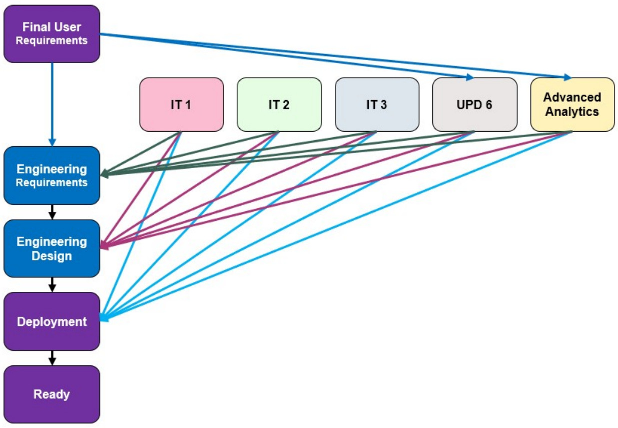

Fig. 4. Required engineering resources before Eclipse Arrowhead

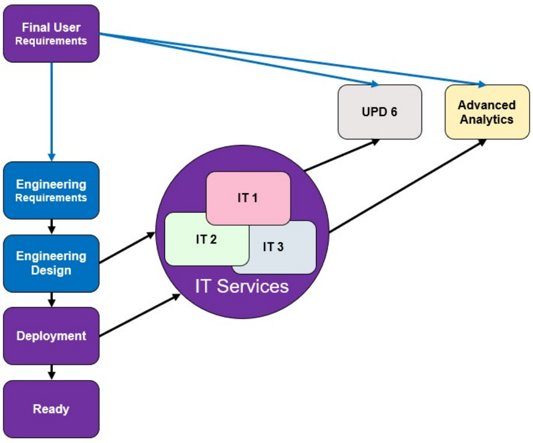

Fig. 5. Reduction of engineering resources after the implementation of Eclipse Arrowhead

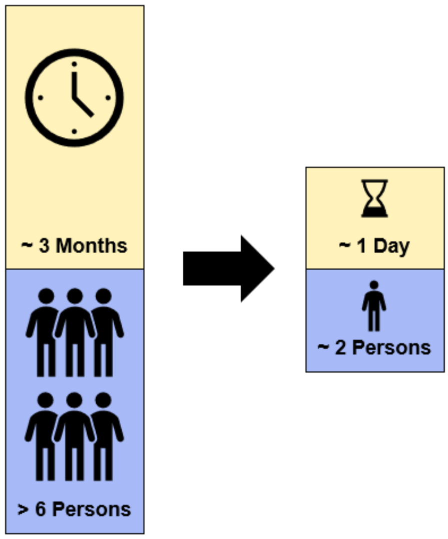

Fig. 6. Engineering resources and time savings before (blue color) and after use of Eclipse Arrowhead framework (yellow color)

The data from the test algorithm is stored in a database at the end to facilitate future data analysis and to enable live monitoring. Regarding how the Eclipse Arrowhead framework works, all required services in the use case must be registered in the service registry. This can be done at the beginning or during runtime and is done only once for one application. A provided metadata description supports the discovery of services, as it can be freely defined as a key-value pair. Subsequently, services that need to consume other services can query them via the Orchestrator service. The Authorization service supports the Orchestrator service in the area of security since only registered systems, which must be activated for other services, can query other services. The validation of the ToF/Radar sensor data fusion use case using the Arrowhead framework opens the door to other possibilities to apply the sensor fusion concept in other use cases by designing similar architectures. In our case, the architecture we choose gives us the possibility to easily integrate more sensors if needed for a better perception of the surrounding environment. Moreover, structuring our process flow into sub-units, each responsible of one part of the whole system gives the user the possibility to apply changes into the used algorithms or even replace some of the used methods (e.g update pre-processing algorithms for the radar raw data , change the fusion architecture, etc..). These changes are automatically considered by the Arrowhead modules, which means no extra effort is needed for the integration. The sending of data between system units is simultaneous, which allows us to meet real-time test requirements.

In the beginning, all participating services are registered in the Service Registry and enabled for communication with each other in the Authorization service. In the provided description is from each service the Topic, to which it sends its data. Then the sensor systems are started, which request the MQTT broker at the Orchestrator service. When an algorithm (”Preprocessing”, ”Fusion”, ”Background substraction”, ”Testing”) is started, it subscribes to its required topic at the MQTT broker and then sends its result back to the broker. The ”Testing” algorithm also stores its test results in a database. This use case can also be transferred to many other applications when different signals are used and combined in a modified or in a new sensor fusion system. Looking into the architecture we propose, which is required to fulfill the eclipse arrowhead requirements, we can integrate new sensors and modify or even replace one or more used algorithms without extra programming effort. Finally, all is designed to ensure real-time tests.

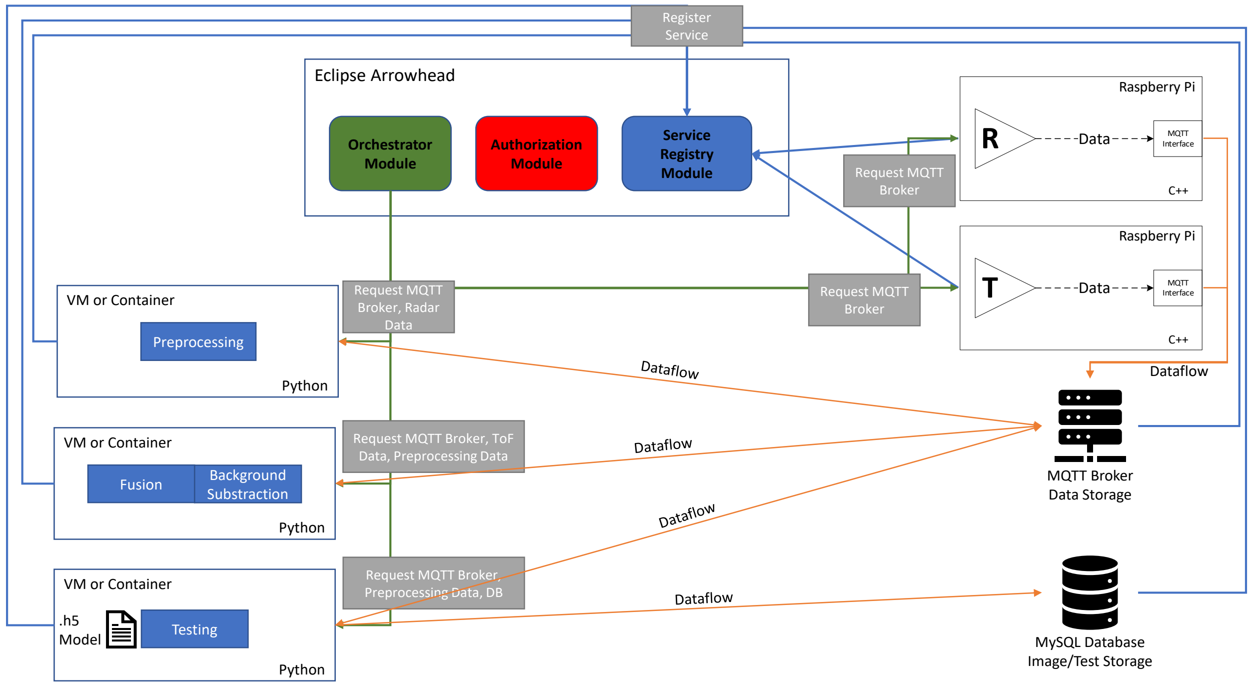

Fig. 7. Architecture using the Arrowhead Framework for more than one sensor which can be applied for use cases with multiple sensor data

V. Conclusion

The use cases showed that significantly fewer departments need to be contacted due to the automation of the integration process, which can be performed without needing a tool stop or the configuration of a multitude of different applications. In the future, the only need consists of picking the most suitable solution and connecting and configuring the sensor to start the analytics. Therefore, this application based on Eclipse Arrowhead will be a contribution of high importance to enhance the competitiveness of a semiconductor factory to install in a very easy and not time-consuming way sensors for advanced process monitoring and can be also used as an enabler for advanced data analytics, machine learning and artificial intelligence. The result of this work provides clear evidence that substantial engineering savings can be achieved using IoT frameworks like Eclipse Arrowhead. The next steps are to investigate the wider applicability of the approach to many other applications in the semiconductor industry and the overall supply chains of the entire component systems.

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Paul Patolla holds a Diploma in business informatics from the University of Applied Science of Dresden (HTW) in 2019. Paul worked already as a student member at IFD from 2016 to 2019 in the material management department. He is a professional in database design and software development. Meanwhile, Paul is a member of smart production system with a focus on IIoT, automation and digitization and he has been working on the arrowhead tools project since 2019.

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