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Industrial IoT solutions for digital twins: An overview

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Summary

A digital twin (DT) is a digital representation of a real-world entity, such as a device, machine, process, or complex system. The regular synchronisation between the DT and its physical counterpart offers better monitoring, improved performance, optimised maintenance, reduced downtime, and a network of connected products.

Industrial Internet of Things (IIoT) is considered as a subset of the Internet of Things (IoT) that connects various industrial assets (including machines and control systems) with the information systems and the business processes and can be utilised for optimal industrial operations. The IoT essentially connects 'things' to the Internet and to networks that use Internet technology. These things or items collect and share data about their internal state, the objects to which they are attached, and the environment they are in through gateways and edge computing devices. The data from such items, when fed to the DT models that combines modelling and analytics techniques using, e.g., artificial intelligence, provide information about the past and present operation and forecast the future of its physical counterpart, thus enabling the prevention of minor problems from turning into major ones and extending asset's lifecycle.

This work introduces some of the prevailing IIoT platforms for developing DTs indicated by various studies. Information about the IIoT solutions are collected from websites and online documentation. These platforms have similar types of capabilities, with one IIoT platform performing better in one area than another. The selection of a suitable platform could be challenging as there are very few examples documented in the literature and the available information is largely from marketing materials. The future work could be focused on exploring the practical applications and limitations or scope of the IIoT platforms introduced in this study.

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Preface

The concept of digital twin (DT) is evolving, and several industries are interested in its practical applications. The successful implementation of DT technology also requires advancements in enabling technologies, such as the Internet of Things (IoT), artificial intelligence, and modelling and simulation techniques. The Industrial Internet of Things (IIoT) is considered as a subset of the IoT and deals with the industrial applications of IoT, which is the focus of this work.

The IIoT platform connects things to the Internet and networks that use Internet technology. The aim of connecting devices is to share and exchange data and information that can be used for various purposes, such as better monitoring, control, and performance. The DT and its physical counterpart are linked via the IIoT platform to follow the state and performance of the physical asset and determine the necessary actions using the DT models. Thus, the IIoT platform plays a crucial role in the proper operation of DT technology and should be carefully selected. In this study, an overview of the IIoT platforms for developing DTs is presented.

This work is part of the DigiBuzz research project which focuses on the business aspects of DT technologies, as well as other technical and new business opportunities. We thank the funding parties, Business Finland, and the participating companies and organisations for enabling such an interesting and significant research project.

Espoo 12.11.2021

Authors

Contents

1. Introduction

A digital twin (DT) is a digital representation of a real-world entity, such as a device, machine, process, or complex system. The term digital twin has been defined by many and according to the Digital Twin Consortium [1], “a digital twin is a virtual representation of real-world entities and processes, synchronised at a specified frequency and fidelity”. In its most basic form (low fidelity), a DT encompasses metadata about the respective physical asset and the means to monitor it. The more advanced (high fidelity) DTs consist of analytical models (i.e., physics-based and machine or deep learning-based) that enable simulation and prediction, thus allowing for comparison of expected versus real behaviour, what-if scenarios, and continuous improvement of digital models through feedback loops. As by definition, the DT requires a physical counterpart for data acquisition and context-driven interaction, the virtual system model in the DT can change in real-time as the state of the physical system changes, for example, during operation [2]. The regular synchronisation between the DT and its physical counterpart results in better monitoring, improved performance, optimised maintenance, reduced downtime, and a network of connected products [3].

The key enablers of the DT technology include artificial intelligence (AI) and Internet of Things (IoT) or Industrial Internet of Things (IIoT) [4]. The IoT essentially connects ‘things’ to the Internet and to networks that use Internet technology [2]. These things or items collect and share data about their internal state, the objects to which they are attached, and the environment they are in through gateways and edge computing devices [5]. The pre-processed online sensory data as well as the necessary offline data are fed to the DT model. The DT may combine physics-based modelling and analytics techniques (e.g. using AI) to generate a living model of the physical asset that allows to monitor the past and present operation and forecast the future of its physical counterpart, thus preventing minor problems from turning into major ones and extending assets’ lifecycle [6], [7], [8], [9].

The IIoT is a subset of IoT and focuses on industrial applications. An IIoT platform provides several services for the management of DT related data and information, such as resource aggregation, dynamic configuration, associate the edge infrastructure with the DT in the downward direction, and transfer and store the data in the cloud in the upward direction. One can say that IIoT platform activates the life of a DT. Figure 1 shows how the IIoT network serves as a bridge between the physical object and its virtual twin [10], [11], [12]. The development in DT concept would require improvements in IIoT standards and technologies, hence both serving each other.

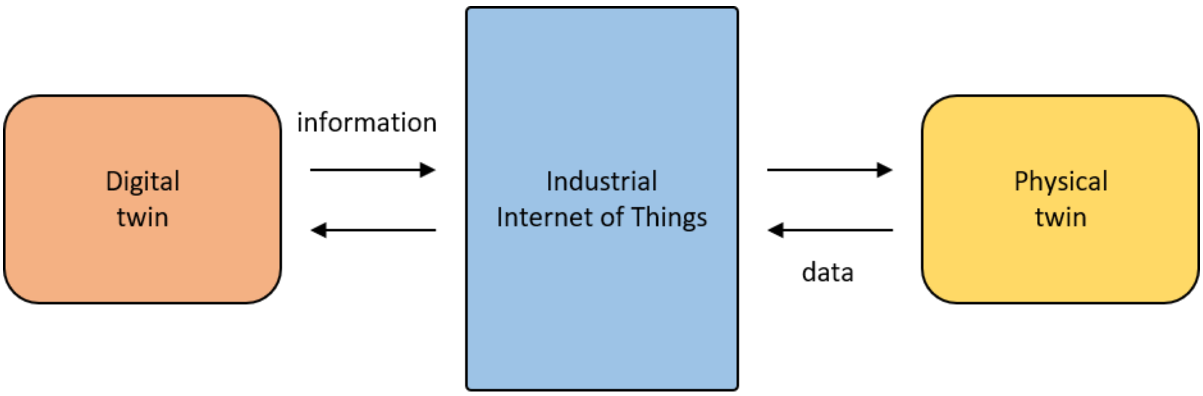

Figure 1. IIoT connecting the physical space and virtual space.

Due to the limited resources for this work, we focus on introducing various IoT and IIoT solutions for DT development offered by renowned vendors. In addition, the requirements for IIoT systems could be case specific, hence the IIoT selection process is not taken into account. Furthermore, technical details about the different layers of IoT platforms (i.e., sensors, actuators, gateways, middleware) could be covered in a devoted study and is considered beyond the scope of the current work.

The rest of the report is organised as follows. Section 2 describes the concepts of IoT and IIoT in the DT context. Section 3 provides a list of IIoT platforms that could be utilised for developing DTs. Finally, Section 4 summarises and concludes the findings of this study.

2. IoT and IIoT in the context of DTs

The main idea behind the IoT concept is to connect billions and trillions of smart objects capable of sensing the surrounding environment, transmit and process the acquired data, and provide feedback [13]. The interconnected devices, systems, and computing platforms handling large sets of data over the network using machine-to-machine communication result in smart health, asset tracking, environmental monitoring, predictive maintenance, home automation, and so forth [5].

IoT is an umbrella term for a broad range of underlying technologies and services which depend on the use cases and, in turn, are part of a broader technology ecosystem that includes related technologies, such as artificial intelligence, cloud computing, next-generation cybersecurity, advanced analytics, big data, various connectivity or communication technologies, digital twins, augmented and virtual reality, blockchain and more, as shown in Figure 2.

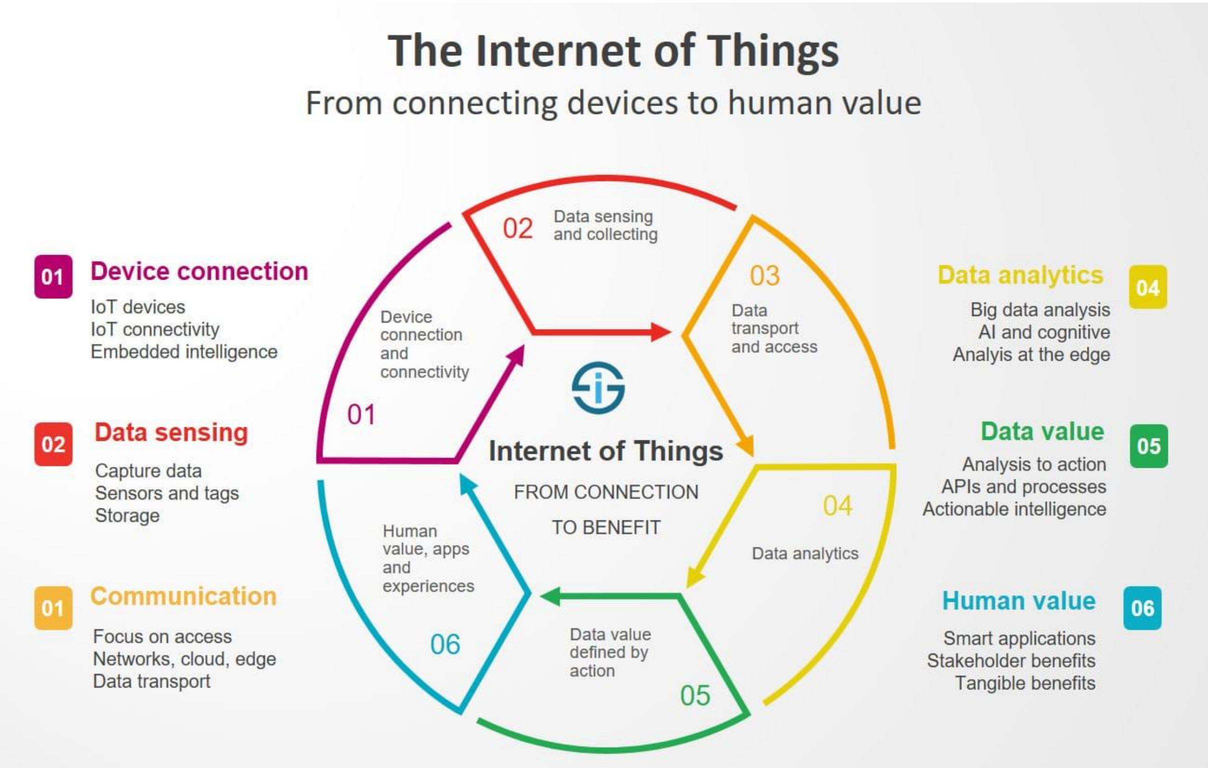

Figure 2. IoT and the underlying technologies and services [5].

The concepts of IoT, IIoT, and Industry 4.0 are closely related but cannot be interchangeably used. Figure 3 shows the associations among IoT, IIoT, Industry 4.0, and Cyber-Physical System (CPS) concepts [13]. The IIoT can be seen as a subset of IoT and it connects the industrial assets, including machines and control systems, with the information systems and the business processes, and can be employed for optimal industrial operations. The Industry

4.0 concept has been coined for addressing the use of Internet technologies in order to improve production efficiency by means of smart services in smart factories. The cyber-physical system (CPS) extend real-world physical objects by interconnecting them and providing their digital descriptions.

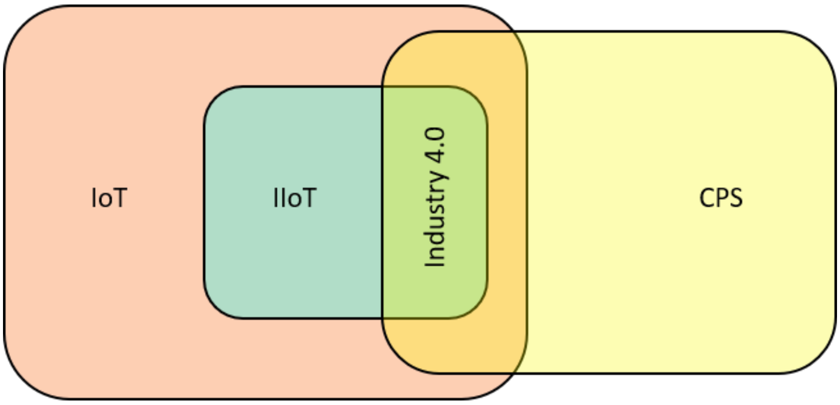

Figure 3. Associations among the IoT, IIoT, Industry 4.0, and CPS concepts.

The IIoT is also known as “Industrial Internet”, “Internet of Everything” and “Internet 4.0”. The broader horizontal concept of IoT can be differentiated into various vertical IoT strategies (e.g., the consumer, enterprise, commercial, and industrial forms of the Internet), each having very different target audiences, technical requirements, and approaches, as shown in Figure 4. For example, the consumer IoT focuses on consumer-oriented devices, such as wearables and smart home solutions. The commercial market includes, for example, banking, insurance and financial services, and ecommerce, which focus on consumer history, performance, and value. The enterprise IoT deals with, for example, small-, medium-, and large-scale businesses.

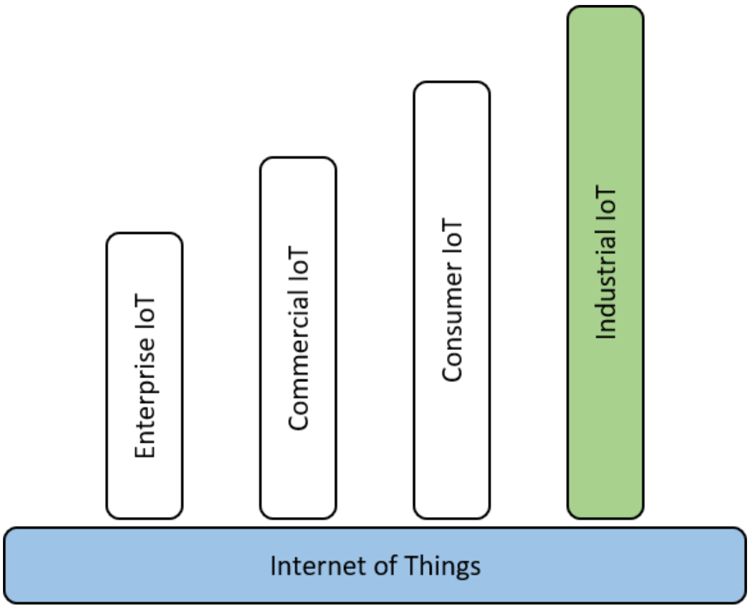

Figure 4. Horizontal and vertical aspects of IoT. According to [15].

The Industrial IoT or IIoT (which is the focus of this study) consists of many disciplines, such as energy production, manufacturing, agriculture, health care, and transportation. The IIoT specifically refers to the IoT in industrial operations, typically associated with manufacturing, supply chain management, transportation, energy/utilities, mining and metals, and healthcare [14]. Common applications for IIoT include monitoring, predictive maintenance, and solutions for operational improvements which are essential for the successful implementation of DT technology. The demands on IIoT are typically (but not always) higher than on consumer or commercial oriented IoT in terms of availability, security, and scalability [3].

The IIoT has been defined on several occasions and there exists many definitions in the literature. The authors in [16] reviewed several existing IIoT definitions and provided the following:

> "*Industrial Internet of Things: A system comprising networked smart objects, cyber-physical assets, associated generic information technologies and optional cloud or edge computing platforms, which enable real-time, intelligent, and autonomous access, collection, analysis, communications, and exchange of process, product and/or service information, within the industrial environment, so as to optimise overall production value. This value may include improving product or service delivery, boosting productivity, reducing labour costs, reducing energy consumption, and reducing the build-to-order cycle.*"

Figure 5 shows the various layers of a concept DT model proposed by Al-Ali et al. [17]. The communication network layer (i.e. the IoT network) serves as a bridge and connects the physical space with the virtual space. The physical twin's data are collected by an edge computing device and transmitted to the enterprise computer centres or cloud-based services where it is augmented with the pre-stored data such as bill of material, historical data, and 2D and 3D models. All this data is processed at the data analytics and visualisation layer and utilised in several applications. The security layer provides protection against potential vulnerabilities and attacks.

The IoT platform must connect devices, must collect data, must handle thousands of vendors, dozens of standards and must be able to scale to millions of devices sending billions of messages. To deliver true value beyond the basics, it must add cognitive, security, privacy, insight generation, and close loop automation. With these capabilities and the supporting technology advancements, the IoT platform becomes an agent of transformation for a business [18].

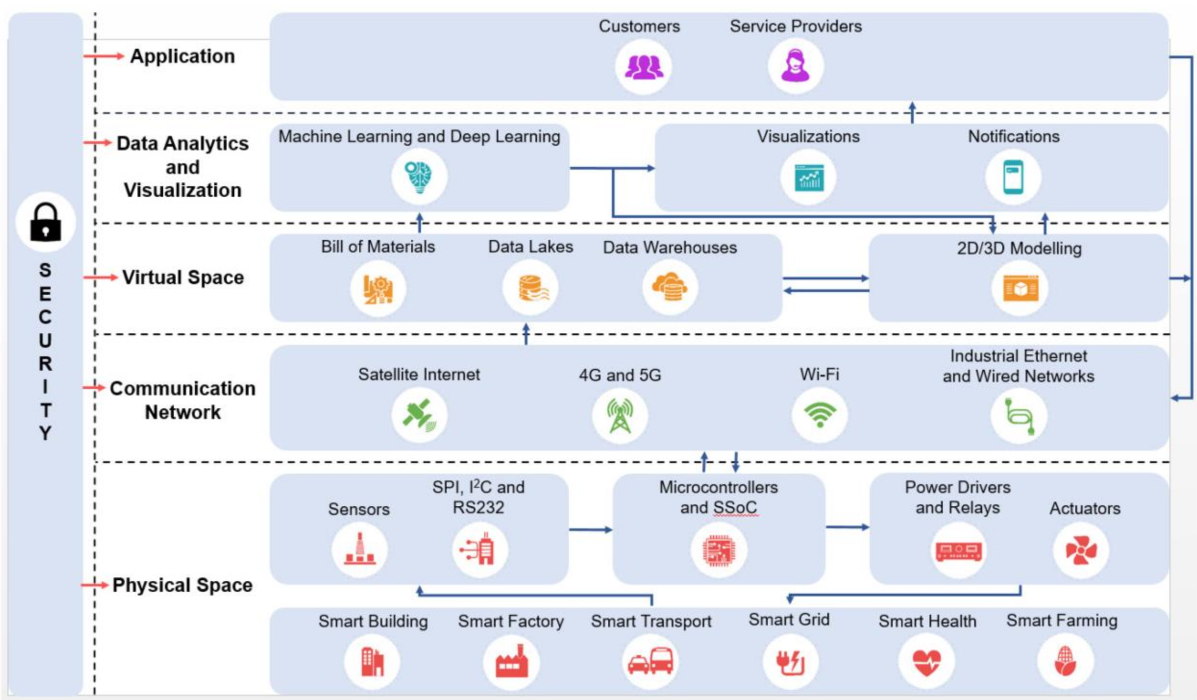

Figure 5. A conceptual model of DT in the context of Internet of Things [17].

Although IoT and IIoT are having several similar communication requirements, plenty of the requirements can be remarkably different in terms of, for example, availability, reliability, security and privacy. In [13], the IoT is described as of revolutionary nature focusing more on the design of new communication standards which can connect novel devices into the Internet ecosystem in a flexible and user-friendly way. The IIoT, on the other hand, is considered as evolution dealing with possible integration and interconnection of once isolated plants and working islands or even machineries, thus offering a more efficient production and new services. [13]

3. IIoT platforms for DTs

While IoT is about connecting resources and collecting data about the physical world, DTs are the virtual representations of resources organising and managing information and being tightly integrated with artificial intelligence, machine learning and cognitive services to further optimise and automate production. The concepts of DT and IoT are overlapping when it comes to describing, discovering and accessing resources. Thus, when we speak about investments in and solutions for DTs, we will typically encounter the names of companies that are very active in the IIoT, such as GE, PTC, Siemens, SAP, and Amazon [19]. For instance, IBM is marketing DTs as part of its IoT push, and Microsoft is offering its own DT platform under the Azure cloud computing umbrella [20].

Gartner developed a “Magic Quadrant” for IIoT platforms based on three asset-intensive industries, such as manufacturing and natural resources, transportation, and utilities [21]. In their market evaluation, vendors are placed under the “leaders” quadrant (e.g., Hitachi, PTC, Microsoft), “niche players” quadrant (e.g., AWS, Oracle, IBM, GE Digital, etc.), “visionaries” quadrant (e.g. Software AG), and “challengers” quadrant. Gartner considers:

- the leaders as those who invest in and shape the future of IIoT
- the challengers as those who are influential in the future of IIoT
- the visionaries as those who have a clear view of the market’s requirements and direction
- the niche players as those who focus successfully on a set of products and services and, often, focus on a narrow set of industry use cases.

The strengths and weaknesses of these vendors have been highlighted, such as the ease of implementation, dependency on external markets, communication barriers, security features, size and growth opportunities, pricing and licensing, analytic styles and documentation, security compatibility with third-party infrastructure, and so forth. For the detailed discussion on the vendor strengths and cautions, the reader is advised to look at the original document at [21].

Similarly, the VDC Research (a technology market intelligence and consulting firm) has reported the top vendors of IIoT solutions with the 2020 “Platinum” and “Gold” vendor favourability awards, including Google, IBM, SAP, AWS, Exosite, GE Digital, Hitachi, Microsoft, Oracle, Siemens. These award winners have helped their customers begin to harness the vast potential of the IIoT and will be instrumental in the continued digitisation of industry as a whole. Understanding which vendors have the most favourable standings within different IIoT-related product categories can provide industrial organisations with a valuable head start in designing their own IIoT strategy. [22]

Furthermore, a list of IoT platforms for DTs is available at [23]. These platforms are provided by many vendors, such as GE Digital, Amazon, IBM, Google, Microsoft, Siemens, and so on. Table 1 shows some of these vendors and short description of their services. Details about each IoT platform can be found at the respective link.

Table 1. IIoT platform for developing DTs.

Vendor	IoT solution	Description
Amazon	AWS IoT Analytics, AWS IoT Core, AWS IoT Device Management, AWS IoT SiteWise	Provide analytics for IoT devices, connect devices to the cloud, onboard and remotely manage IoT devices, IoT data collector and interpreter. More information: https://aws.amazon.com/iot/?nc2=h_ql_prod_it
Siemens	MindSphere	MindSphere collects live performance data from production lines and connected products to create fully functional, closed-loop DT. It uses advanced analytics and AI to power IoT solutions from the edge to the cloud. More information: https://www.plm.automation.siemens.com/global/en/products/mindsphere/
GE Digital	Predix	Predix provides asset connectivity, edge technologies, analytics and machine learning, big data processing, and asset-centric DTs. The Predix Cloud platform is hosted on AWS. More information: https://www.ge.com/digital/iiot-platform
IBM	Watson IoT, Maximo	The Watson IoT helps to identify, aggregate, and transform data from IoT sources into asset-based structures in order to, e.g., understand current conditions and trends, and extract valuable insights. The Maximo is an integrated cloud-based platform that uses AI, IoT and analytics to improve monitoring, inspection, and predictive maintenance. More information: https://www.ibm.com/cloud/internet-of-things
Bosch	Bosch IoT Things	The Bosch IoT Suite for Asset Communication is a service package dedicated to support the scalable and secure ingestion of large volumes of sensor and asset data, and support the remote control of assets. The package includes Bosch IoT Things that manages the digital twins of physical devices. Bosch IoT Things is the commercial product based on open-source Eclipse Ditto. More information: https://docs.bosch-iot-suite.com/asset-communication/Introduction---Asset-Communication-package.html
Microsoft	Azure IoT, Azure Digital Twins	Azure IoT Hub connects, monitors and manages IoT assets. Azure Machine Learning platform is aimed for experimentation and model management. Azure data, analytics, and AI services are made available for DT models. Device management and IoT data stream capabilities. More information: https://azure.microsoft.com/en-us/overview/iot/#overview
Google	Google Cloud	Google Cloud IoT is a set of fully managed and integrated services to easily and securely connect, manage, and ingest

		IoT data from globally dispersed devices at a large scale, process, and analyse or visualise that data in real time, and implement operational changes and take actions as needed. More information: https://cloud.google.com/solutions/iot/
PTC	ThingWorx	ThingWorx uses multiple analytic methods and advanced AI and machine learning techniques to analyse large volumes of data, enabling powerful solutions for design, manufacturing, service, and industrial operations. More information: https://www.ptc.com/en/resources/iiot/brochure/thingworx-overview
SAP	SAP IoT	Big data management and digital twin modelling are among the key features of SAP platform. The SAP Analytics Cloud solution is aimed for better data visualisation. More information: https://www.sap.com/products/iot-data-services.html
Exosite	Murano	Exosite's Murano Platform handles connected IoT devices, IoT data processing and storage, application hosting, and orchestration of applications, services, and integrations. More information: https://docs.exosite.io/murano/overview/
Hitachi	Lumada	Lumada Software for IIoT provides services for DT modelling, advanced analytics and AI, automated data management, and so forth. More information: https://www.hitachivantara.com/en-us/products/iot-software-solutions/lumada-software-for-iiot.html
Oracle	Asset Monitoring Cloud Service	The Oracle IoT Asset Monitoring Cloud Service creates a DT version of an organisation and organisational assets, and helps in monitoring the location, condition, and utilisation of the assets. It improves productivity and reduce the operational costs and inefficiencies associated with asset management. More information: https://docs.oracle.com/en/cloud/saas/iot-asset-cloud/iotaa/oracle-iot-asset-monitoring-cloud-service.html

All these IoT platforms have similar types of capabilities, with one IoT platform performing better in one area than another [24]. The reason why the market is so diverse is related with the origins and background of the platform which in turn says something about their strengths. For example, a platform from a network operator would typically be stronger in the communications and network capacity area, whereas a platform designed for application enablement would offer stronger capabilities on that level, and a platform from device manufacturer would be stronger in device management. Organisations looking for the best IoT solutions for their goals need to think carefully ahead and look at the broader digital business initiative for a long term. The IoT projects are a matter of partnerships with various stakeholders enabling results, customisation, growth, scale, end-to-end security and support applications, assets, use cases and context. The selection of an IoT platform is usually joining an ecosystem and depends on a mix of supporting features.

3.1 About IoT platforms, their architecture and surrounding ecosystems

There are numerous IoT platform providers in the market offering services for both open source and commercial solutions. An IoT platform normally consists of several components and services, such as an information technology platform, application programming and data interfaces, and even hardware system for connectivity. Hence, an IoT platform solution is often a collaboration of several providers each having a special role in the overall ecosystem. This type of model is depicted in Figure 6. The approach has been applied, e.g., by Siemens in its MindSphere product [25] and GE in its Predix product [26]. Both these IIoT platforms are based on the open source core IoT platform called Cloud Foundry[1], which can be extended to include specific features and functionalities required by the industrial needs. In addition, the underline ecosystem of these IIoT platforms provides the flexibility to further develop the platforms and build add-ons and services. Such a platform ecosystem approach facilitates fast development of products and services, leading to the creation of new markets of digitalisation and IoT.

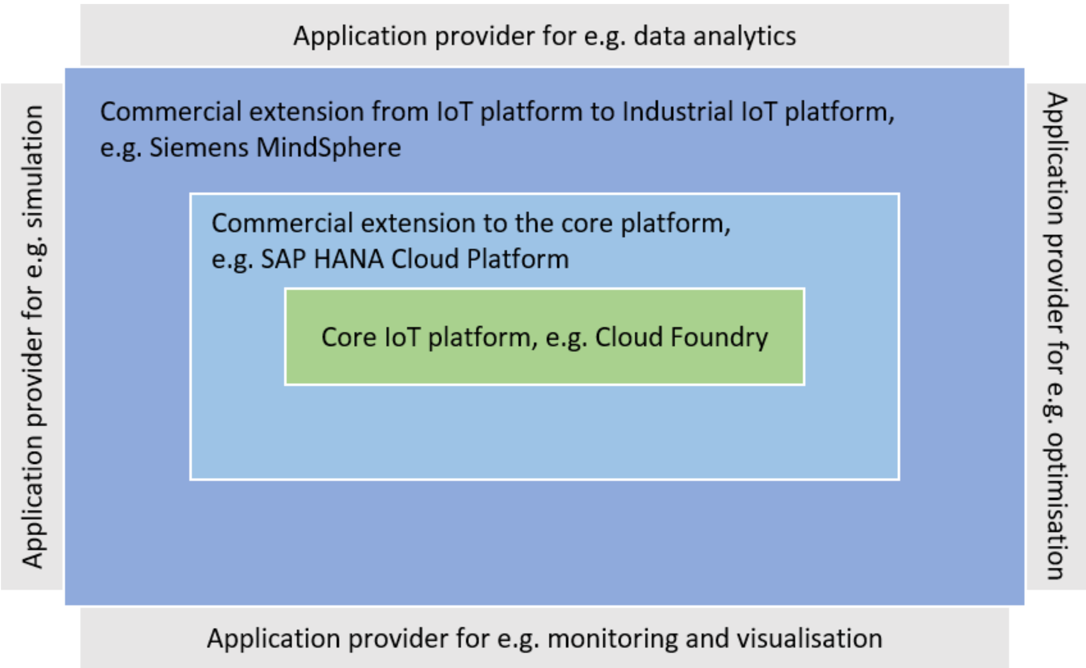

Figure 6. A layered model of an IoT platform and the ecosystem around the platform providing additional features and services.

4. Conclusion

An IIoT platform is one of the enablers for realising the added value of DTs in industrial applications. There are several IoT platform types and vendors with their own focuses and go-to-market strategies. This study introduced the IoT services marketed by various companies. The information about these IoT solutions were collected from websites and online documentation, due to the scarcity of scientific literature. The selection of a suitable platform could be challenging as there are only few documented use cases and the commercial documentation materials to a large extent are meant for marketing purposes only. The future work could be focused on exploring the practical applications and limitations or scope of the IoT platforms introduced in this study.

[1] The Cloud Foundry website: https://www.cloudfoundry.org/

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