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1. Abstract

This document provides an overview of the State-of-the-Art (SotA) of the fields addressed by the Machinaide project. The Machinaide project is targeting to innovate the development and operation of digital twins. The main innovation topics are Digital twin interoperability, Processing of multiple industrial data, Query mechanisms and Human machine interfaces.

For coping with this development, Machinaide aims to support innovative concepts for accessing, searching, analysing and using multiple Digital Twins data for the major purpose of increasing usability and functional upgrading of machines and equipment within the crane and printing machine domains.

2. Change Log

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V0.2	07/02/2021	Zeki ÇELİK	Check and edit all contributions

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4. Acronyms

ADT	Azure Digital Twins
API	Application Programming Interface
AR	Augmented Reality
AR/VR	Augmented Reality/ Virtual Reality
AWS	Amazon Web Services
CAD	Computer Aided Design
CPS	Cyber Physical System
DT	Digital Twin
ER	Entity-Relationship
HDTV	High Density Television
HMI	Human Machine Interface
HTTP	Hypertext Transfer Protocol
IOT	Internet of Things
JSON	JavaScript Object Notation
MR	Mixed Reality
MQTT	Message Queuing Telemetry Transport
NLI	Natural Language Interface
NLP	Natural Language Processing
ODBC	Open Database Connectivity
O-DF	Open Data Format
OPC	Open Platform Communications
RDF	Resource Description Framework
REST	Representational state transfer
PaaS	Platform as a Service
PRA	Path Ranking Algorithm
VOWL	Visual Notation for OWL
VR	Virtual Reality
WOL	Web Ontology Language
W3C	World Wide Web Consortium

5. Introduction

Digital Twin (DT), even though one of the popular buzzwords in the last decade, that actually goes backs to beginning of the 90s, called as “Mirror Worlds” (Gelernter, 1991), basically “is a virtual representation of a device or a group of devices that resides on a cloud or edge node. DT can be used to represent real-world devices which may not be continuously online, or to run simulations of new applications and services, before they get deployed to the real devices” (W3C, 2021). At first digital twins were used in the manufacturing and heavy industries as a part of maintenance. Nowadays, the usage of digital twins is increased to other domains compared to its initial advent for example product design and customization, experimental modeling, personalized care, quality management, simulate networks/supply chain/autonomous systems, etc. are the first intentions of the usage of developing digital twin technology. Digital twins are becoming more sophisticated with the advancements related to internet of things, machine learning algorithms, artificial intelligence and dramatic changes in the HMI technology like augmented reality (AR), virtual reality (VR), natural language processing (NLP) etc.

To develop a digital twin concept requires three basic things: a physical model, a virtual model and a strict connection between the models. Physical model can be a product, device, production line, complete factory etc. Virtual model is the digital twin, “mirror” or virtual representation of the physical model and should have same features that physical model has. Common benefits of digital twins are planning future developments, troubleshooting easily and efficiently, predictive analysis for unexpected failures, running simulation without risking physical model, monitoring all part and equipment of physical model. These benefits outweigh complex and long development process of digital twin.

The core part of the digital twin is the providing physical system data via sensors, data pipelines or any other data streaming tools. Digital twin should process provided data, and produce results with AI and ML algorithms, which is the main purpose of it. Interacting with digital twin via HMI is also an important feature. Classical HMIs have been interacting with screens, but digital twin interaction technology evolves with smart glasses for AR/VR. This technology can provide 3D model of the physical system or at least highlight some part of the physical system when it is checked by AR/VR glasses.

6. Platform Interoperability

6.1. Introduction

Interoperability between assets has been recognized as a crucial feature for digital twins to achieve their full potential. This means availability of data (including metadata such as descriptive data and structural data), accessibility of Internet of Things (IoT) interfaces and usability of analysis tools and their results across a network of assets. Interoperability is required for each different ecosystem. An ecosystem is specified as a set of machines, such as a crane or assembly plant, and sensors with devices and technologies connected. In this project, each partner country has their own ecosystem. The objective of the Machinaide project is to create a connection between those ecosystems.

Well-defined interfaces of ecosystems are crucial for implementing a framework that connects these ecosystems. The interfaces under interest for interoperability are interfaces that allow automatic data exchange. In addition, the interfaces should be accessible from the internet and use common internet protocols, such as HTTP (Hypertext transfer protocol, and data formats, such as JSON (JavaScript Object Notation). REST (Representational state transfer) APIs (Application Programming Interface) are often favourable due to their scalability allowed by caching and easy implementation with uniform interface.

Aalto University has previously studied interfaces and interoperability. The feature-based Digital Twin Framework developed by Autiosalo et al. (2019) for structuring digital twins relies on interfaces and features connected by Data Link or Broker. The Data Link was developed further in a recently published paper (Ala-Laurinaho, Autiosalo, Nikander, Mattila, & Tammi, 2020) that presented a practical implementation of a digital twin. The importance of interfaces was also recognized in an article (Ala-Laurinaho, Autiosalo, & Tammi, 2020), in which an application estimating the usage roughness of an overhead crane was developed, partly remotely, and in an article by Autiosalo et al. (2021) which also emphasized the benefits of well-defined interfaces in application development.

In addition to interfaces and their accessibility, important aspects of interoperability are semantics and metadata which allows machines (and humans) to understand the meaning of the data exchanged. For describing data, there are several methods and formats such as O-DF (The Open Group, 2020), JSON-LD (World Wide Web Consortium, 2020) and RDF (World Wide Web Consortium, 2014). Sometimes data needs to be transformed from one format to another. Because of the numerous different data formats, digital twins should be able to advertise which data and features they can offer, and for that we propose that the Data Link/Broker also distributes metadata of the digital twin using, for example, Digital Twin Definition Language (Microsoft, 2020) or Web of Things Thing Description document (World Wide Web Consortium, 2020).

6.2. Connected Supply Chain of Digital Twins

As a context for the different Machinaide ecosystems, the overlaying principle is that connecting ecosystems bring further value in any supply chain or operational process. On the broader scale connecting larger supply chains, there is no standardization of commercial offerings in the market. Neither are there many actors driving the optimization on a large scale, most likely due to complexity and lack of standardization of connecting assets.

The connected supply chain ecosystem (Figure 1) illustrates the potential in connecting a typical supply chain from a factory to another, where the digital twin ecosystem (or broker) is sharing the crucial information between assets to assure optimal performance, such as just in time arrival, etc. However, connecting different factories from various domains is laborious, and we could not identify nothing but articial use cases for this within the consortium. Therefore, Machinaide project focuses on the Smart Factory Concept (Figure 2), which relies on a similar concept and technology that could enable the larger scale standardization.

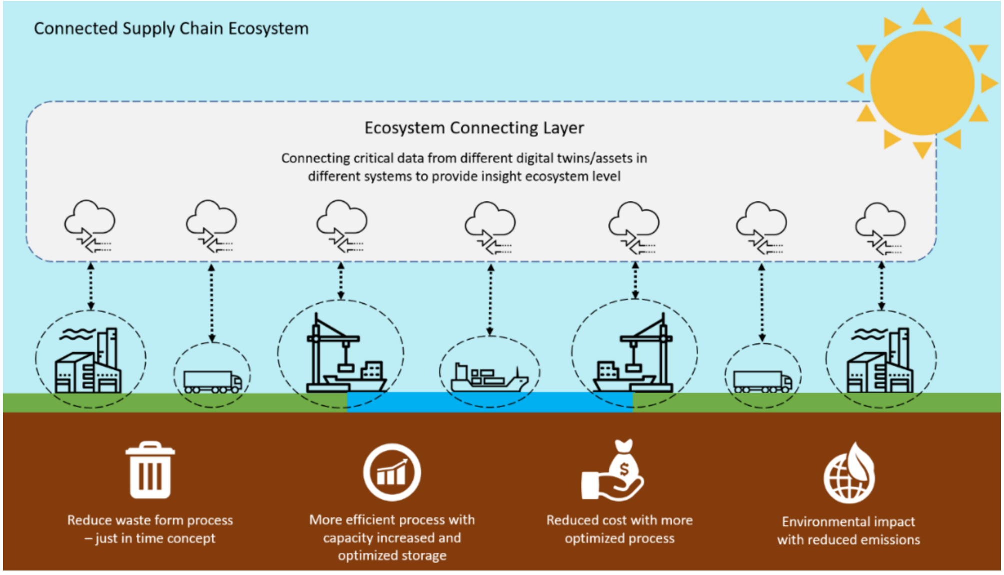

Figure 1: Connected supply chain ecosystem showing the potential of getting supply chain optimization and transparency.

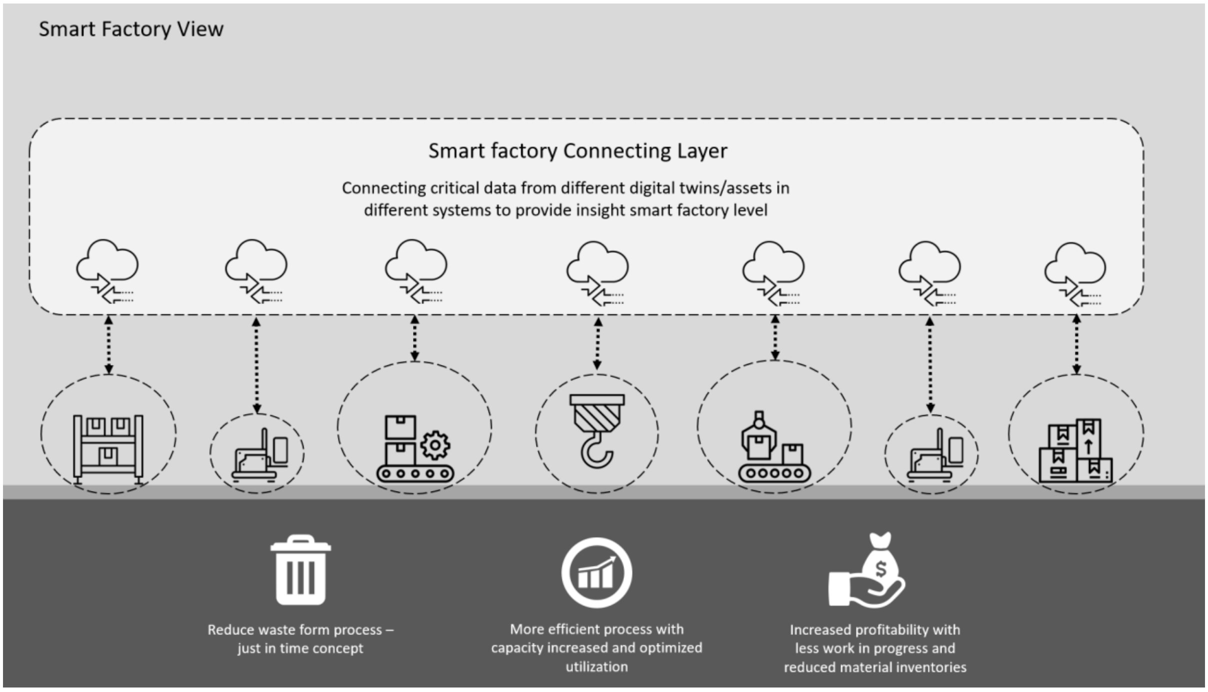

Figure 2: Smart factory view showing how connected assets within a factory can bring new value to companies.

6.3. Description of International Machinaide Ecosystem

The term smart factory refers to U-factory (ubiquitous factory) (Yoon, S.Shin, & Suh, 2012), the factory of things (Lucke, Constantinescu, & E. Westkämper, 2008), or the intelligent factory of the future (Hameed, Durr, & Rothermel, 2011) (Hozdic, 2015). In the Machinaide project, a smart factory will be generated. This section presents the Machinaide project's international ecosystem.

An ecosystem is a set of machines and sensors such as a crane, assembly plant with devices and other technologies connected. In the Machinaide project, each partner country has their ecosystems, and the objective is to create a connection between those ecosystems to generate an International Machinaide Ecosystem. At the highest level, the Machinaide ecosystem forms a Smart Factory

Ecosystem that brings together all the national and local ecosystems (Figure 3). In the following sections each national ecosystem is described in more detail.

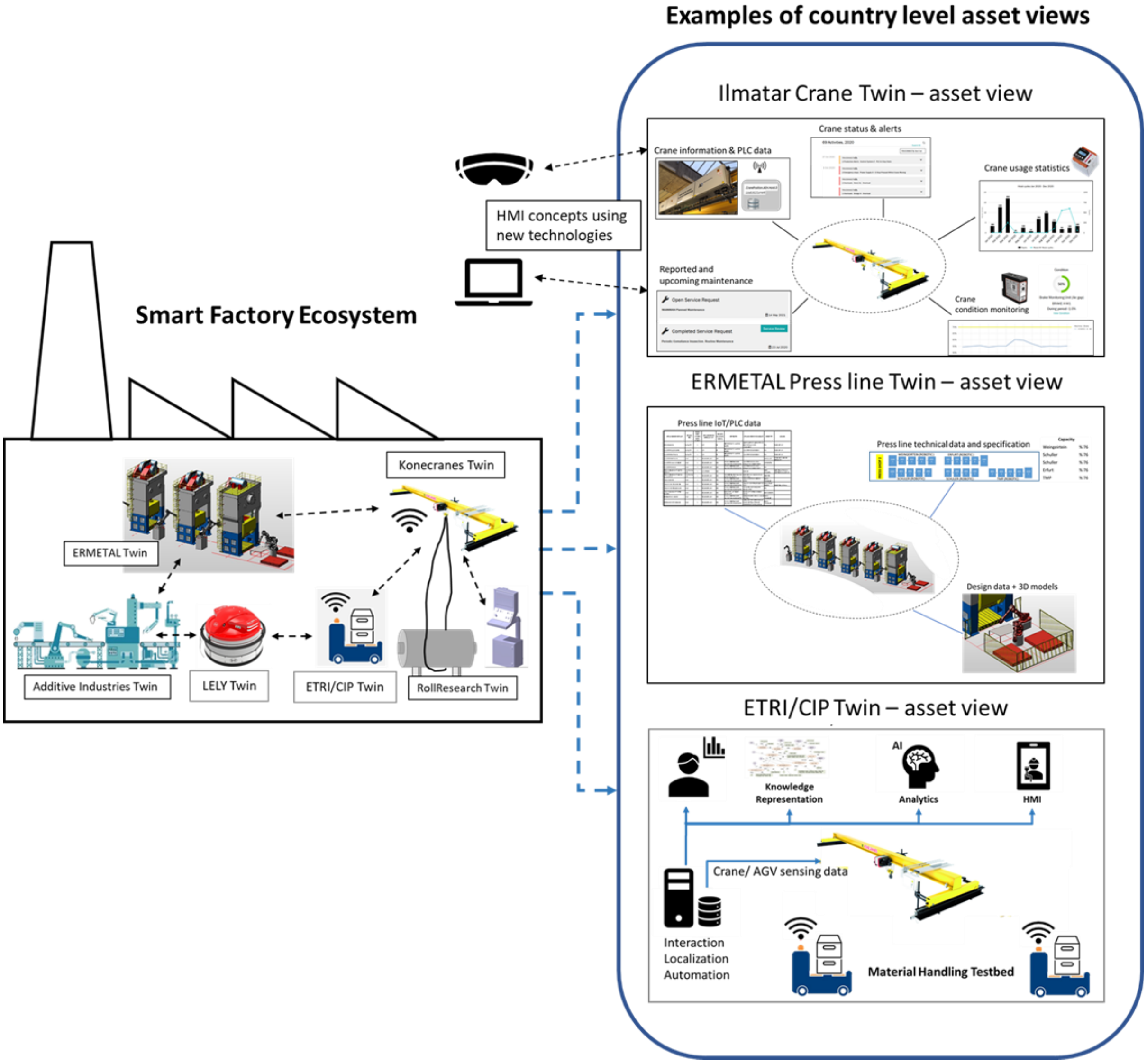

Figure 3: Asset level views in the Smart Factory Ecosystem. Three different assent views are shown as an example. There may be more or less asset views in coming demonstrations.

The Finnish consortium consists of five partners, Konecranes, Aalto University, Remion, Roll Research International and Ideal. The use case which the Finnish consortium addresses is an industrial smart crane, Ilmatar (Autiosalo, 2018), together with an intelligent grinding machine in a Smart Factory Ecosystem. The ecosystem represents central platform and research environment for developing new technologies for the machines of the ecosystem and ways to integrate them seamlessly to operate in smart and connected factories of the future. The Finnish demonstrator is shown in Figure 4.

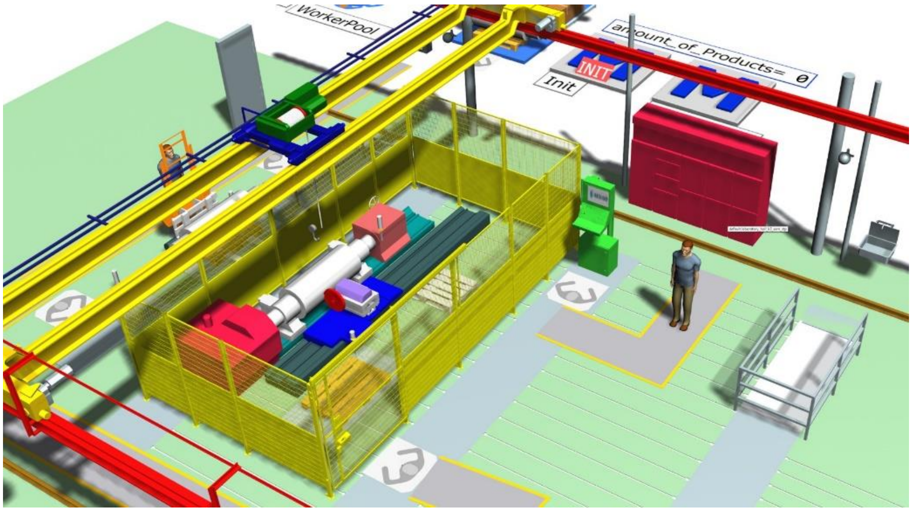

Figure 4: Virtual view of Ilmatar use case from Aalto Industrial Internet Campus. Some machines like Ilmatar crane and control system for virtual grinding machine are real machines, but grinding machine is virtual model that is scaled down to fit in the AIIC laboratory hall.

The focus of the Dutch partners is to make machine data available for an integrated DT environment. Two use-cases are considered: Improving the operational efficiency of a 3D printer provided by Additive Industries and Lely's agricultural robot called Juno. Each partner focusing on different parts of the continuous improvement cycle. In general, the operational data of both machines can be analysed to provide better insights which lead to software updates or a change in parameters that affect performance. The Dutch ecosystem overview can be seen in Figure 5.

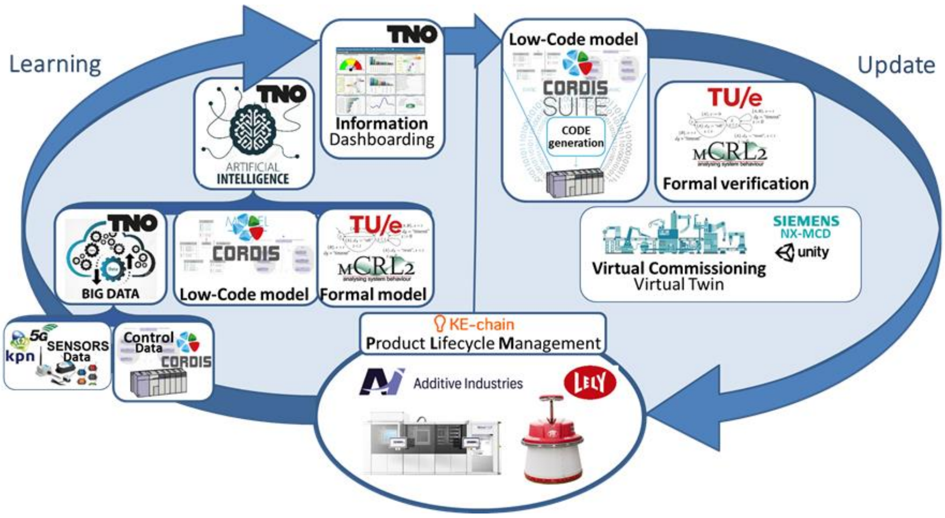

Figure 5: Overview of the Dutch ecosystem: The continuous improvement of a 3D printer provided by Additive Industries and Lely´s agricultural robot called Juno by means of software updates.

Main objective of the Turkish use case scenario, 1600T press line (Figure 6), is to monitor all sensors, create alarms, generate a predictive maintenance calendar, identify required spare parts for maintenance with machine learning models. Another objective is acquiring experimental data and outcome of raw material process simulation with press line digital twin.

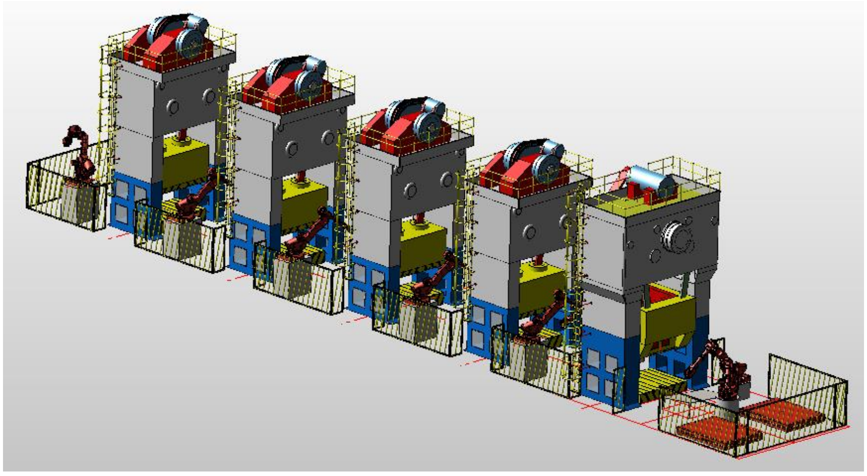

Figure 6: 3D visualization of Ermetal's 1600T press line

The Korean consortium's main scenario is to efficiently carry out material transport to the destination in collaboration with cranes and AGVs. The primary role of ETRI is to design the system architecture for material handling service and develop the main components in the system. CIP focuses on integrating the automatic logistics system (Figure 7).

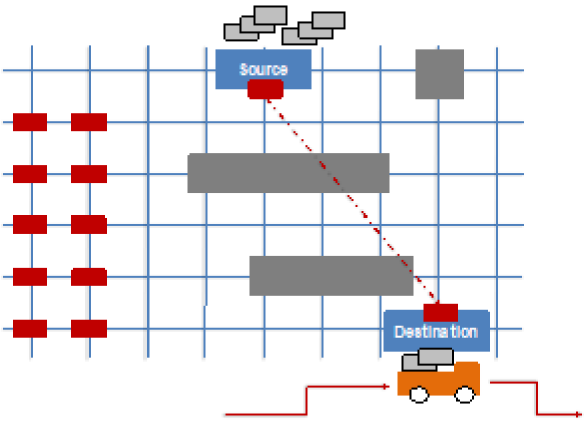

Figure 7: Service scenario for automatic logistics service using AGVs

To connect local ecosystems into one consortium wide Machinaide ecosystem, local interfaces have been gathered that are now provided by the partner system. These interfaces enable the connectivity within the ecosystems and between the national ecosystems. The most common interfaces used by the local ecosystems are OPC UA (and OPC classic), MQTT, Low-level IO, GraphQL, and XML. Other interfaces include, but not limited to the following technologies: REST API, Open Database Connectivity (ODBC), Oracle11g, PLCSIM, SIMiT, Socket ActiveX, C, JSON, Beckhoff ADS, and various web user interfaces and graphical interfaces. While there are many interfaces available, only a few systems support multiple interfaces. Thus, the "brokers" are needed in many cases to connect different ecosystems together.

6.4. Existing Solutions for Digital Twin Based Manufacturing

In order to ensure the interoperability among heterogeneous Digital Twins aimed at Machinaide, it is necessary to analyse in more detail various Cloud-IoT services that become the base platform of each Digital twin services. Solutions that support the digital twin service are mainly offered competitively between cloud providers and IoT device manufacturers, and each vendor is striving to secure the digital twin standard. In addition, platforms to support digital twins are being developed in open-source camps.

6.4.1. Cloud Service Provider

- **Microsoft:** Azure Digital Twins (ADT), one of MS Azure IoT Services, is a platform as a service (PaaS) offering that enables the creation of knowledge graphs based on digital models of entire environments such as buildings, factories, farms, energy networks and more. In ADT, you can describe digital models including their state properties, telemetry events, commands, components and relationships using a JSON-like language called Digital Twins Definition Language (DTDL). In addition, Azure Digital Twins explorer as a live execution environment is provided for visualizing of your Azure Digital Twins graph. (Microsoft, 2020)
- **Amazon:** AWS (Amazon Web Service) offers Device Shadow Service for AWS IoT as simplified Digital Twins service, focused on device management. Actually, AWS does not offer specific digital twins service as SaaS, but there are options to create own custom solution using Amazon AI and IoT Core services in integration with services for 3D modelling. The AWS IoT Device Shadow enables Internet-connected devices to connect to the AWS Cloud and let application in the cloud interact with internet-connected devices. (MateevMihail, 2020)
- **Google Cloud:** Google does not offer a specific Digital Twin solution. However, similar to AWS solutions, providing analytics with Digital Twins should be based on existing IoT and AI components with custom development and configuration. Google Cloud IoT Core is a fully managed service to easily and securely connect, manage, and ingest data from globally dispersed devices with components like device manager and protocol bridges (for MQTT and HTTP). (Google, 2020)
- **IBM Cloud:** Watson IoT is IBM's platform for connecting devices, building IoT applications and making sense of the data. Communications between devices and the cloud happen via the open, lightweight MQTT protocol. With IBM's Watson IoT Platform for Bluemix, you can connect devices, gateways and applications, allowing for analytics to be performed on the real-time data collected from your organization. (Knolleary, 2017)

6.4.2. Industrial Device Provider

- **Siemens:** Siemens' MindSphere, cloud based IoT operating system in the form of a platform as a service (PaaS) that enables customers to develop, run and manage their applications without the complexity of building their own infrastructures or managing complex software stacks. With the numerous applications, services, and closed-loop digital twin capabilities of MindSphere, you can reduce costs and accelerate time to market by connecting your assets and harnessing the wealth of data. (Siemens, 2017)
- **GE Digital:** GE Predix is an industrial IoT Software Platform from GE digital that simplifies creating dynamic digital models of physical assets and systems. It helps building and operating digital twin apps, and gain knowledge and insights about performance and predictions of future operations. (GE Digital, 2019)
- **Bosch:** Bosch IoT Suite is a set of cloud services and software packages for the development of IoT applications. It is available as Platform as a Service (PaaS) for developers, who can quickly build and implement cloud-based and highly scalable IoT applications. (Bosch.IO, 2020) Bosch IoT Things, one of the Bosch IoT Suite services & software packages enables applications to manage digital twins of IoT device assets in a simple, convenient, robust, and secure way. With Bosch IoT Things, applications can manage digital twins of IoT device assets in a simple, convenient, powerful and secure way to store and update the asset's data, properties and relationships, and to be notified of all relevant changes. To do this, you can interact with the digital twins using HTTP JSON APIs or a connection-based integration via WebSocket, AMQP, and MQTT. (Bosch.IO, 2020)

- **Schneider Electric:** EcoStruxure is Schneider Electric's IoT-enabled, plug-and-play, open, interoperable architecture and platform, in homes, buildings, data centers, infrastructure and industries. Innovation at every level from connected products to edge control, and apps, analytics and services. It provides solutions such as EcoStruxure Building, EcoStruxture Plant & Machine, EcoStruxture Grid, EcoStruxture IT, EcoStruxture Power and EcoStruxture Platform for applications in various industries. (Schneider Electric, 2020)

6.4.3. Open-Source Solution provider

- **Eclipse.org:** Eclipse Ditto, open-source digital twin framework, is a technology in the IoT implementing a software pattern called "digital twins". With Ditto a thing can just be used as a web service via its digital twin. However, it should be noted that Ditto is not another fully-fledged IoT platform. It does not provide software running on IoT gateways and it does not define or implement an IoT protocol in order to communicate with devices. Its focus lies on back-end scenarios by providing web APIs in order to simplify working with already connected (e.g. via Eclipse Hono) devices and "Things" from customer apps or any other back-end software. It also does not specify which data or which structure a "Thing" in the IoT has to provide. (Eclipse Foundation, 2020)

7. Processing of Multiple Industrial Data

7.1. Introduction

Processing multiple industrial digital twin data is a key feature of digital twin technology to enable interoperability. Each digital twin has to interpret its own data model and process the data collected from the physical twin. The data model enables both the digital twin and people to understand and use data. However, the data models from heterogeneous digital twin may differentiate from each other, and thus it is difficult to process data from another digital twin. For instance, simple queries in multiple digital twins may be challenging if it is not known the exact name of an object to be searched.

Digital twins are expected to combine real-life and modelling data in convenient ways and possibly bring intelligent features for data analysis product design and performance management. The ecosystem of multiple digital twins in the project context is assumed to integrate digital twins in different factories and countries together. Accessibility to those data poses a challenge if we need to know exact names of the objects in digital twin ecosystems. In this chapter, we introduce two approaches to access multiple digital twin data.

7.2. Ontology Based Semantic Transformation

Semantic transformation is the process of using semantic information to aid in the translation of data in one representation or data model to another representation or data model. Semantic transformation takes advantage of semantics that associate meaning with individual data elements in one dictionary to create an equivalent meaning in a second system. An example of semantic transformation is the conversion of XML data from one data model to a second data model using formal ontologies for each system such as the Web Ontology Language (OWL). This is frequently required by intelligent agents that wish to perform searches on remote computer systems that use different data models to store their data elements. The process of allowing a single user to search multiple systems with a single search request is also known as federated search.

Semantic transformation should be differentiated from data mapping tools that do simple one-to-one translation of data from one system to another without actually associating meaning with each data element. Semantic transformation requires that data elements in the source and destination systems have "semantic mappings" to a central registry or registries of data elements. The simplest mapping is of course where there is equivalence. There are three types of Semantic equivalence:

- Class Equivalence- indicating that class or "concepts" are equivalent. For example: "Person" is the same as "Individual"
- Property Equivalence- indicating that two properties are equivalent. For example: "PersonGivenName" is the same as "FirstName"
- Instance Equivalence- indicating that two individual instances of objects are equivalent. For example: "Dan Smith" is the same person as "Daniel Smith"

Semantic transformation is very difficult if the terms in a particular data model do not have direct one-to-one mappings to data elements in a foreign data model. In that situation, an alternative approach must be used to find mappings from the original data to the foreign data elements.

A semantic mapper is a tool or service that aids in the transformation of data elements from one namespace into another namespace. A semantic mapper is an essential component of a semantic broker. Essentially the problems arising in semantic mapping are the same as in data mapping for data integration purposes, with the difference that the semantic relationships are made explicit through the use of semantic nets or ontologies which play the role of data dictionaries in data mapping.

A semantic mapper must have access to three data sets:

- List of data elements in source namespace
- List of data elements in destination namespace
- List of semantic equivalent statements between source and destination (e.g. owl:equivalentClass, owl:equivalentProperty or owl:sameAs in OWL).

A semantic mapper processes on a list of data elements in the source namespace. The semantic mapper will successively translate the data elements from the source namespace to the destination namespace. The mapping does not necessarily need to be a one-to-one mapping. Some data elements may map to several data elements in the destination (Figure 8).

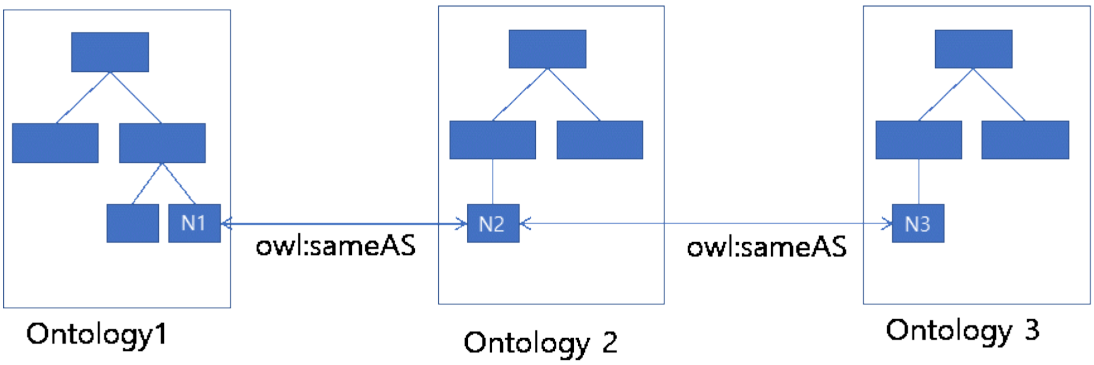

Figure 8: Concept of semantic mapping

Ontology alignment, or ontology matching, is the process of determining correspondences between concepts in ontologies. The Ontology Alignment is performed according to a strategy or a combination of techniques for calculating similarity measures, and it uses a set of parameters (e.g., weighting parameters, thresholds, etc.) and a set of external resources (e.g., thesaurus, dictionary, etc.). At the end, we obtain a set of semantic links between the entities that compose the ontologies. There are several methods for calculating similarity between entities of several ontologies:

- Terminological methods: These methods are based on the comparison of terms, strings or texts. They are used to calculate the value of similarity between units of text, such as names, labels, comments, descriptions, etc. These methods can be further divided into two sub-categories: methods that compare the terms based on characters in these terms, and methods using some linguistic knowledge.
- Structural methods: These methods calculate the similarity between two entities by exploiting structural information, when the concerned entities are connected to the others by semantic or syntactic links, forming a hierarchy or a graph of entities. We call internal structural methods, methods that only exploit information about entity attributes, and external structural methods, methods that consider relations between entities.
- Extensional methods: These methods infer the similarity between two entities, especially concepts or classes, by analysing their extensions, i.e. their instances.
- Semantic methods: a) Techniques based on the external ontologies: When two ontologies have to be aligned, it is preferable that the comparisons are done according to a common knowledge. Thus, these techniques use an intermediate formal ontology to meet that need. This ontology will define a common context for the two ontologies to be aligned. b) Deductive techniques: Semantic methods are based on logical models, such as propositional satisfiability (SAT), SAT modal or description logics. They are also based on deduction methods to deduce the similarity between two entities. Techniques of description logics, such as the subsumption test, can be used to verify the semantic relations between entities, such as equivalence (similarity is equal to 1), the subsumption (similarity is between 0 and 1) or the exclusion (similarity is equal to 0), and therefore used to deduce the similarity between the entities. These alignment techniques are integrated into approaches for mapping ontologies. We find approaches that combine multiple alignment techniques. Much work has been developed in the area of Ontology and focus on the alignment techniques.

7.3. Adaptor Based Schema Mapping

Adaptor-based data model mapping is a method for integrating a variety of different data into one data using structured data model. This method creates a mapping table by defining a data structure model in advance and matches different data model entities based on it. Mapping tables and mapping rules are used to consolidate data into one. The mapping table is a table in which meanings between different entities are defined and listed in advance, and mapping rules are created based on this and data model matching is performed (Figure 9). This enables interoperability between heterogeneous data models.

Source entity	Target entity
namespace:K	namespace1:K1
	namespace2:K2
	namespace3:K3
namespace:L	namespace1:L1
	namespace12:L2
namespace:S	namespace1:S1
	namespace2:S2

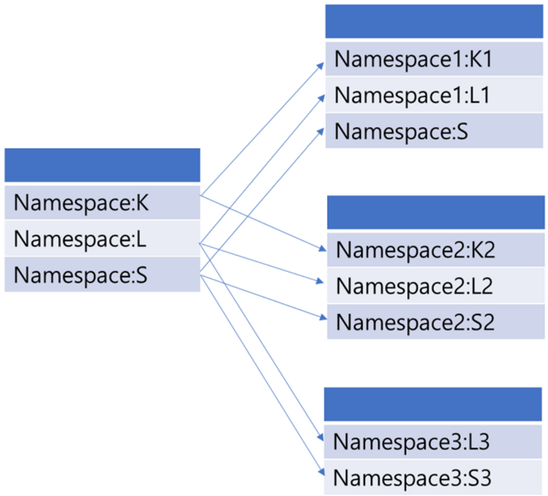

Figure 9: Concept of adaptor-based schema mapping

Using this method, the unified data model integrates all information related to digital twins and HMI will query data in unified data model. Then the queries for unified data model are transformed into each specific queries for each digital twin databases (Figure 10).

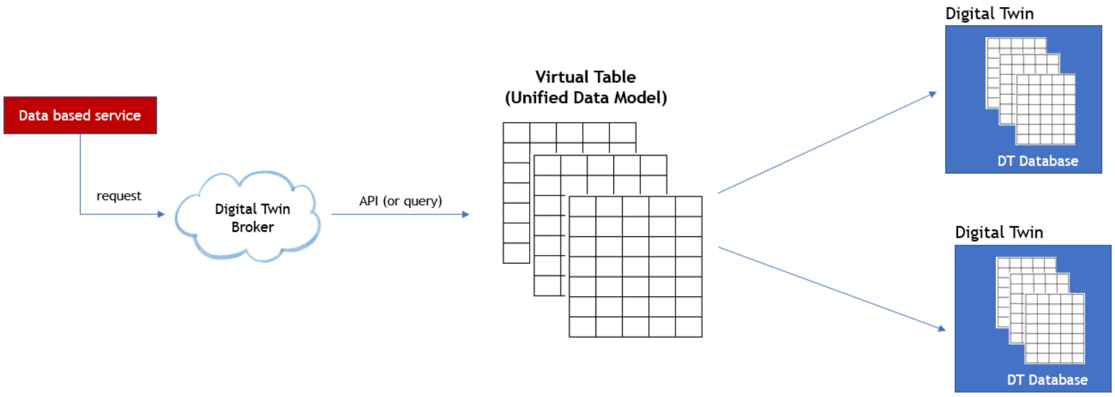

Figure 10: Conceptual view for generating unified data model

8. Query Mechanism of Digital Twin

8.1. Introduction

When creating a digital twin, it is important that the information is machine-readable. Determining the right methodologies and tools for querying and aggregating sensor data is critical to constructing a digital twin due to the complex process of extracting practical knowledge from heterogeneous data (Zheng, 2020). There are different types of data and different ways to query databases. Query mechanisms range from arbitrary text search, text-to-sql and SQL-like queries, entity-relationship diagram (ER) queries to sound-based queries and virtual reality (VR) techniques.

Various use cases and applications of the Internet of Things and digital twins require working with different types of data. When trying to access the collected information related to existing resources the primary focus is on the datamodel, the supported network protocols and query capabilities (Jacoby & Usländer, 2020).

In the context of smart manufacturing, there might be several databases that in practice need to complement each other to ensure low latency: key-value databases can be used for storing software log files from connected Cyber-physical Systems (CPSs); documents can be stored in document databases to ensure high flexibility and durability; engineering knowledge can reside in graph databases to accelerate querying and reasoning; column stores allow for fast querying and processing and it is heavily used for big-data analysis where speed is critical (Yuqian Lu, 2020).

8.2. Digital Twin Data Querying

The data model query mechanisms explain how the user interacts with the digital twin system by querying the digital twin data model. Continuous updating of data and information between physical and virtual systems is fundamental to the dynamic behaviour of a digital twin.

The digital twin ontology model, which is used to synthesize the minimal data structure for the digital twin data model, offers a five-step methodology for extracting the digital twin data model structure from the ontology using ontology-to-conceptual data model transformation. The solution addresses the digital twin scalability issue and shows how quantifier constraints created from the minimal data structure for the digital twin data model and OWL DL script. Quantifier constraints such as someValuesfrom, allValuesFrom, and cardinality restrictions provide a system to deal with digital twin dynamics challenges (Singh, 2020).

The introduction of the model-based feature information network framework facilitates access to dynamically evolving data for use within physics-based models, thereby enabling a digital twin description of the component or system (Gopalakrishnan, Hartman, & Sangid, 2020). It provides a comprehensive framework that facilitates storing, updating, searching, and retrieving of relevant information across a product’s lifecycle. The data model provided by the Quality Information Framework, which is an existing model-based definition capability for storing and exchanging quality inspection data. The framework has been directly utilized to create data linkages between feature definitions in a component, originating from its CAD model to more broadly defined feature-specific metadata, including product lifecycle data originating from disparate sources during the design, manufacturing, and sustainment stages (Gopalakrishnan, Hartman, & Sangid, 2020).

Another approach establishes the novel six-layer digital twin model (Figure 11). In this approach all automated calculation jobs should be driven by digital twin metadata such as the hyperparameters of machine learning. Using hyperparameters the metadata will be updated by metadata updating feedback flow which most current digital twin projects are missing (Fahed, 2020).

Digital twin ontology model can query the data within the Data Lake, which is a vast data store located at the data tier and composed of multiple databases or other data providers (Bibow, ve diğerleri, 2020). Both unstructured and structured data from a wide variety of sources, such as sensors in CPPS (Cyber-Physical Production Systems), are stored in raw or pre-processed form and annotated with metadata containing semantic information.

Data Processor connects the Data Lake with components at the application layer and creates Digital Shadows - a set of temporal data traces that encapsulate the exact information required by the application-level components.

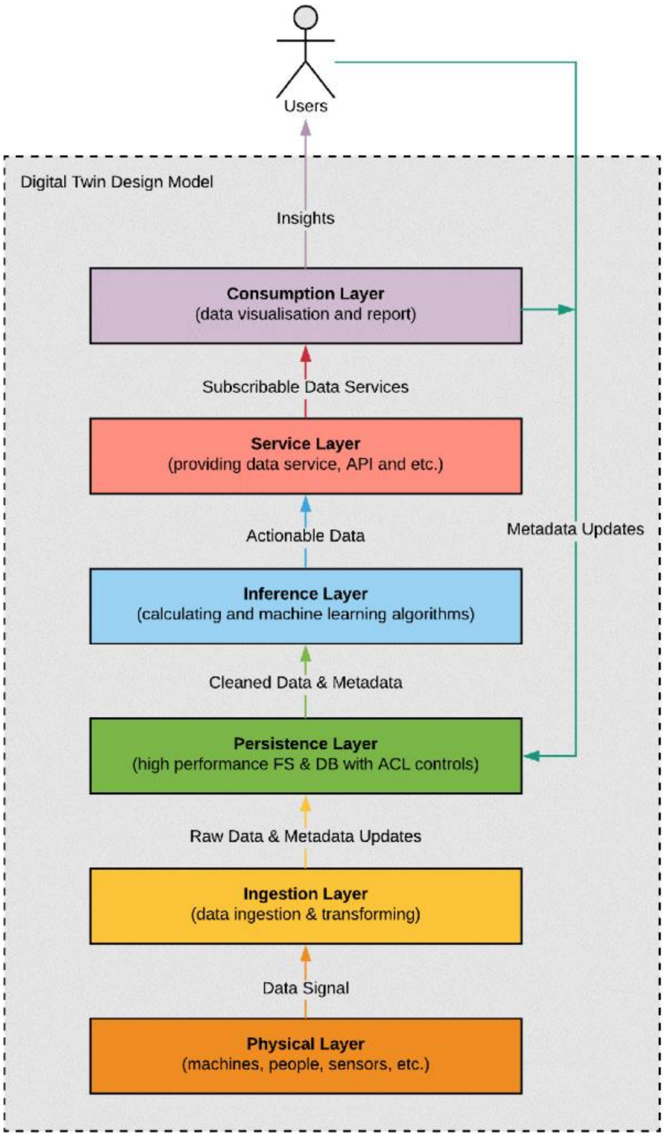

Figure 11: Proposed Six-layer digital twin model with upstream and feedback flows.

The Data Processor Logic receives application-level digital shadow requests, translates them into data queries, and generates digital shadows from those queries. The data processor adaptor converts data requests into queries for specific databases in the data lake. It receives a decision from the application layer that describes how the CPPS should behave.

Digital Twin viability depends on the capability to correctly represent data and its semantics and make complete datasets available for knowledge processing. The value of knowledge bases in the context of semantics and linked data is emphasized on the conceptual representation of real-world things, integration, and web-based communication of the Digital Twin data, thus, the use of graph databases is gaining traction in the domain of the built environment (Boje, Guerriero, Kubicki, & Rezgui, 2020). The advantages of using web services for developing digital twins include platform independence, compatibility with multiple devices and operating systems, elimination of installation processes, and ease of deploying updated capabilities to distributed users (Fonseca & Gaspar, 2020).

8.3. Semantic Relationship

A way to extract and infer knowledge from large-scale production line data, as well as improve the management of manufacturing processes using reasoning capabilities by introducing a semantic query mechanism is presented by Banerjee et. al. (Banerjee, Mittal, Dalal, & Joshi, 2017). The proposed system is enriched with inference rules and uses a graph-based query language equivalent to conjunctive queries, and the ontology framework was constructed that is tailored towards manufacturing. A knowledge graph based on the ontology was generated and in order to extract semantic relation from the knowledge graph, a Path Ranking Algorithm (PRA) was used. The PRA considers a generalized version of the knowledge graph and tries to derive relationships based on the paths it can follow.

For example, considering the query "What is the average time variance of feature X?".

To draw a conclusion about the correlation between the variance of stations with respect to lines and a feature X (*Figure 12 Proposed System Architecture Diagram*), PRA traverses the generated knowledge graph, starting from the source node extracted from the query (isTimeVariance (T1)) and considers every station si/si and traverses individual lines li - li for the feature X. After failing to find any direct correlation, it generates a feature vector for each pair (si, li), starting from the TimeVariance node with respect to si / li. In this case, there is only an indirect boundary sequence between the source and target nodes (T1-StationID-FeatureID-LineID-T1), and the value of this feature vector is evaluated as nonzero. The probability of such path sequences generated by PRA is used to derive semantic relationships.

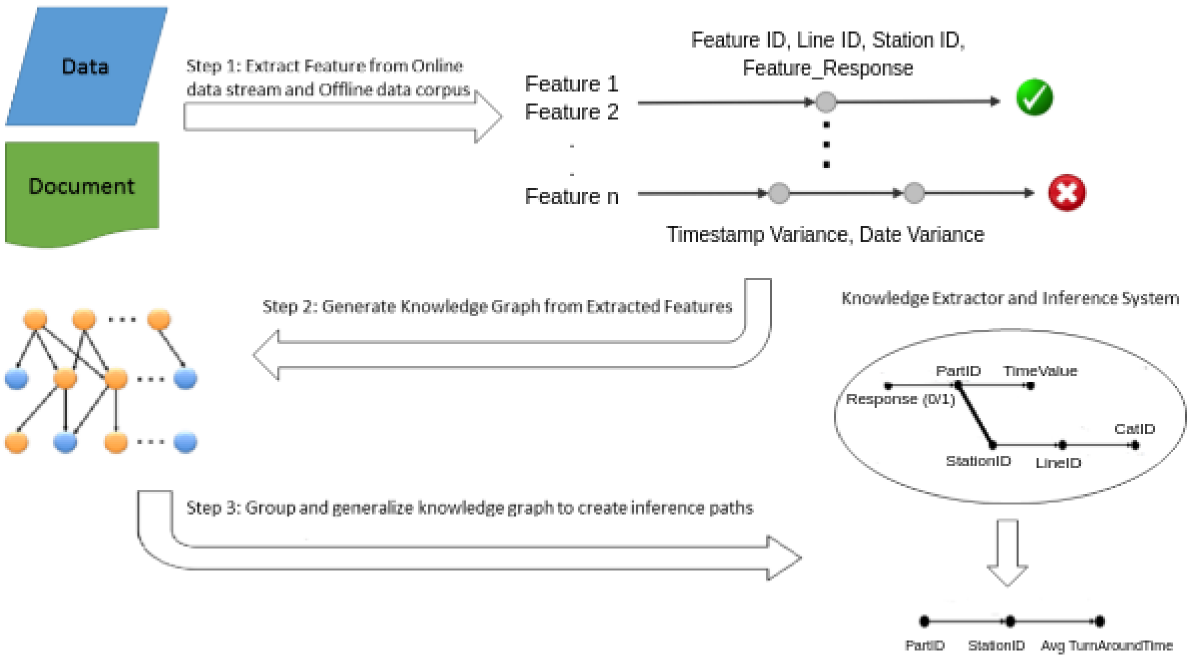

Figure 12 Proposed System Architecture Diagram

The Semantic Web can help overcome current big data challenges and move one step closer to smart factories (Moder, Ehm, & Jofer, 2020). Semantic Web technologies allow IT systems to process information from websites/web application and other data resources to recognize relationships and dependencies between pieces of data. It has been very successful for search engines like Google and social networks like Facebook, however, it has not yet gained widespread industrial use. The Semantic Web extends the current structure of the World Wide Web (WWW) and links information at the data level using a Resource Description Framework (RDF). It is understandable and interpretable by both humans and machines, which allows better collaboration between computers and humans and improves the ability to analyse data as well as extract knowledge.

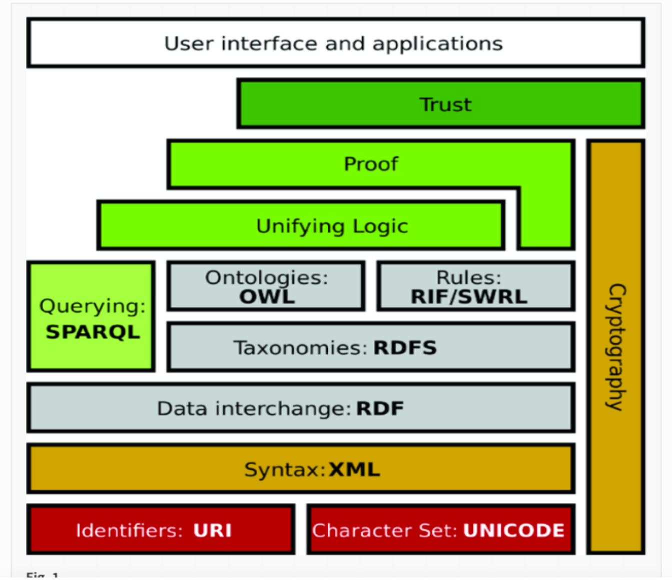

Figure 13: The Semantic Web Stack.

Data is expressed as triplets containing a subject, predicate, and object:

- A subject (resource) - is an object or thing of interest.
- The predicate (property) - relates the subject and the object with an attribute.
- An object property is used to associate a resource with another resource, and a data property is used to associate a resource with a piece of literal data. Each resource and property have a unique identifier (URI) and the URI refers to the address where the defining ontology is stored.

The Semantic Web uses ontologies and languages such as OWL to define classes, properties, and individuals, and their relationships. Encoding information using an ontology language makes it possible to interpret, extract, and make an explicit specification of implicit knowledge, allowing us to perform advanced functions with data. Figure 13 demonstrate main blocks of semantic web stact.

SPARQL, a semantic query language for databases, allows you to retrieve and process data stored in RDF ontologies by selecting information based on graph assemblies, which provides filtering strategies based on logical comparisons. WebVOWL, a web application for interactive visualization of ontologies, serves a human operator, and the ontology with all its entities can be graphically represented by implementing visual notation for OWL ontologies (VOWL). The application is interactive, and a custom visualization of the ontology can be saved and published in the JavaScript Object Notation (JSON) file format, which improves the readability of the associated representation.

8.4. Natural Language Processing (NLP)

Text to SQL conversion can be placed into three broad categories (Pradhan, 2020):

Symbolic Approach (Rule-Based Approach - Figure 14): entities are picked from a list of query tokens and are translated based on general grammar rules and self-defined sketches on a case-by-case basis. This approach implies human participation in the development and improvement of the system. the main advantage of this approach is that there is always a way to check if a user's query can be processed by the system. Since the rules are written by people it is easy to locate and fix any reported bug. The disadvantage of a rule-based search is that it requires a deep understanding of the domain and a lot of manual job, such as complex and time-consuming creation of guidelines for a complex system.

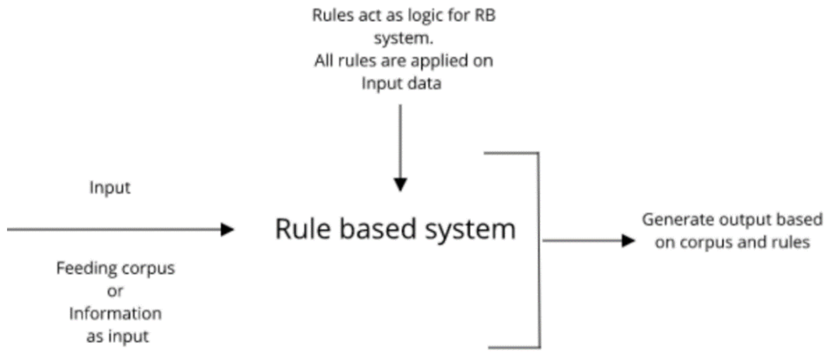

Figure 14: Rule Based System

Empirical Approach (Corpus-Based Approach): queries are translated based on statistical analyses of large collections of texts. A corpus is a collection of text drawn from typical sources that can be used as a test data set to evaluate NLP systems. Corpus contains structured and variable but representative text. The corpus is a powerful source of discourse analysis, since the linguistic and semantic relationships contained in it play an important role in the manifestation, adjustment and expansion of systems to harmonize with its discourse (Shams, 2012).

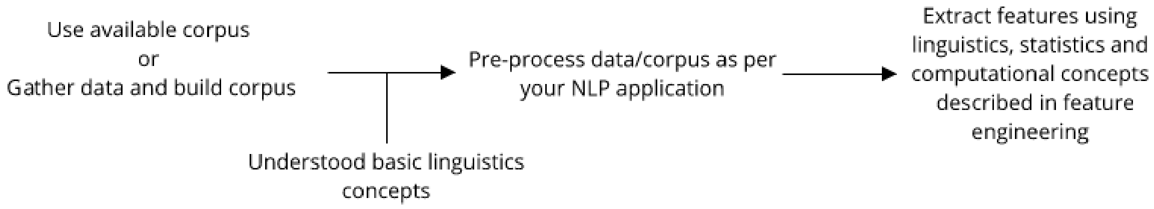

Figure 15: Corpus-based system

Connectionist Approach (Using Neural Networks - Figure 15): Sequence-to-Sequence models are used to translate one language to another – in this case, English to SQL. The model is trained with an extensive collection of English commands and the corresponding SQL queries (such as WikiSQL) and finally used to predict a SQL query from any given English query and the corresponding database schema. These models can often be trained with a single end-to-end model and do not require traditional task-specific function design. Recently, deep learning approaches have achieved very high performance in many different NLP tasks. Deep NLP becoming more effective and accessible due to recent advances; however, the field still has a long way to go before anything close to human understanding or synthesis is demonstrated.

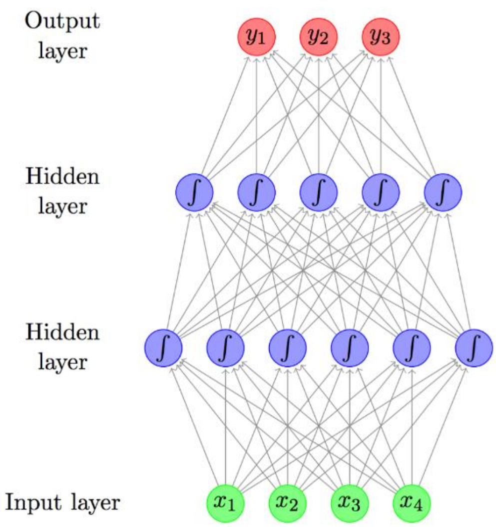

Figure 16: Neural-network model for NLP

Natural Language Interface (NLI), which is applied to relational databases translating Natural Language Queries to Structured Query Language (SQL), allows people to interact with a computer using natural language. The proposed NLP-based system (Anisha, P, & Murali, 2019) transforms natural language queries into database queries using a deep neural network. The sequence-to-sequence deep neural network, basic encoder-decoder model, and encoder-decoder model with attention were used.

Easy, medium, and hard - three types of queries are handled by the system. It is evaluated on the Spider dataset, a large, complex, cross-domain semantic parsing and text-to-SQL dataset that directly benefits the NLP and DB communities. To better understand the model's performance, queries are divided into three levels: light, medium, and hard. However, research shows that the overall performance of all models explored in the paper indicates that there is still much room for improvement.

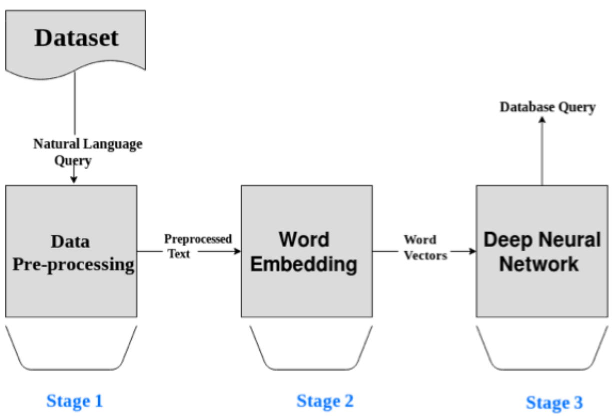

Figure 17: Basic Architecture of Text-to-SQL Task

A simple and efficient network structure HydraNet is proposed that makes the best use of the capabilities of the base language model by precisely matching the task of converting text to SQL with the base language models. In this structure, the question and the NL column are encoded directly by the host language model without any additional join operations, which counts to be the best encoder type for fixing a question column relationship in Text-to-SQL. The proposed hybrid ranking mechanism and execution-guided decoding handle column-column relations and effectively improve accuracy. Execution-guided decoding (EG) was applied, which executes a predictable SQL query at runtime and makes corrections if the database engine returned a runtime error or empty output.

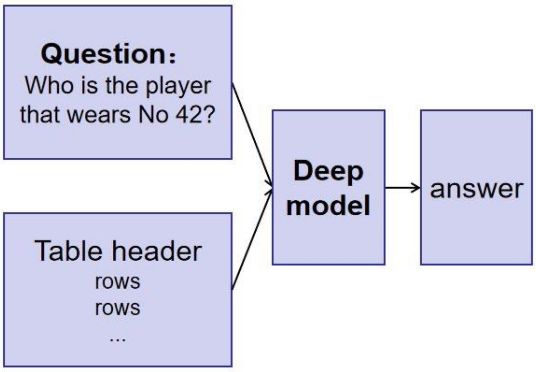

Figure 18: Natural language to SQL for question answering

Question	Who is the player that wears no 42?				
SQL	SELECT Player FROM Players Where No.=42				
Result	Art Long				
Players:					
Player	**No.**	**Nationality**	**Position**	**Years in Toronto**	**Club Team**
Antonio Lang	21	United States	Guard-Forward	1999-2000	Duke
Voshon Lenard	2	United States	Guard-Forward	2002-2003	Minnesota
Martin Lewis	32	United States	Guard-Forward	1996-1997	Butler CC
Brad Lohaus	33	United States	Guard-Forward	1996-1996	Iowa
Art Long	42	United States	Guard-Forward	2002-2003	Cincinnati

Table 1: An example of the WikiSQL semantic parsing dataset.

This approach achieves the best result on WikiSQL dataset. WikiSQL is the first large-scale text-to-SQL dataset, containing about 80,000 annotated pairs of NL questions and SQL queries. Although limited in size, the dataset is still very complex because the tables and questions are very diverse.

Table *1*, listing simplified version of players table, was queried with text-to-SQL implementation, and expected data acquired from the system.

9. HMIs for Industrial Use Cases

9.1. Intro

The term "user interface" refers to the methods and devices that are used to accommodate interaction between machines and the humans who use them. The user interface of a mechanical system, such as a vehicle or an industrial installation, is often referred to as the human – machine interface (HMI). In any industrial control system, the HMI can be used to deliver information from machine to people, which allows people to control, monitor, and record the system through devices such as image, keyboard, Ethernet, screen, video, radio, software, etc (Hooper, 2017). It’s the primary tool that industrial operators and line supervisors rely on for the coordination and control of manufacturing or industrial processes, typically in a plant environment.

Industrial HMIs can operate in a wide range from simple to complex. The specific functionality of an interface varies from device to device or machine to machine, depending largely on the functions of the machine and what controls are necessary to coordinate operation (Hooper, 2017). HMIs can take many forms including:

- Touch display panels
- Push buttons and switches
- Mobile devices
- Computers with keypads

Although there are many techniques and methods used in industry, the HMI always accomplishes two fundamental tasks: communicating information from the machine to the user and communicating information from the user to the machine (Zheng, 2020). On the factory floor, HMIs provide valuable data enabling operators to optimize efficiency, such as reallocating staff to compensate for slow production in another area or fine-tuning machine settings to correct performance issues. HMIs can be placed on the machine or device itself, in a portable, handheld or in a central control room (Hooper, 2017).

Human-machine interfaces are used for myriad applications across manufacturing, automotive, processing, and other industries, such as (Hooper, 2017):

- Food processing
- Pharmaceutical manufacturing
- Oil and gas
- Mining operations
- SCADA systems
- Robotics applications
- Transportation
- And much more

There are two basic types of HMI software: supervisory level and machine level. The supervisory level is designed for control room environment and used for system control and data acquisition (SCADA), a process control application which collects data from sensors on the shop floor and sends the information to a central computer for processing (Hooper, 2017).

In industrial applications, HMIs are often robust and complex interfaces which are capable of handling the volume and complexity of inputs and outputs necessary to operate industrial machinery or plant-wide operations. Designing a functional user interface is a challenging process that should begin with a comprehensive analysis of requirements, specifications, and all relevant contexts.

The advances in information and communications technology (ICT) have contributed immensely to numerous fields, among other things, bringing innovation and revolution to HMI studies. New emergent technologies like web, mobile, big data, AI, digitalization, AR/MR, speech generation and recognition gradually take place in HMI activities, with wearable devices like wristbands, watches, overhead displays involved.

New HMIs are becoming more sophisticated for enhanced efficiency and remote service operations, especially when workers are interacting with technologies in different environmental conditions such as dusty, humid, or dark environments. Critical decision making is done with the operators' involvement in the manufacturing process. Therefore, it is expected from the HMI system to allow commands that are easily and rapidly entered to increase the accuracy, safety, efficiency and speed of problem-solving. New types of HMIs are being implemented now by Industry 4.0 and IoT developers are mainly classified as enhanced touch interfaces, voice interfaces, gesture interfaces, and AR/VR glasses.

9.2. Touch

Touch screen displays/panels make the communication between human and machine easy and have found common use since their introduction at the end of the last century: they became more user-friendly and powerful for visual data representation. Industrial interfaces enable IoT and M2M connectivity and allow manufacturing companies to monitor and control industrial operations from local and remote plant and facility locations. Modern touch interfaces are sensitive and allow to manage machines even in gloves, which brings additional comfort and safety to the operator.

9.3. Voice Interfaces

The voice is most important and one of the natural forms of communication. The voice is a signal of numerous information. In this field, numerous data and information can be collected in the voice signal. There are many aspects in this field of research like voice recognition, voice verification, voice synthesis, speaker recognition, speaker identification language recognition, etc.

Voice recognition is a dominant tool for the information interchange using the acoustic signal. Due to these reasons, the voice signal is the leading subject of research for many decades. With the help of a microphone, we can easily store or capture the voice of any speaker. All captured words are later-on recognized by the voice recognizer, and in the end, the system outputs the recognized words. Voice recognition is basically the science of talking with the computer and having it correctly recognized. A literature survey reveals that, voice recognition techniques are suitable for the area where security is very important. Figure 19 highlights main block of speech to text process.

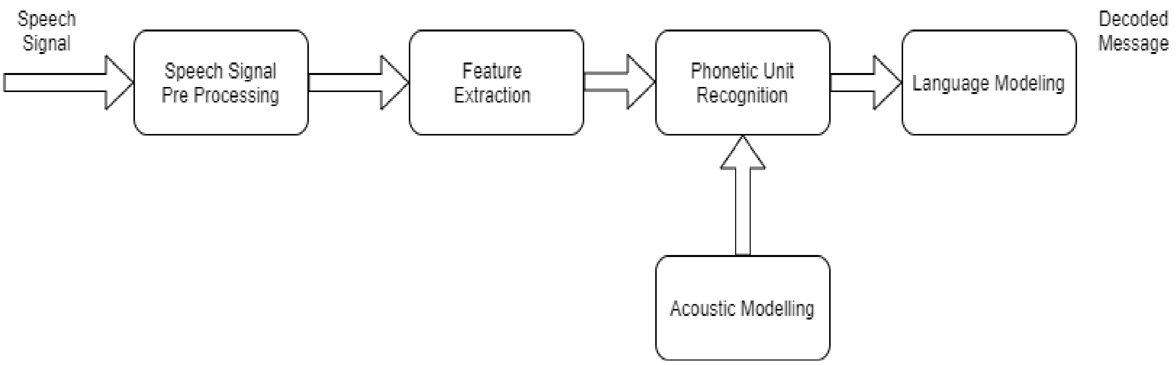

Figure 19: Acoustic Modeling of Speech Signal using Artificial Neural Network

9.3.1. Basics of Speech Recognition Techniques

To understand the field of speech recognition the following definitions and classifications are important. The speech recognition approach is dependent on various factors. We can simply divide these factors into three categories: Type of utterances, vocabulary size and speaker dependency.

9.3.1.1. Type of Utterances in Speech Recognition

- **Isolated Words:** Isolated words recognition is to recognize an isolated speech signal as a single word, where the signal is well segmented and the output is unique. The recognition is mainly based on the acoustic models of all possible hypotheses, with little consideration, if any, for language models. Isolated word recognizers usually need each of the utterances to have quiet on both sides of the sample window. It means that it requires a single utterance at a time. These systems generally have "Listen/Not listen" states, because they require the speaker to wait between utterances.
- **Connected Words:** Connect word systems are similar to isolated words but allow separate utterances to be 'run-together' with a minimal pause between them.
- **Continuous Speech:** Continuous speech recognition deals with a signal without knowing the number of contained word units and the segmentations; it needs to recognize the most likely string of units and determine the boundaries of the recognized units simultaneously.
- **Spontaneous Speech**: At a basic level, it can be thought of as speech that is natural-sounding and not rehearsed. A Speech Recognition system with spontaneous speech ability should be able to handle a variety of natural speech features such as words being run together, "ums" and "ahs", and even slight stutters (A Survey: Speech Recognition Approaches and Techniques, 2018).

9.3.1.2. Vocabulary Size

The speech recognition system can be divided on their recognition ability on the basis of vocabulary size. The system which can be recognized the speech with a limited and given set of the vocabulary of a few hundred words or sentences can be called a limited vocabulary speech recognition system. The system which has a broader capacity to recognize vocabulary such as from few hundreds to thousands of words are called medium vocabulary speech recognition system. The third is the system which has more than thousands of words and sentences are called large vocabulary speech recognition system. (A Survey: Speech Recognition Approaches and Techniques, 2018)

9.3.1.3. Speaker Mode

There are two types of speech recognition. One is called speaker-dependent and the other is speaker-independent. Speaker–dependent software is commonly used for dictation software, while speaker–independent software is more commonly found in telephone applications.
Speaker–dependent software works by learning the unique characteristics of a single person's voice, in a way similar to voice recognition. New users must first "train" the software by speaking to it, so the computer can analyse how the person talks. This often means users have to read a few pages of text to the computer before they can use the speech recognition software.

Speaker–independent software is designed to recognize anyone's voice, so no training is involved. This means it is the only real option for applications such as interactive voice response systems — where businesses can't ask callers to read pages of text before using the system. The downside is that speaker-independent software is generally less accurate than the speaker-dependent software.

Speech recognition engines that are speaker-independent generally deal with this fact by limiting the grammars they use. By using a smaller list of recognized words, the speech engine is more likely to correctly recognize what a speaker said (A Survey: Speech Recognition Approaches and Techniques, 2018).

9.4. Gesture

Due to the presence of interactive computing nowadays, efficient human-computer interactions have an utmost important role. Gesture recognition can be termed as an approach in this direction. It is the process by which the gestures made by the user are recognized by the receiver.

Gestures are expressive, meaningful body motions involving physical movements of the fingers, hands, arms, head, face, or body with the intent of conveying meaningful information or interacting with the environment. They constitute of one interesting small subspace of possible human motion. A gesture may also be perceived by the environment as a compression technique for the information to be transmitted elsewhere and subsequently reconstructed by the receiver. Gesture recognition has wide-ranging applications such as the following:

- Developing aids for the hearing impaired,
- Enabling very young children to interact with computers,
- Designing techniques for forensic identification,
- Recognizing sign language,
- Medically monitoring patients' emotional states or stress levels,
- Navigating and/or manipulating in virtual environments,
- Monitoring automobile drivers' alertness/drowsiness levels etc.

Generally, there exist many-to-one mappings from concepts to gestures and vice versa. Hence, gestures are ambiguous and incompletely specified. For example, to indicate the concept "stop", one can use gestures such as a raised hand with palm facing forward, or an exaggerated waving of both hands over the head. Like speech and handwriting, gestures vary between individuals, and even for the same individual between different instances. Moreover, gestures broadly are of the following types: hand an arm gestures, head and face gestures, body gestures

9.4.1. Hand and Arm Gestures

Human gestures typically constitute a space of motion expressed by the body, face, and/or hands. Of these, hand gestures are often the most expressive and the most frequently used. This involves: 1) a posture: static finger configuration without hand movement and 2) a gesture: dynamic hand movement, with or without finger motion. Gestures may be categorized as given in the following list, such that as we proceed downward this list, their association with speech declines, language properties increase, spontaneity decreases, and social regulation increases:

- **Gesticulation:** Spontaneous movements of the hands and arms that accompany speech.
- **Language-like Gestures:** Gesticulation that is integrated into a spoken utterance, replacing a spoken word or phrase.
- **Pantomimes**: Gestures that depict objects or actions, with or without accompanying speech.
- **Emblems**: Familiar gestures such as V for victory, thumbs up, and assorted rude gestures.
- **Sign Languages**: Well-defined linguistic systems. These carry the most semantic meaning and are more systematic, thereby being easier to model in a virtual environment.

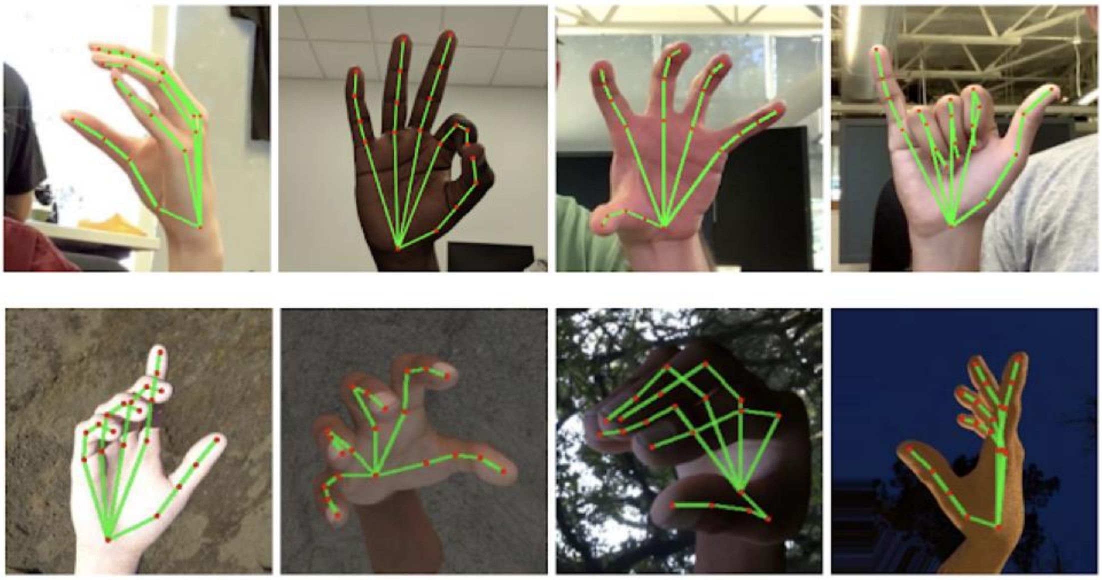

Figure 20: Hand Gesture Sample ((Valentin Bazarevsky and Fan Zhang, 2019))

Face and Head Gestures

The face is a unique feature of a human being. Humans can detect and identify faces in a scene with little or no effort. Their robustness is tremendous, considering the large changes inherent in the visual stimulus due to: 1) viewing conditions (such as variation in luminance); 2) facial expression; 3) aging; 4) gender; 5) occlusion; or 6) distractions such as glasses, hairstyle or other disguises. Human faces are nonrigid objects with a high degree of variability in size, shape, color, and texture. The goal of face detection is to efficiently identify and locate human faces regardless of their positions, scales, orientations, poses, and illumination. Any automated system for face and facial gesture recognition will have immense potential in criminal identification, surveillance, missing children retrieval, office security, credit card verification, video document retrieval, telecommunication, high-definition television (HDTV), medicine, human-computer interfaces, multimedia facial queries, and low-bandwidth transmission of facial data Figure 21.

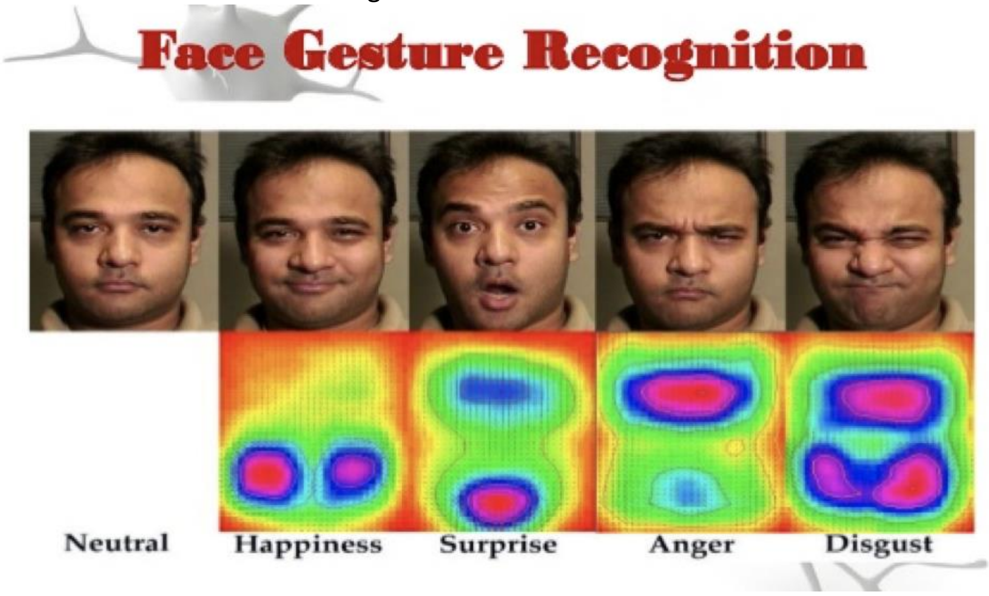

Figure 21: Face Gesture recognition (Pandey, 2014)

9.4.2. Augmented Reality, Virtual Reality, Mixed Reality

Augmented reality (AR) is defined as extended reality where supplementary contextual computerized information is added to the reality and enriches the user's perception of the real environment (Lucio, 2014).

VR is a related but distinct concept, where the user is fully immersed in a computerized virtual environment without any reference to the real world, meaning that even such as the fundamental physics law of gravity, time and materials can be overridden and replaced those ones in the real world with the computerized ones (Milgram, Takemura, Utsumi, & Kishino, 1995).
Mixed reality (MR) is characterized by the combination of both AR and VR environments. It is acknowledged as the forthcoming evolution in the interactions among humans, computers and the environment (See Figure 22).

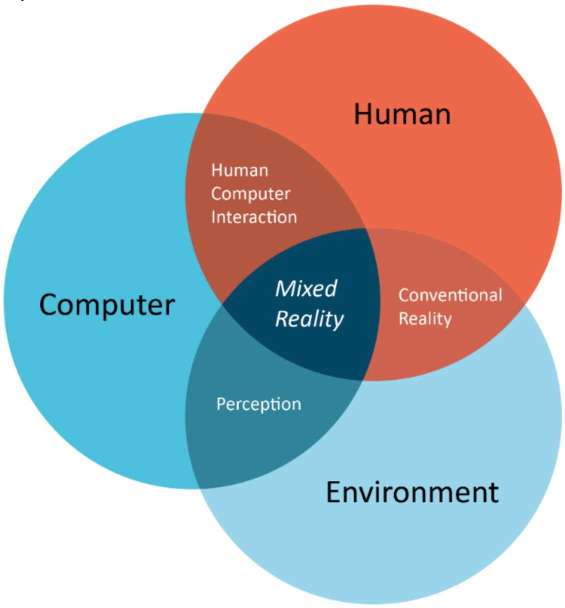

Figure 22: Human-Computer-Environment Interactions (Bray et al., 2018)

MR technologies offer new opportunities for developing a hybrid reality with digital content embedded in the real world. Empowered by the technological advances and developments in the fields of display, sensors, graphical processing power, input systems and computer vision, the possibilities for MR are boosting beyond our imagination. (Bray et al., 2018).
The concepts of AR/ MR can be adopted in an interchangeable manner. AR is most frequently used in gaming, such as in the trendy mobile game "Pokemon Go". Nonetheless, the huge potential of this technology is foreseen in the industrial and manufacturing domain with numerous related studies going on. AR has been acknowledged as one of the top ten strategic technology trends of the year 2018 (Cearley David; Burke Brian, 2018).

AR/MR in industry 4.0

AR/MR technologies are expected to bring a disruptive transformation to the manufacturing and production industry. Industry 4.0 has already been witnessing plenty of applications of AR/MR, such as visualization of product 3D design, guidance on complicated assemblies tasks, the assistance of machine/process maintenance and hands-on safety training, etc.

The vacuum-pump manufacturer, Leybold, has utilized AR/MR technologies in the in-house sales activities and customer support process. For this, an AR/MR app has been developed both for

HoloLens and iPad platforms. With the app, users can view and explore the information on the structure and different components of a vacuum pump, with no additional steps of disassemblies (Nichols, 2019).

An "augmented smart factory" app, through which operators can interact with a cyber-physical system, is developed utilizing AR/MR technologies. In detail, the App can visualize the critical information of the system into virtual objects and superimpose them directly into the real-world scene surrounding the user. Use cases of this app range from in-process monitoring, maintenance to intervenue and servicing, based on the visualization of the system's real-time status, interactive CAD or simulation models. Platform-independent software interface standards like OPC UA and web technologies are usually adopted to enable the information communication between the AR/MR interface and data gathered from CPS and the data integration within IoT systems (Gorecky, Schmitt, Loskyll, & Zühlke, 2014).

AR/MR systems developed and run-on wearable devices such as smart glasses and head-mounted displays are stated to be advantageous, as the way of hands-free interaction enables users to operate the machines smoothly and effectively. When the AR/MR devices are utilized, no additional effort of checking manuals is required since all the related information can be overlayed directly in the real-world scene in front of users or even attached to the corresponding real-world objects. This will therefore reduce operational errors as comprehensive instructions are displayed right in the sight of users and easy to refer to.

According to a study by Boeing, AR/MR interfaces boost productivity and effectiveness in assembly tasks of wiring harness by 25% improvement. As reported by GE Healthcare, operators utilizing AR/MR interfaces at the warehouse could accomplish assembly tasks with a 46% higher speed. AR/MR interfaces are acknowledged to play a role in tackling the skilled worker shortages, as they could promote and ease the training process, empower the machine operators and free them for high-skill tasks, and equip their performance with high safety and productivity (Abraham & Annunziata, 2017).

9.4.3. Reactive Display

Visualization on display is one of the significant factors in HMI. Mostly, digital twins in manufacturing may need much interaction with humans. For example, we use screens for various graphical information, but the large displays cause a challenge for managing enormous on-screen visible details. It means that critical information on the display may be missed when the display area is larger than the user's field of view. Reactive displays, which are attentive user interfaces that employ knowledge of the user's looking behaviour, are the right choice for this challenge.

Reactive displays are HMI technologies that react to a user's interaction, such as gesture, sensor, and motion, by changing its graphical content. Reactive displays have been adopted since the early days of computing. However, research on reactive displays is still in its early stages. One of the main reasons is difficulty in developing cognitive models for predicting the user's attention trajectory and necessary information.

The advent of digital twins has brought the reactive displays back into the spotlight. This recent interest of reactive displays shows that user interface research moves fast from a passive, direct-manipulation paradigm toward active and autonomous modes. The main goal of reactive displays is to present the right information at the right place and at the right time. Therefore, reactive displays help the user address productivity, innovation, and globalization needs.

One of the earliest displays is the storytelling display. The storytelling display continuously computes a measure of interest for each display object based on user glances. The object with the highest levels of interest reacts with narrated stories. The storytelling display can aid systematic search and reduce working memory load, thereby enhancing the user's problem-solving performance. In particular, the display guides the user's visual attention along paths of causal propagation and displaying potential behaviours of individual components improves mechanical problem-solving accuracy.

Reactive displays deal with four kinds of knowledge to provide the right information in the right place and at the right time

1. knowledge about the system/domain that is being displayed
2. knowledge about the problem-solving task that the user is engaged in
3. knowledge regarding an applicable problem-solving model
4. knowledge about the trajectory of the user's attention shifts.

Designing reactive displays has six principles for effective information presentations. These can be described as follows.

1. Decomposition principle: Provide cues in verbal and visual representations that help users decompose the system or process
2. Prior knowledge principle: Use words, pictures, sounds that help users invoke and connect their prior knowledge to the external representations.
3. Co-reference principle: Use interactive and deictic devices to indicate the common referent if the presentation contains multiple entities in different media.
4. Basic laws principle: When The system operation depends on fundamental principles that might not be understood, describe these principles explicitly in the context of the system is explained.
5. Lines of action principle: Help a user understand the physical, causal, and logical relationships that determine how the behaviour of each part of the system influences that of others.
6. Mental simulation principle: Encourage and aid users in mentally simulating the system and provide external representations and interactive facilities to reduce their working memory demands.

Reactive displays can be particularly useful in domains that require visual, spatial, and causal reasoning. These domains share five characteristics:

1. objects of the domain are spatially distributed
2. the domain is dynamic, i.e., objects and their properties change over time
3. objects causally interact with each other
4. interactions can be traced along chains of cause-effect relationships
5. predicting the future evolution of a system in the domain requires reasoning from initial conditions and inferring the causal chains of events.
6. Domains satisfying these criteria include cranes, grinding machines, and 3D printing machines.

Reactive display technologies are also applied to virtual reality, which instigates a feeling of discovery while exploring 2D content. By considering the user's position and motion, reactive displays for virtual reality compute holography-based mappings that adapt the 2D content and re-project it onto the display. This technology allows the viewer to obtain a richer experience of interacting with 2D content. It is similar to the effect of viewing through the window at a scene. Reactive displays also support 3D contents in virtual reality. VR interfaces use a constrained set of reactive displays to browse through 360° content easily. These interfaces provide a natural room-like intermediate interface before changing 360° content. Therefore, they remove the problem of nausea caused by existing interfaces like photospheres.

10. Conclusion

Although it is nearly 30-year concept, the digital twin technology, which has achieved tangible developments in the last decade and continues to improve, will enter and affect many more businesses and industries in the market. As we are living in the digital age, the implementation of digital twin system heavily depends on data acquisition and data processing. The digital twin implementation acquires data via physical sensors and IoT devices and the smooth interconnection of a digital twin to the physical twin improves the accuracy of any insight. Digital twin concept becomes more appealing due to the dramatic advancement of HMIs and machine learning algorithms. Machine learning algorithms have become mature enough to trust with a high accuracy level which means adding a machine learning layer to the digital twin produces outcomes for the future estimations.

The Machinaide project will develop four digital twin applications for each independent use cases. Even though the purpose of usage varies and implementation steps can be different, the main insight and usage of data are very similar to each other: provide appropriate data to digital twin and obtain estimation for related physical twin.

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