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PHD IN MANAGEMENT, PRODUCTION AND DESIGN

IoT for Smart Production

FRAMEWORK FOR INDUSTRY 5.0 COMPLIANT IOT ARCHITECTURES ENABLING DIGITAL TWINS

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Abstract

Digital twins are regarded as the subsequent advancement in cyber-physical systems based on the Internet of Things (IoT). They enable the continuous monitoring of assets in real-time and offer a thorough comprehension of system behavior. This facilitates data-driven insights and enables well-informed decision-making. Nevertheless, there is currently no all-encompassing framework available for the creation of digital twins based on the Internet of Things (IoT). In addition, the current frameworks fail to include the elements brought about by the Industry 5.0 paradigm, including sustainability, human-centricity, and resilience. This thesis presents a framework that utilizes the IoT Architectural Reference Model (IoT-A or IoT-ARM) to create a standardized IoT framework incorporating digital twins. This framework defines and applies a set of standardized tools for modeling IoT systems in the 5.0 era. It serves as a reference point for designing and implementing an IoT architecture that emphasizes digital twins and promotes the sustainability, resilience, and human-centric nature of the information system.

The thesis is based on analyzing three different IoT implementation problems from various industries and domains. The first case study deals with collaborative robots within a manufacturing enterprise. The main problem targeted is the issue of creating a process digital twin towards an efficient product management. The research objectives involve the creation of an information system to support the development of the digital twin.

The second Case study is in the primary sector of agriculture, specifically the dealing with the problem of optimizing vertical farming production systems (VFPS). The main research objectives is to develop an IoT platform that includes digital twin services, and a relative KPI model to support the process of delivering AI services for managing growth and harvest phases of VFPS. The resulting implication of this work is an Infrastructure to support a methodology with the aim of defining a crop growth procedure (CGP) to balance resource utilization and productivity in aeroponic greenhouses.

The final Case study is in the Teritiary sector of education, more specifically it deals with the issue to Propose a quantitative method in order to set a multicriteria evaluation of the course outcomes, and developing course management IoT platform that is easy understandable by students. The research objective is to Apply the two-dimensional Bloom's Taxonomy as a KPI set and insert the industry 5.0 meta-information structure in the course evaluation. The resulting implication of this case study is to test the industry 5.0 proposed framework, i.e., the meta-information structure of data generated by students and tutors, in a highly human-centric data environment.

Introduction

Background

In the era of Industry 4.0, industrial IT technology has transformed manufacturing by integrating and interfacing information with the physical world in the form of cyber physical systems. A big component of this transformation is IoT technologies that provide huge amounts of data. However, seamless integration and undisturbed data flow between different hierarchies of Industrial enterprises is yet to be achieved. This in turn has led to the issue of "information islands"; whereby each informatic system used in a manufacturing firm is managed separately with minimal or no integration with other neighboring systems.Therefore this new availability of data requires; new management tools, new information flows and a more careful assessment of security risks, economic risks, governance and acquired benefits.

Furthermore, industry 4.0 has failed in facing the environmental, social and sustainability challenges of our world today. This is because industry 4.0 is primarily a techno-economic vision. To this end the European commission introduced the concept of Industry 5.0 to face these challenges. The notion of Industry 5.0 encompasses three fundamental components: a focus on human needs and preferences, a commitment to environmental sustainability, and the ability to adapt and recover from challenges. These features enhance and expand upon the technical principles of industry 4.0 in order to achieve the goal of Industry 5.0. Instead of beginning with emergent technology and exploring its potential to enhance efficiency, a human-centric approach in industry prioritizes the fundamental demands and interests of humans in the production process. Instead of inquiring about the potential applications of new technology, we inquire about the capabilities of the technology to benefit us. Instead of requiring the industrial worker to modify their abilities to keep up with fast advancing technology, our aim is to utilize technology to adjust the production process according to the worker's requirements, such as providing guidance and training. Additionally, it entails ensuring that the utilization of novel technology does not infringe upon the essential rights of workers, such as the right to privacy, autonomy, and human dignity.

The rise of this new paradigm created a need to view and implement Industry 4.0 through the vision and values of sustainability, social responsibility, and environmental stewardship. Despite the push toward the Industry 5.0 topic, its concept and form remain unclear, In particular, the application of these values within Industry 4.0 technologies and more specifically IoT is still abstract, lacks significant practical cases, and requires an in-depth study of its implementation aspects.

Aim of the Research

The goal of this work is to contribute to research on methods and strategies for handling IoT systems within enterprises, that is, to use IoT in away that aligns with the 5.0 Industrial philosophy. This thesis is concerned with the lean intelligent organization of Industrial process's (Design, Manufacturing, Maintenance, Accounting) through the identification of appropriate methods, tools and procedures (Framework), this objective is achieved by firstly identifying a methodology for the sharing, usage and management of data generated by IoT systems within an Industrial firm. Secondly, it involves identifying organizational models within enterprises that leverage the integrated principles of Industry 5.0 to efficiently manage data and information resources. And lastly, the the creation of a comprehensive framework designed to guide the implementation and utilization of IoT technologies across diverse industrial sectors. By addressing these objectives, the research seeks to enhance the effectiveness and sustainability of industrial operations in the context of evolving technological landscapes and industry paradigms.

This study presents a framework based on the IoT Architectural Reference Model (IoT-A or IoT-ARM) to address the lack of IoT frameworks for digital twin development and the limitations of existing frameworks in satisfying the requirements of Industry 5.0. The suggested framework employs the IoT-A reference architecture as the foundation for organizing the IoT system. It consists of three sub-models: the domain model, the information model, and the functional model. These models are used to handle the information systems that are governed by the IoT data and knowledge. Another key feature is the formalization of the digital twin component, which functions within the system as a virtual entity.

The suggested framework functions as a standardized set of architectural tools for designing IoT systems, completely integrating with the Industry 5.0 vision. The importance of having a standardized collection of architectural tools guarantees the ability for different IoT ecosystems to work together, be compatible with each other, and be able to grow and expand. This promotes the integration and communication between different devices and platforms that may be different from each other. In essence, a standardized set of architectural features is crucial for creating unified, dependable, and expandable IoT architectures that support the strong growth and implementation of digital twins in many fields. The research methodology adopted throughout this doctoral thesis can be summarized as follows:

- The analysis of increasingly relevant data and information flows between the different hierarchical levels of the production system and the enterprise
- Analysis of data management methodologies based on procedural (Business Process Management) and experimental (Business Intelligence) approaches
- The development of KPIs to evaluate the impact of industrial IoT systems in terms of Sustainability and Human Centricity
- The identification of enterprise organizational models that allow an effective lean management of data and information
- Applying and assessing the framework in specific case studies across different economic sectors

Objective and Research Questions:

The goal of the thesis is the lean intelligent organization of processes (Design, Manufacturing, Maintenance, Accounting) through the identification of appropriate methods, tools and procedures (Framework). This is to be achieved by:

- Identifying a methodology for the sharing, usage and management of data generated by IoT systems within an Industrial firm.
- The identification of enterprise organizational models that, using the integrated approach of Industry 5.0, allow an effective management of data and information.
- Development of a “Lean” framework for the usage of IoT in various industrial sectors

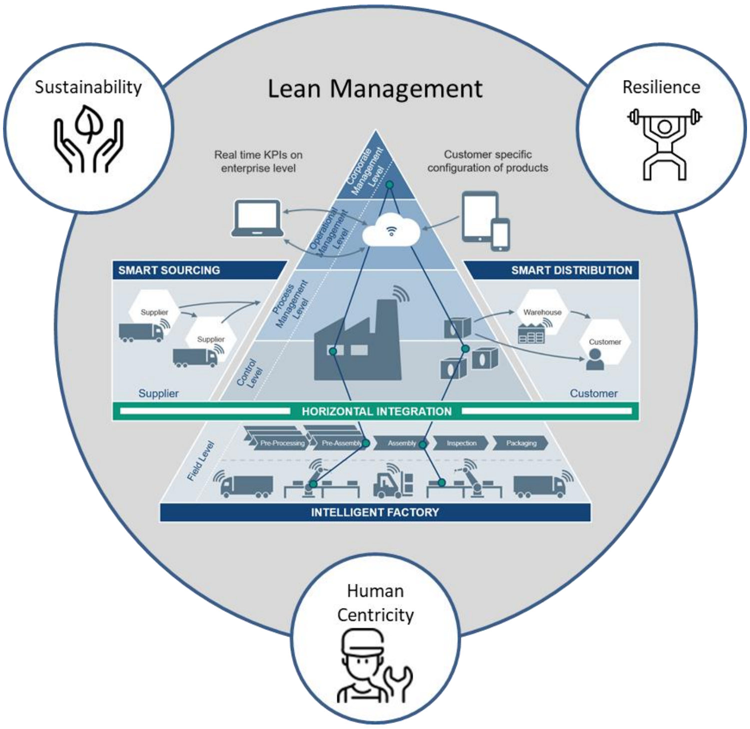

Figure 1: Lean Framework

By Focusing on the Human Centricity aspect of Industry 5.0, the research aims to answer the following Research Questions (RQs).

1. How can an IoT system support the Industry 5.0 vision given by the European Commission?
2. What is the role of the human being in an information system structured with the proposed framework?
3. How can the framework be applied in an industrial setting to achieve Smart manufacturing?
4. How can the framework be transferred to other economic sectors?

Thesis Outline

The present thesis consists of the following chapters:

1. Introduction: This first chapter introduces the authors background, provides a description of the problem, the aims of the research, and lastly the research questions.
2. Production Context: Chapter two provides a brief description of the concepts and technologies this work is based on. More specifically it gives an overview of Enterprise information systems, Industry 4.0 technologies and the Industry 5.0 vision.
3. IoT Framework definition:} this chapter introduces the IoT framework and delves into the intricacies of the developed framework, moreover it provides a road-map for the framework application
4. Secondary Sector (Manufacturing): The fourth chapter presents the first case study within the secondary economic sector (i.e manufacturing), specifically in the realm of collaborative robotics
5. Primary sector (Agriculture): This chapter describes the second case study where the framework is applied in vertical farming, representing the primary economic sector (agriculture)
6. Tertiary Sector (Services): The third case study is presented in this chapter, on applying the framework in the education sector, by using it as an aid to design an IoT course within higher education institutes.
7. Conclusions: The final chapter provides a summary of the work, gives conclusive remarks, highlights the limitations and provides a discussion for future improvements

The utilization of the multiple case study technique in research has gained significant popularity over time and has demonstrated several important advantages. Through the analysis of several instances within a certain framework, researchers can get a more thorough comprehension of the topic being studied. This technique also offers a means to overcome the constraints of individual case studies, such as the incapacity to extrapolate findings to different scenarios or to establish cause-and-effect linkages.

Framework Description:

Overview:

The suggested framework seeks to achieve a 5.0 characterization by determining the structure of the information model, functional model, and information view in accordance with the IoT-A reference architecture. Furthermore, there is a strong emphasis on creating the IoT system around digital twins, highlighting the relationship between actual objects and their virtual counterparts. In order to accomplish these objectives, the succeeding section addresses particular criteria that are in line with the contextual expectations of the 5.0 framework. It is important to highlight that, as defined by the Oxford Dictionary, an asset is an object or property that is considered valuable. Therefore, the term asset is mostly associated with the commercial elements of the Internet of Things (IoT). Given that the framework is a technological instrument, we employ the phrase "physical entity" in lieu of "asset."

The suggested methodology commences with the establishment of generic requirements for industrial IoT systems [1]. These criteria are subsequently supplemented with Industry 5.0 standards, which prioritize human-centricity, sustainability, and resilience. These standards serve as the foundation for the develop of key performance indicators (KPIs). In addition, the authors define a methodology for incorporating these requirements into a domain model based on the Internet of Things Architecture reference model (IoT-A) [2]. This methodology includes two supplementary sub-models: an information model and a functional model. A proposed system architecture is derived from this model and frameworks that have been documented in the literature. The derivations of each general phase utilized throughout the framework are illustrated in Figure 2.

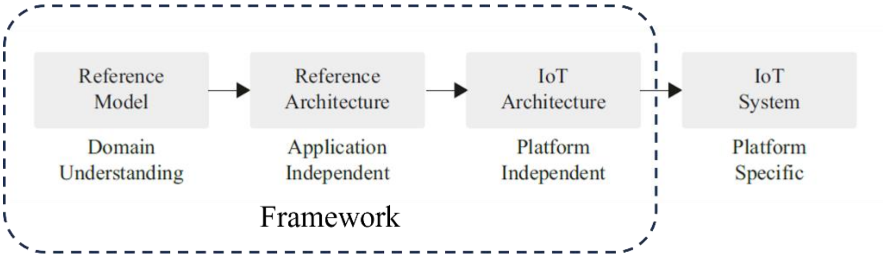

Figure 2: Framework application in IoT development process

Industry 5.0 Requirements

System requirements are typically classified based on their functional and non-functional characteristics. Functional requirements delineate the desired functionalities and capabilities of a system from the user's point of view, whereas non-functional requirements are not directly perceptible to end-users. Functional requirements pertain to the interaction between users and the system, particularly in relation to the user interface. For example, in a banking system, this may involve the ability for users to transfer funds between accounts. On the other hand, non-functional requirements specify the expected performance of the system, with an emphasis on qualities such as performance, security, reliability, and scalability. When discussing IoT systems, there are typically several overarching functional requirements that are defined for the system's development. These can encompass tasks such as acquiring real-time data from sensors, ensuring the dependable transmission of data, and managing devices, among others. The developer implements these requirements as features. To fulfill a single requirement, it may be necessary to have multiple features, and conversely, a single feature can meet multiple functional requirements.

This work prioritizes non-functional requirements essential for Industry 5.0 compliance, rather than supplementing functional requirements for IoT systems. Non-functional requirements are expressions of how functional requirements are achieved. The objective is to formalize the analysis and management of the operation of the IoT system during development, ensuring that it aligns with the functional requirements. In order to adhere to the fundamental principles of Industry 5.0, which include sustainability, human-centricity, and resilience, it is essential that the formalization of I5.0 requirements inherently includes these pillars. The main focus of the discussion is to convert the fundamental qualities of human-centricity, resilience, and sustainability into specific system requirements. The requirements identified, which are based on the vision of Industry 5.0, are intended to be incorporated into the framework. The framework is anticipated to not only streamline the evaluation of system compliance with these requirements but also establish the basis for formulating indicators and metrics to assess Industry 5.0 conformity.

IoT Domain Model

The IoT domain model delineates the essential elements of the IoT. Moreover, it establishes the essential characteristics of these concepts, including their designation and identification, as well as the interconnections among them [3]. The main goal of a domain model is to establish a collective understanding of the target domain and to document the essential concepts and relationships that are relevant to IoT stakeholders. The domain model encompasses diverse elements that serve as fundamental components and enable the representation of different attributes and systems within an IoT setting.

The first aspect is the physical entity, a visible component of the material world that is significant to the user's goal. Physical entities encompass a wide range of objects and environments, such as individuals, animals, vehicles, retail or supply chain items, computers, electrical devices, jewelry, and clothing.

Virtual entities are digital representations of physical entities. Various forms of digital representations exist for physical entities, including 3D models, database entries, and objects (or instances of a class in an object-oriented programming language). Virtual entities can be classified as either active or passive. Active Digital Artifacts (ADA) refer to software programs, agents, or services that possess the ability to access other services or resources. Passive Digital Artifacts (PDA) refer to inactive software components, such as database records, which can function as digital representations of physical entities. In order for an element to be classified as a virtual entity, it must meet two essential criteria:

1. Virtual entities are coupled with a single physical entity, which the virtual entity itself represents; however, a single PE can be represented by multiple unique VE's, providing a distinct representation for each application domain.
2. Synchronization, i.e., VE's must provide synchronized representations of a specified set of features (or qualities) of the physical entity, i.e., a change in the physical world must be reflected in the physical entity and vice versa.

Devices, as technological objects, act as interfaces that connect the digital and physical worlds, enabling a link between virtual and physical entities. As a result, these devices need to demonstrate functionality in both the physical and digital realms. However, the primary emphasis of the IoT domain model is on its ability to enable the monitoring and manipulation of the physical environment through the digital realm. If additional characteristics of a device hold importance, then the device would be represented as an entity. According to the IoT-ARM specifications, there are three main categories of devices: sensors, actuators, and tags.

In the context of the Internet of Things (IoT), resources are software components that either collect data from physical entities or are essential for their operational processes. On-device resources can be distinguished from network resources. On-Device Resources are software installed directly on a device and are connected to the physical entity. These resources consist of executable code specifically created for the purpose of accessing, analyzing, and storing sensor data. Additionally, they include code that enables the control of actuators. Network Resources, in contrast, pertain to resources that can be accessed via the network, such as databases hosted in the cloud. This differentiation emphasizes the crucial significance of both On-Device and Network Resources in the overall structure of the IoT ecosystem.

Services, as defined in the study [4], function as the means to synchronize requirements with capabilities. Within the Internet of Things (IoT) framework, services are limited to technical services that are provided through software. They serve as the intermediary connecting the Internet of Things (IoT) components of a system with other elements within an information system, such as enterprise systems, that are not specifically designed for IoT. The integration of both IoT-related services and non-IoT services enables the complete development of a system. Unlike heterogeneous resources, which rely heavily on the device's underlying hardware for implementation, a service offers a transparent and standardized interface that includes all the necessary functionalities for managing resources and devices associated with Physical Entities. Low-level services are crucial in the service hierarchy as they directly interact with resources and are located closest to the device's actual hardware. Other services may call upon these basic services to provide more advanced features, such as carrying out a business process activity. The hierarchical structure emphasizes the layered composition of services in the IoT spectrum. Low-level services serve as the base, facilitating interaction with device hardware, while higher-level services build upon this foundation to enable intricate functionalities and business processes.

Figure 3 depicts the IoT domain model, emphasizing the connections among the aforementioned elements. The model depicts a physical entity with an attached device. We refer to this device as a "smart device," as defined by [5], to denote an electronic component capable of connecting, sharing, and interacting with its user and other smart devices. Additionally, this definition of a device includes sub-device classes like sensors that can directly interact with IoT systems without requiring an interface, such as a PLC or a gateway. This is particularly relevant in many Industry 4.0 environments currently in existence. A smart device can incorporate either a sensor or an actuator to observe or manipulate a physical entity. The intelligent device utilizes both its own on-device resources and network resources. The user can access these resources through a service that they can either invoke or subscribe to. In the digital realm, a virtual entity is used to represent the physical entity. In some cases, this virtual entity becomes the digital twin entity. The virtual entity is linked to a distinct collection of resources that are made accessible to it through a service. Further details regarding the correlation among virtual entities, resources, and services will be provided in the information model section.

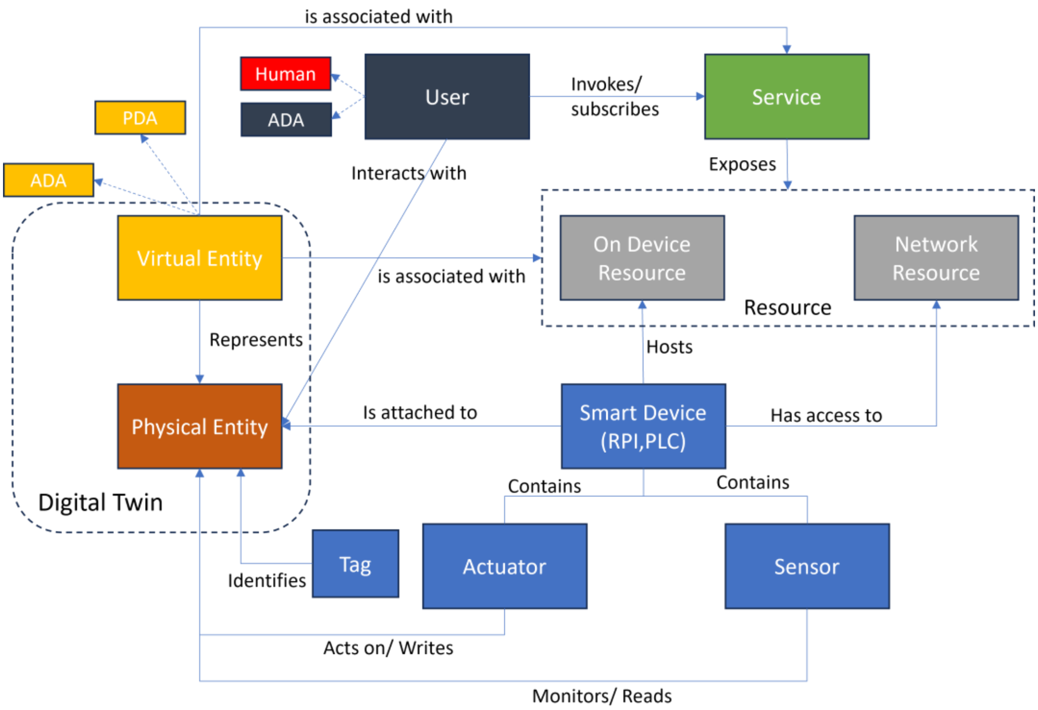

Figure 3: IoT Domain Model

Information Model

The IoT information model encompasses the structure of information for virtual entities, including their relationships, characteristics, and services. The virtual entity is a fundamental concept in any IoT system, as it represents the physical entity or object that is the actual element of interest. The term "information" is employed in relation to the definitions of the DIKW hierarchy [6], wherein "data" refers to values that lack meaningful or useful context. Information serves to provide contextual details for data and addresses frequently asked questions regarding the identity, nature, and timing of events.

The IoT information model elucidates the process of modeling a virtual entity. Figure 4 illustrates that the virtual entity comprises attributes that possess a name, a type, and one or more values that can be associated with metadata. Meta-information encompasses various details such as the unit of measurement, the time and location of data capture, and the quality of the digitization process, specifically referring to the accuracy of the measurement. The virtual entity is connected to the rest of the system (information sources) by its capability to access a service through the service's description, which explains how the service provides information.

We have made a modification to the virtual entity in the IoT-A information model to ensure its compliance with Industry 5.0. This is accomplished by formalizing a precise explanation of how the service, resource, and device descriptions manage information associated with Industry 5.0. Additionally, a framework is established for the Metadata component, which will encompass the meta-information relevant to the previously mentioned Industry 5.0 requirements.

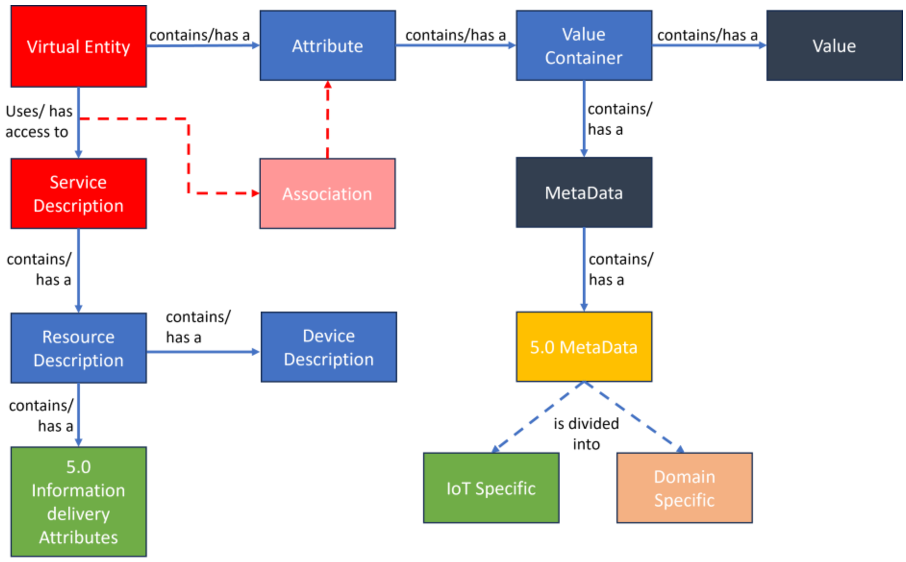

Figure 4: IoT Information Model

Functional Model

Functional Decomposition (FD) is the methodical identification and association of the various Functional Components (FCs) that constitute an IoT system [7]. The main purpose of Functional Decomposition is twofold: firstly, to decrease the intricacy of an IoT system by breaking it down into smaller, more controllable components, and secondly, to understand and illustrate their interconnections. The functional model in IoT-A is described as an abstract framework that helps to comprehend the primary Functionality Groups (FG) and their interactions. This framework establishes the shared meaning of the primary functionalities and will be utilized for the creation of Functional Views that adhere to the IoT-A standards.

The IoT functional model utilized in this framework is derived from [8], which is built upon the original IoT-A functional model and its subsequent modifications proposed by the same authors in [9]. The primary enhancement offered by this "enhanced functional model" is the substitution of virtual entity management with digital twin management. Figure 5 illustrates the functional model, which encompasses eight layers or functional groups. These layers span from the device layer, which is connected to physical entities, to the application layer, which facilitates different user interactions. The device layer encompasses the tangible components, such as sensors and actuators, that are connected to and directly engage with physical objects, as specified by the IoT domain model entity known as a device.

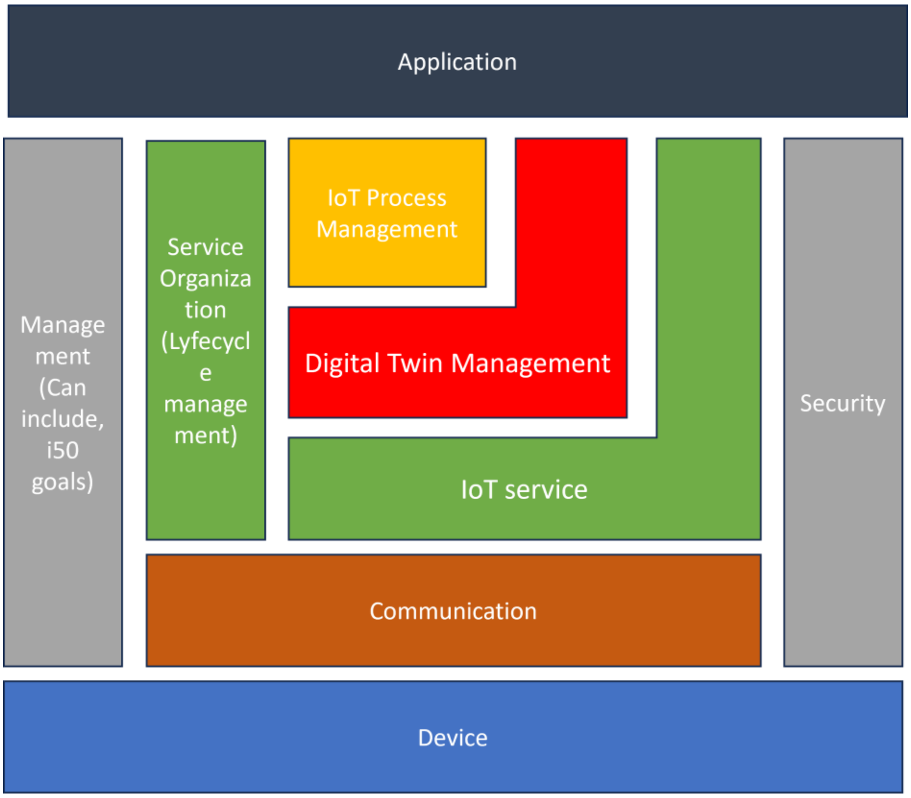

Figure 5: IoT Functional Model

Case Studies

In order to test its applicability and the added value the developed framework brings it has been applied to several case studies belonging to different economic sectors, namely manufacturing, agriculture and education services. The reason for this this is the similarity that can be drawn between these sectors from an IoT point of view where all their sub elements can be modeled as cyber physical systems, furthermore from a business process prospective some of these sectors share similar characteristics.

Manufacturing

The advent of Industry 4.0 technologies has ushered in significant opportunities for enhancing economic and societal transitions in business and elevating living standards. Concurrently, Industry 5.0 builds upon these technological advancements by prioritizing human-centric, sustainable, resilient, and environmentally friendly approaches to industry and society. Digital Twins serve as pivotal enablers in facilitating such transformative endeavors. However, the heterogeneity inherent in manufacturing technologies presents specific challenges in the development and adoption of Digital Twins.

One of the most groundbreaking Industry 4.0 technologies that aligns seamlessly with the Industry 5.0 vision are collabortive robots, which are the technological focus of this chapter. The main goal of this chapter is to propose, assess and justify the proposed framework for manufacturing technologies, such as collaborative and mobile robots. More specifically this part of thesis attempts to apply the framework to a manufacturing process consisting of muliple collaborative robots, while focusing on the process as whole and not merly its individual components to provide an example of a "process digital twin" rather than a compnent specific digital twin (Product or equipment)

A process digital twin represents a specialized iteration within the realm of digital twins, honing in on the meticulous emulation and refinement of a specific operational process or workflow within an organization. Unlike traditional digital twins, which predominantly mirror the physical attributes and functionalities of tangible assets or systems, a process twin delves deeper into the procedural intricacies, nuances, and performance dynamics of a targeted process. At its core, a process twin serves as a dynamic simulation model that meticulously replicates the sequence of activities, dependencies, decision points, and resource allocations inherent to a particular process. By harnessing real-time data inputs, historical trends, and advanced analytics algorithms, it offers stakeholders a comprehensive digital representation of how the process unfolds in various scenarios, facilitating deeper insights, informed decision-making, and performance optimization.

Furthermore, a process twin operates as a living entity within the digital ecosystem of an organization, continuously evolving and adapting to reflect the ever-changing operational landscape. Through ongoing synchronization with real-world data streams, feedback loops, and optimization algorithms, it not only captures the current state of the process but also facilitates predictive analysis, scenario planning, and iterative improvement initiatives. In essence, the concept of a process twin epitomizes the synergy between digital technologies, domain expertise, and process optimization methodologies, empowering organizations to gain granular visibility into their operational workflows, identify inefficiencies, mitigate risks, and drive continuous innovation. By fostering a holistic understanding of process dynamics and fostering a culture of data-driven decision-making, process twins play a pivotal role in enhancing operational excellence, agility, and competitiveness in today's dynamic business landscape.

The existing research on digital twins of collaborative robot processes has made significant progress in areas such as integration and control [10], dynamic modeling of robot joints [11], and human-robot interaction [12]. However, there are still some key research gaps that need to be addressed. Firstly, there is a need for further development of digital twin models that can accurately simulate the complex dynamics of collaborative robot systems, including the interactions between human and robot [13]. Secondly, the current focus on kinematic-level digital twins needs to be expanded to include the integrated system dynamics of collaborative robot processes [11]. Lastly, there is a need for more research on the practical implementation and real-time monitoring of digital twins in collaborative robot processes, particularly in the context of small and medium-sized enterprises (SMEs) [14].

This chapter addresses the last two gaps by providing a real-world implementation of a digital twin that includes an error handling mechanism that is not limited to the collaborative robot but rather extended to the whole collaborative process. While many theoretical frameworks exist for collaborative digital twins, a practical case study can provide a clearer idea of the tangible benefits obtained in a material handling process. Moreover, while existing research focuses on performance monitoring this work explores how digital twins can actively identify and address process errors in a collaborative setting. Finally moving beyond static task assignment, this chapter investigates how digital twins can dynamically allocate tasks based on real-time data and error detection, contributing to adaptive and optimized workflow.

Developed Digital twin model

The framework has been used to develop the digital twin showed in figure 6 below. The Digital twin of the process was developed in flexsim, which is a versatile platform widely used in the realm of discrete event simulations [15]. It has been deemed suitable for this implementation due to its 3D modeling environment that allows the recreation of the robots, workstations, and material flow, fostering a comprehensive understanding of the process dynamics.

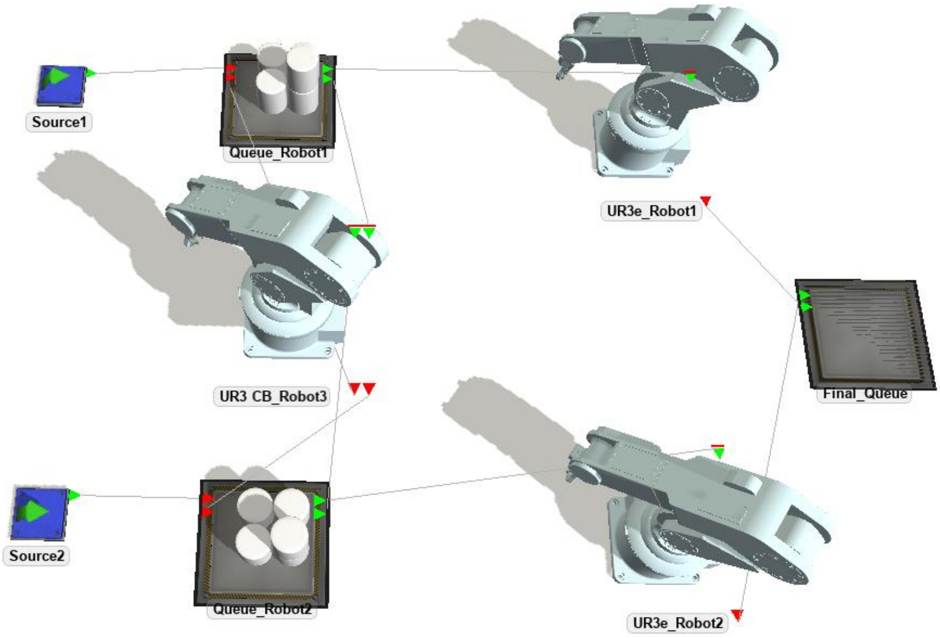

Figure 6: Virtual Model of Digital twin

Agriculture

According to United Nations projections, the world's population is expected to reach approximately 8.5 billion by 2030 and is predicted to further rise to 9.7 billion by 2050 [16]. The considerable increase in population requires a substantial increase in agricultural production to guarantee food security. Nevertheless, the growth of this production is limited by environmental crises and the detrimental consequences of traditional open-field agricultural methods [17, 18]. In order to address these difficulties, the implementation of advanced agricultural methods, such as aeroponics, presents a hopeful opportunity to enhance the efficiency of resource allocation. As stated in [8], a smart farming system can be defined as a cyber-physical control cycle that effectively combines sensing and monitoring, intelligent analysis and planning, and the intelligent management of farm operations across all relevant processes. Nevertheless, the effective execution of these contemporary agricultural methods is highly dependent on accurate and current data regarding farm activities. Digital twins (DTs) play a crucial role in improving and optimizing agricultural practices by providing real-time insights and data, enabling informed decision-making. Within this particular framework, DTs can assist farmers in acquiring data pertaining to the fields and overall agricultural patterns, thereby enabling them to make more informed decisions regarding crop management strategies. Data collection enables the prediction of crop yield, growth stage, nutrient content, and weather conditions.

The use case pertains to soilless farming in controlled agricultural environments, commonly known as vertical farming, which is distinguished by extensive utilization of advanced technology. Lettuce crops are cultivated in a meticulously regulated environment where all factors essential for plant growth are artificially supplied, including growth medium, irrigation, nutrition, and climatic conditions. The plants are cultivated within a growth chamber comprising multiple sensors and actuators that are linked to a controller. Each growth chamber, along with its corresponding sensors, actuators, and controller, is referred to as a module. Every module transmits its data to a distant database for the purpose of storing and conducting more sophisticated analysis. Furthermore, a production planning system is linked to the Internet of Things (IoT) system through a dedicated application programming interface (API) in order to obtain plant data. The comprehensive Internet of Things (IoT) system is depicted in the context diagram illustrated in Figure 7.

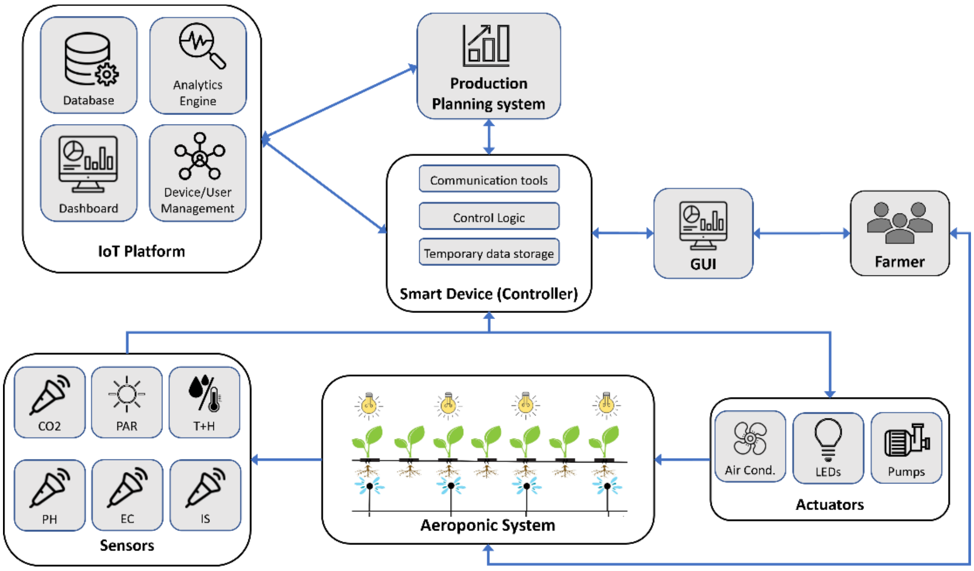

Figure 7: Vertical Farming IoT Context Diagram

Developed system architecture based on framework

By integrating the components outlined in the domain model, the information structure emphasized in the information view, and the functional functions illustrated in the functional view, a system architecture is formulated as illustrated in Figure 8. This system comprises an assortment of effectors and sensors that are interconnected via an IoT platform and Raspberry Pi.

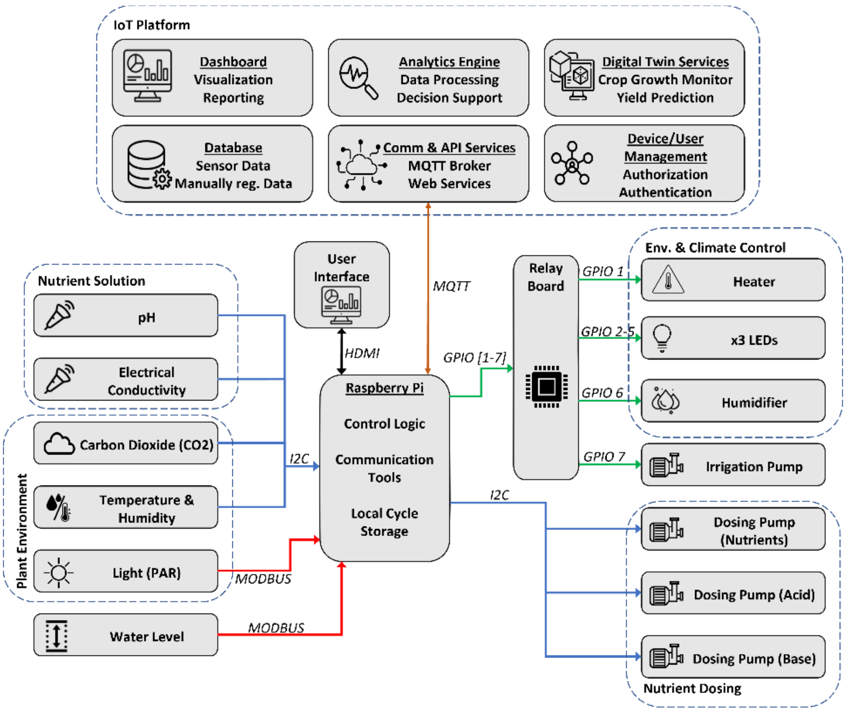

Figure 8: System Architecture for Aeroponic system

Education

The Third Case study is in the Teritiary sector of education, more specifically it deals with the issue to Propose a quantitative method in order to set a multicriteria evaluation of the course outcomes, and developing course management IoT platform that is easy understandable by students.

Within the dynamic realm of Industry 4.0, there is an increasing need for proficient professionals who possess a comprehensive understanding of Internet of Things (IoT) technologies. Nevertheless, educational environments encounter a substantial obstacle in the form of inadequate and ineffective approaches to teaching practical IoT knowledge and skills. This chapter outlines a methodology for conceptualizing and executing an Internet of Things (IoT) laboratory wherein learners can gain practical experience and understanding of various elements comprising an IoT environment. These elements include sensor data analysis, IoT platform development, and messaging protocol configuration. A Cyber-Physical System (CPS) framework is utilized to integrate instructors, classrooms, and resources in order to establish a comprehensive learning environment. Bloom's taxonomy is utilized to evaluate the effectiveness of the proposed method with respect to the acquisition of knowledge and development of cognitive abilities. Through the evaluation process, the benefits of a hybrid learning environment that incorporated both in-person and online instruction were revealed. The case study is administered to first-year engineering students in a course of higher education. The results obtained from this study establish the foundation for an Internet of Things (IoT) training program that can be remotely delivered. This contributes to the progress of IoT education and ensures that students are adequately prepared for the dynamic environment of Industry 4.0.

Moreover, the proposed IoT framework is implemented in this case study to validate its potential usage in service sectors. More specifically the framework is used to analyse the the CPS that integrates various informatics aspects of the didactical eco-system, this includes the IoT system developed by the students and how their system fits with the remainder of the information flows within the classroom experience.

The main objective is to focus on the principles of designing and developing an IoT platform specifically for managing industrial resources, known as an IIoT platform. This will be achieved by combining theoretical and practical explanations based on the lecture program, along with continuous analysis of the class's interaction with the IoT system created for the course. Although the system does not meet manufacturing requirements, it still shares significant similarities with IIoT systems. The course is structured and implemented using a CPS model, which incorporates an IoT system. This IoT system can be considered an IIoT system due to the inclusion of physical entities such as teachers, students, and the system under analysis. These entities are closely integrated with the IoT system, similar to an industrial setting.

Educational Taxonomy

As a framework for classifying statements of what we expect or intend students to learn as a result of instruction, a taxonomy of educational objectives is proposed. For this work, a revision of Bloom's taxonomy proposed by [44] is used. Any objective is represented in two dimensions shown by Table. 1, called taxonomy table and representing two learning process dimensions: the Knowledge and the Cognitive ones. The knowledge dimension consists of the following subcategories: (A) Factual Knowledge referring to basic elements, (B) Conceptual Knowledge referring to inter- relationships among such elements, (C) Procedural Knowledge that is how to do something, and (D) Metacognitive Knowledge that refers to self-awareness and independency in decisions making (cognitive) processes, i.e., this knowledge helps learners to monitor their own progress and take charge of their learning experience as they read, write and solve problems in the classroom. The cognitive process dimension is made by the following subcategories: (1) Remember or long-term memory, (2) Understand the meaning of instructional information, (3) Apply and use adequate procedures for each scenario, (4) Analyze and detect relationships between parts, (5) Evaluate based on criteria and standards, and, finally, (6) Create new solutions according to requirements. Therefore, Table. 1 is a formalization of the aims of the proposed course according to Bloom's structure and it provides a description of the learning objectives for every element of the table.

Cyber Physical System Structure of Course

The course is modeled as a CPS (for many aspects it can be assumed as a Digital Twin of it) [45], in which students, professors, educators, technicians, laptops, servers, and all other human and machine resources of the course dynamically interact with each other to achieve both local and global goals. Following standards provided by ISA-95 [46], Figure 9 shows the organization of the CPS refers to the course. Referred to the professor is the level of planning, that is, the level of legal responsibility, or delegated by an organization such as a university or academy may be, and thus the level with the highest degree of complexity, needing to interact tactically or strategically and, therefore, for a course of training, with frequencies on the order of magnitude of the week or month. The execution level is given by operative standards and monitoring and control systems applied by the human organization that manages the course: a school, a university or an academy, and any other type of organization that managed the entire student lifecycle. The functional data flow model is given by mails, chats, in presence or remote lectures (a datum is everything that can generate an useful information regarding the CPS under analysis, i.e., the course), any material used during the lectures or provided for activity extra than lectures, any material or repository used for students evaluations (exams paper sheets, digital test, surveys, oral examinations, …), and, finally, any information resources provided by the overall organization (for example a digital platform used by university to manage students, professors and researchers). The class control level refers to lectures, including theory, exercise, evaluation, projects and all the possible activities involved during the lectures, and the re- sources implied like physical components to be monitored, sensors, actuators and edge controlling tools.

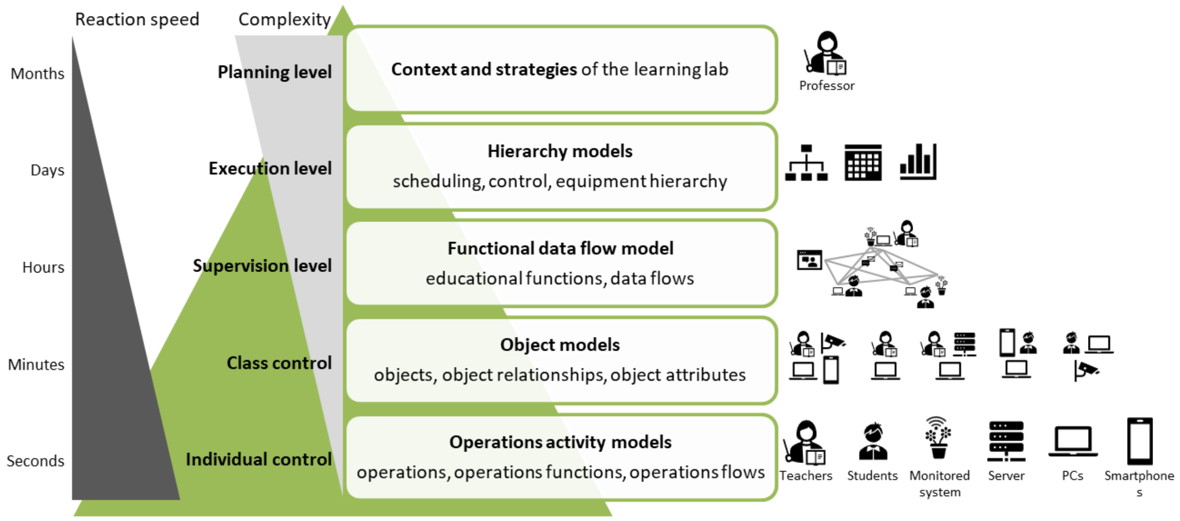

Figure 9: CPS of the Course based on ISA 95

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