Available online at www.HEFJournal.org

Journal of Human, Earth, and Future

HUMAN, EARTH AND FUTURE
Ital Publication

ISSN: 2785-2997

Vol. 2, No. 4, December, 2021

Review Article

Review of Pairing Exercises Involving a Real Event and its Virtual Model up to the Supervision of Complex Procedures

Adel Razek [1*]

[1] *Senior Researcher, Group of Electrical Engineering – Paris (GeePs), C.N.R.S., Paris-Saclay and Sorbonne Universities, GeePs, CentraleSupelec, 11 rue Joliot Curie, F 91192 Gif sur Yvette, France*

Received 28 September 2021; Revised 14 November 2021; Accepted 19 November 2021; Published 01 December 2021

Abstract

Matching of a real procedure with its virtual model is performed in a variety of natural and artificial situations. The exercise of this concept in science, technology, and innovation is assessed in this review. This involves off-line as well as real-time pairing practices. The off-line case regards mainly the management and ruling of elegant theories; computing tools imitating physical paradigms; and computer-aided design. The real-time pairing concerns in particular natural phenomena, online matching devices in autonomous automated systems and in complex procedures. The article is constituted of three consequential divisions: the observation-theory framework; innovations relative to matching concepts; and observation-modeling matching in complex procedures. The paper first presents a framework for the observation-theory pair. This will highlight the complementary aspect of such a duo, its ability to validate or invalidate an elegant theory, its use to explicate an observation, and finally, how a theory can unify different observations into an elegant mathematical representation. At the end of this section, innovative computing tools that imitate physical paradigms are introduced. In the following section, the paper then illustrates recent innovations relating to the notions of pairing concerning theories addressing natural functions and design approaches in industry, as well as the task of matching virtual estimates to their actual values in automated systems. The role of the observation-modeling pair in complex procedures is then investigated in the last part. In this frame, matched twins in complex procedures are examined, highlighting the concept of the digital twin. Examples of the use of this concept are presented to illustrate the range of its applications in different domains, including energy, production, maintenance, mobility, healthcare, smart cities, etc.

Keywords: Matching; Computer-Aided Design (CAD); Observation; Virtual Model; Complex Procedure; IoT; Uncertainaties.

1. Introduction

Cognitive deduction or virtual modeling can represent the observation of an object, a phenomenon, or a procedure. The matching or mirroring of an observable and its virtual representation has been and still is practiced in many natural and artificial situations. The observable and its matched model are ideally closely related, but each of the observing and modeling activities can contain uncertainty. Humankind and other creatures, as well as further natural items, often exercise the practice of sensory observation, experience, or manipulation. At the same time, from this practice, they will possibly use deduction (or mimesis) skills to manage their evolution, their self-protection, their comfort, and their survival. The activity of deduction associated with observation is one of the first natural duties born in the world.

* Corresponding author: adel.razek@centralesupelec.fr; a.razek@ieee.org

http://dx.doi.org/10. 28991/HEF-2021-02-04-010

Deduction, prediction, or reasoning (modeling) coupled with observation can be encountered in inherent natural events or fabricated procedures. Such a couple often works by using a pairing or imitation process. If the two members of the couple (observation and modeling) are interconnected by a bidirectional information link, this permits through matching, improving their individual capacities and countering their uncertainties. For example, in nature, based on observation, cases of mimetic simulation (adaptive imitation strategy) are very frequent, permitting camouflage [1]. This allows creatures to blend into their environment, which could be variable, allowing the creatures to take on the appearance of their surroundings at all times. Actually, the mimetic individual adopts the look and the colors of his surroundings and remains immobile to go undetected by his predators. In addition to color, some organisms are also able to take the form of the object of their standpoint. Many insects can thus take the appearance of branches or leaves. This defensive imitation gives the individual protection against predation. We can also find cases of offensive imitation, which allow the mimetic individual to hunt their victim without being noticed. The junction between observation and mimetic capacities is practiced in a successive manner that permits the improvement of these capacities.

Many recent innovative technological processes use the concept of pairing physical operations (observable) with their mirror models (virtual). The depth of match is closely related to the fidelity of the virtual model to the real physical object. Such consistency implies the nature and the capacity of the model to take into account the variation of the physical element due to its operational and environmental conditions. Consequently, a complete parameterized model taking into account all the phenomena governing these conditions becomes necessary and the model uncertainty involved in such a circumstance will be of the knowledge type. Currently, in very viable fields, where the large amount of creations and the increasing importance of digital components in automated sets offer an opportunity to achieve higher production levels [2]. Digital technologies allow simple integration of connected smart modules into the set. These tools allow remote and real-time observation and control of devices and processes through arrangement frameworks and therefore offer a more direct fusion and harmonization of the material and virtual spheres. The practice of digital technologies allows the virtual projection of products and processes [3]. The large amounts of data generated can be processed, studied and evaluated by optimization tools so that they can be made accessible to an organization in real time. The combination of physical and virtual elements can be achieved by means of the concept of pairing physical operations with their mirror models - digital twin (DT). DT is gradually being studied as a way to improve the functioning of physical units by taking advantage of computational practices enabled through those of virtual pairing. Bidirectional links feed data from the physical element to its virtual image, and processes from the latter to the physical element [4]. This pairing (matching) sequence is a kind of mirroring of real and virtual items. The virtual one allows various specific tasks of simulation, test, optimization... [5]. Since Michael Grieves introduced the concept of digital twins in 2002, which quickly established itself in various fields; the number of publications about its applications has grown significantly.

The notion based on the pairing of a real procedure and its virtual model, has been and still used in various situations. The investigation of such practices in natural, scientific and artificial events is reviewed in this study. The focus of this review is to illustrate the fact that the coupling of a real and its virtual model is crucial in an assortment of natural and man-made circumstances. To demonstrate this fact, we have selected examples from among many cases representing specific categories in the different sections of the review. This investigative review aims to shed light on several points. The first is the illustration of the magnitude of the concept of adequacy of a real to its virtual representation. The second is the confirmation that the practice of matching is decisive in different forms in many scientific fields as well as for the management of complex procedures. The last concerns the assessment of the behavior, the impact and the management of the uncertainties on both sides and their link of a matched twin and more generally in the pairing of a real and its virtual representation.

The present paper is structured in three consequent parts: the observation-theory framework, the resulting innovations relative to matching concepts and the resulting observation-modeling matching in complex procedures. The paper first presents a framework for the observation-theory pair. This will underline the complementary aspect in such a duo. In addition, we will see how observation makes it possible to validate or invalidate an elegant theory. Moreover, we will discuss how a theory can confirm and explain an observation. As well, how a theory can unify different observations in an elegant mathematical representation. At the close of this part, innovative calculating tools imitating physical paradigms are demonstrated. The second part of the paper illustrates recent innovations relating to the notions of pairing concerning theories addressing natural functions, approaches of industrial design as well as virtual estimates and their actual values in automated procedures. In these two parts, the examples in support of the demonstrations have been selected from numerous existing cases so as not to unnecessarily lengthen the presentation. The third part deals with the observation-modeling couple in complex procedures. Following to the analysis of the last part relative to automated procedures, we will illustrate the need to improve the matching of virtual models to their real procedures. The matching twins in complex procedures are then examined, which sheds light on the concept of digital twin. Next, given the huge literature in the field, we reviewed a limited number of published works in different fields to illustrate the range of applications of this concept. These include energy, mobility, predictive maintenance, healthcare, smart cities, etc.

2. Supervision of the Observation-Theory Duo

Relevant consequences in many theoretical and practical conceptions are authentically associated with the observation-theory duo. These two evaluation concepts could be used separately or in pairing, imitation and / or validation duo. This section aims to examine how observables and their theoretical models are close to each other and how the two items of observation and theory reinforce each other and mutually shape a duo. First, we examine the complementary behavior of the duo. Then we discuss the actions of the duo in the frame of managing of universal theories involving validating, explaining and unifying activities. At the end of this section, we assess innovative computing tools imitating physical paradigms governed by the duo.

2.1. Complementarity of Observation and Theory

In the commencement of this section, we propose to develop a rational notion on the observation-theory duo. Observation or theoretical modeling can be autonomous in areas of exploration that are routinely viewed as ideals. In the common situation of real practical landscapes, we exercise the two investigative concerns on a complementary base. Therefore, yet in areas that usually require observation, it is generally not self-sufficient and it requires modeling for further investigation. Claude Lévi-Strauss (1908-2009) stated, in connection with solitary observation, in "*Structural Anthropologie*" [6], that structural researches in social sciences are implicit outcomes of modern mathematics. In addition, for the fields currently necessitating theoretical modeling, this one is not generally either autonomous and it requires to be validated by observation, simply to be truthful. The philosopher Maurice Merleau-Ponty (1908-1961) affirmed, with regard to isolated theories, that science takes the world as an object of expertise "dissociated" from the materializing element, also that the theory and the spirit are paired and that scientists see the world with a mind linked only to the theory, see for example [7].

2.2. Observation Validating or Invalidating a Theory

In theoretical investigations, it is universally recognized that theories are conditioned on critical fundamental judgments considering the theory-observation duo. Therefore, on the whole, a theory is only supposed to be instituted after it has been corroborated by observation. Moreover, such a theory remains true until disagreement with another observation. Numerous situations of observation validating or invalidating a theory are well recognized in science. We will take two examples among many others, each illustrating one of the two cases of validation and invalidation.

2.2.1. Theory of Superposition States in Quantum Mechanics

Considering first the case of observation validating a theory, most of the eminent findings are in this class. Surveying, the case of the "theory of superposition states" in quantum mechanics proposed by Schrödinger in 1926 [8], (Nobel 1933). The Schrödinger equation is the main motion equation in quantum mechanics. The wave function within this equation shows a quantum superposition, which is the law that any multiple quantum states can be superposed, resulting in another authentic quantum state and vice versa. This concept mathematically belongs to the solutions of the Schrödinger equation. Schrödinger proposed a thought experiment that characterized the quantum superposition, Schrödinger's famous cat. The Schrödinger equation is applied to acquire the authorized energy levels of quantum mechanical systems. The wave function provides the probability of locating the particle at a specific position. Wineland et al. [9] and Brune et al. [10] validated this theory a little before 2000 (Nobel 2012: for revolutionary experimental methods, which make it possible to measure and manipulate individual quantum systems). These experiments played a huge role in the birth of the understanding of quantum physics. Technical growing has enabled these experiments. Wineland's ion traps [9] and the cavity quantum electrodynamics [10] of Haroche (Brune et al. 1992) were the pioneers in this field which is now well spread all over the world. It was only after such validation that this theory was established until a possible future invalidation.

2.2.2. Treatise of JC Maxwell and the Hall Effect

Concerning the situation of invalidation by observation of a theory, one can consider the example of the "Hall Effect" proposed by Hall (1879). This proposition resulting from the experiment concerns the relation between the force and the current in a conductor. It invalidates part of the "treatise on electricity and magnetism" proposed by Maxwell in 1873 [11, 12]. Note that this theoretical treatise is the result of the intelligent unification of the three experimental laws of Gauss, Ampère and Faraday (see section 2.4.).

Hall (1879) revealed and experimentally confirmed in his thesis work, the effect of force on current (distribution) in a conductor immersed in a magnetic field [12]. Maxwell thought there was no such effect. We notice at this point that Maxwell's treatise enhanced the three experimental laws (by mathematical unification, see 2.4.) while such a treatise itself was perfected (by partial invalidation) by means of experimental observation. This clearly illustrates how well the observation-theory duo fits together.

2.3. Observation Confirmed and Explained Later by Theory

One can encounter the circumstances of first realizing a discovery from experiment and then establishing the theory explaining and confirming such discovery. Usually, we come across such a case in a "serendipity situation": we discover something while looking for another. A representative illustration is the revealing of superconductivity phenomenon by Kamerlingh Onnes (1853-1926), (Nobel 1913: for his investigations on the properties of matter at low temperatures which led, inter alia, to the production of liquid helium) [13]. In this circumstance, he was studying the problems relating to the effects of low temperatures on electronics. He could not imagine the phenomenon he observed. All the theories confirming and explaining the superconductivity phenomenon followed his discovery.

2.4. Theory Generalizing and Amalgamating Observations

Various traits can distinguish theories smartness like enhancing, generalizing and fusing. An example of such smartness can be seen in the group of Maxwell's equations that are an illustration of the finest elegant compound theories. These equations created by James Clerk Maxwell (1831-1879) encompass a unification of three experimental laws discovered by three of his predecessors. They are Carl Friedrich Gauss (1777-1855), André-Marie Ampère (1775-1836) and Michael Faraday (1791-1867). The union of Maxwell's equations was only possible, because Maxwell noticed how to progress forward from the work of his predecessors, by introducing into an equation a lacking link, declared displacement current, the occurrence of which guarantees the coherence of the integrated organization [11]. This shows a considerable characteristic of union intelligence.

2.5. Innovative Computing Tools Imitating Physical Paradigms

Different computing tools use imitation of physical paradigms. This is the case of neuromorphic and quantum computing technologies. These two theoretical modeling tools originate straight from two paradigms belong to neurosciences and quantum physics.

2.5.1. Neuromorphic Computing

The brain is an extremely complicated system that performs tasks much faster than the fastest digital computers. Neuromorphic computing uses models inspired by the brain. These are operations built on biologically inspired or artificial neural networks. Neuromorphic computers can perform complicated calculations faster, with higher power efficiency, and with a smaller size than traditional architectures. They have the ability to develop real-time learning algorithms qualified to operate online comparable to real brains. This has shown potential due to the similarities of biological and artificial neural networks (BNN and ANN) [14]. The growing appeal of deep learning and neural networks has encouraged a race to develop artificial intelligence (AI) hardware dedicated to neural network computations [15]. These tools are widely used in optimization, diagnostics, images, machine learning, AI, etc.

2.5.2. Quantum Computing

The concept of states in quantum mechanics is the basis of “quantum computers”, a term coined by Richard Feynman [16]. A conventional computer uses transistors to process information in the mode of sequences of zeros and ones (binary). A quantum computer uses qubits through the laws of quantum mechanics relating to the states of particles. For a qubit, a particle can be in several states simultaneously (superposition). A different phenomenon affects the states of particles called entanglement. That means when two qubits in an overlay join; denoting the state of one depends on the state of the other. Because of these phenomena, a quantum computer can accomplish 0, 1, or both states at the same time for a qubit or an entanglement of qubits. Thus, a quantum computer with n qubits can operate instantly on all 2n possibilities; however, a standard computer with n bits can run on only one of these 2n possibilities at a time. So the first one giving us more processing power. Scientists agree that quantum computers are theoretically exponentially faster and much smarter at cracking codes that are apparently impossible for classical technology [17, 18].

2.6. Ending Remarks On the "Observation-Theory" Duo

From the last subsections, we can summarize the characters of the "observation-theory" duo as follows. A mathematical theory requires observation simply to be credible and the second requires the first for more universal, comprehensible and smarter theories. Figure 1 shows a summary scheme on this duo illustrating its different implicated actions. Besides, we have seen how imitating mathematical tools can be originated from paradigms governed by the duo. Note that all of the duo activities discussed in this section are categorized into off-line pairing practices.

In addition, the particularities of this duo are valuable for the ideas of several innovative research theories, industrial design tools and automated processes; this will be object of the next section.

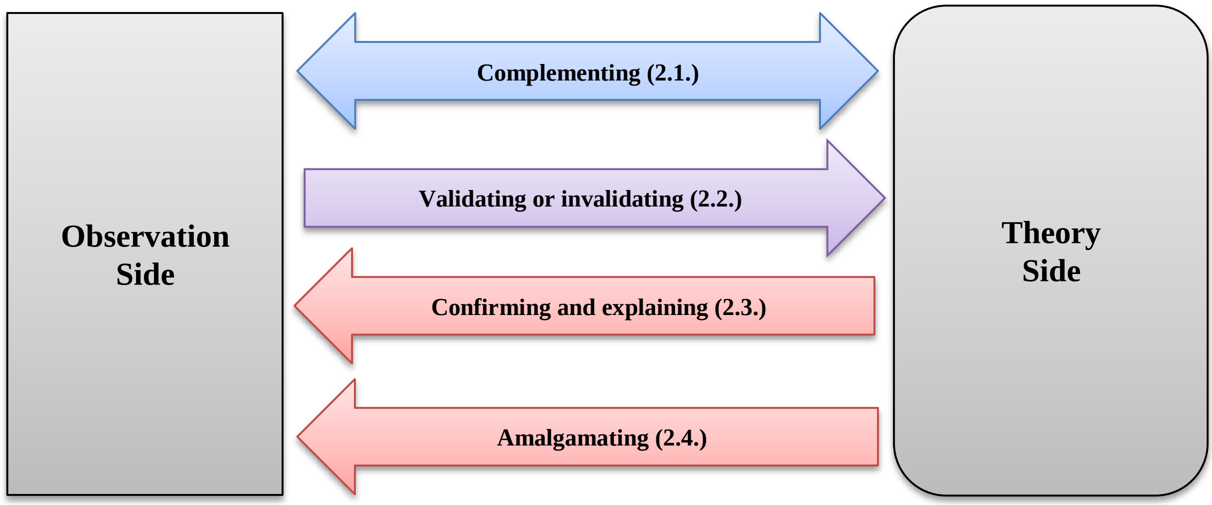

Figure 1. Summary scheme on the observation-theory duo activities

3. Innovations Relative to Matching Concepts

Recent innovations relating to the notions of pairing have been fashioned concerning functional approaches and automated processes.

3.1. Modeling Matching Observation Functional Approaches

Modeling matching observation is driven in theories approaching operations and industrial design approaches. Two examples, one for each of these two cases, are considered; the Bayesian Brain theory in neuroscience and virtual models of industrial prototypes for computer-aided design. The first concerns a natural process practicing a real-time matching while the second regards an artificial procedure exercising an off-line matching.

3.1.1. Bayesian Brain Theory

As mentioned in Section 1, creatures often engage in the practice of sensory observation and simultaneously use deductive skills to manage their natural lives. Also that the activities of deduction and prediction associated with observation are one of the first natural duties born in the world.

Bayesian brain theory in neuroscience is widely recognized with regard to brain function. This theory briefly indicates that after a cerebral sensory observation (vision, smell, hearing, etc.), the predictive model of the brain generates, from the data learned, cerebral perspectives of the phenomenon or object observed. Moreover, only error (prediction versus observation) is involved in the spread neuronal discharges acting in an adjustment procedure to identify the nature of such an observation. Note that in this case, the predictive model is managed by a sophisticated supercomputer (Human brain: 10^{11} neurons each linked to 10^{4} others).

Bayesian theory of the brain explains the cognitive capacities of the brain to work under circumstances of uncertainty to attain the optimum advocated by Bayesian methodologies [19]. It is presumed that the neural structure keeps interior probabilistic models revised by sensory information via neural processing [20]. The Bayesian inference functions at the level of cortical macrocircuits, which are structured consistent with a hierarchy that reflects the scenes of observable objects that surround us. The brain encodes a model of these objects and makes predictions about their sensory input: predictive coding. The corresponding areas of brain activity will be close to the upper hierarchy. The links from the upper zones to the lower ones then convert a model describing the scenes. The lowest level predictions are compared to the sensory inputs and the prediction error is distributed up in the hierarchy. This happens simultaneously at all hierarchical levels. Predictions are sent down and prediction errors are sent back in a dynamic process. The prediction error indicates that the actual model did not completely consider the input. Readjusting the next level can increase accuracy and reduce the prediction error [21, 22].

From the upper outline of how the neural system operates under uncertain conditions, it is clear that the matching duo prediction-observation is entirely affected in a two-way real-time pairing process. This involves a top-down adjustment of perception by minimizing the formation of the prediction error as illustrated in figure 2. All levels of neural edifice comprise probabilistic models renovated by sensory information observed through iterative neural processing matching.

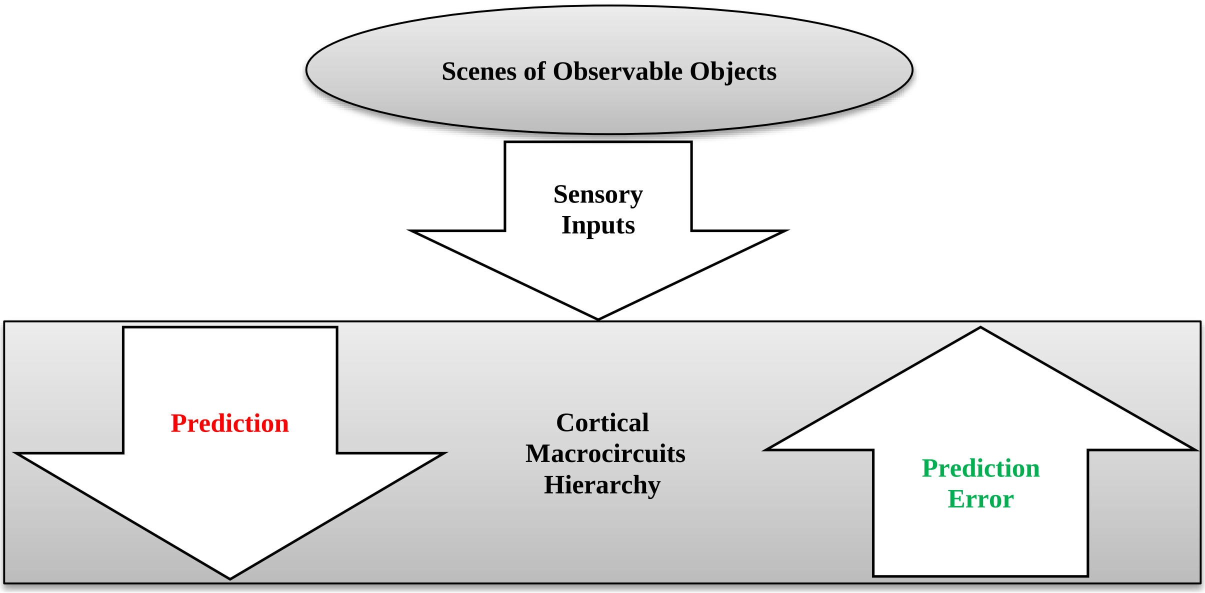

Figure 2. Top-down adjustment of perception by minimizing the prediction error in a two-way real-time pairing process

3.1.2. Real Prototype versus Virtual Emulating Model

For several decades, there has been a trend in research to move from real prototypes to virtual emulation tools. It becomes possible that some investigates of a physical system can be simulated using computers. By understanding and imitating the behavior of a particular system on a computer before physical creation, the number of tests and experiments can be greatly reduced. Therefore, virtual system design provides a useful way to build systems without the need for in-depth physical evaluation.

In recognition of these advantages, a number of virtual systems have been developed. This work was carried out for the purpose of computer-aided design (CAD) or to simulate the behavior of the system. Some of these simulations were performed to build a complete model, while others were performed to simulate a specific type of application. Examples of such virtual models can be found, e.g. in the case of electromagnetic systems, see for example [23-28].

The reliability of the behaviors provided by virtual systems strongly depends on the level of emulation of the physical systems. However, due to the complexity of the system and the uncertainty of the process, it is often difficult to build a realistic virtual system compared to its specific physical counterpart. The complexity of a system is related to its operation as well as its environmental conditions. The uncertainty of the process is related to the precision of the virtual model (mathematically and numerically). In such a case, we need composite 3D virtual models taking into account all the physical phenomena involved in the functioning of the system, see for example [29-32]. Note that the process described here involves an off-line pairing practice.

3.2. Automated Procedures

In various automated procedures, sensors are commonly used to determine specific operating variables and system parameters. However, in some situations, estimation can be used for variables or parameters that are difficult to measure. Accurate parameter estimation plays a crucial role in the operation of automated systems. The implementation of an estimation algorithm on an on-board controller platform requires the simplification of the mathematical model of the system. This is why we often have to perform this estimate offline to achieve reasonable accuracy. For this, we can use Computer Aided Design (CAD) tools based on complete models representing the systems in their environments (see section 3.1.2.). In such a case, the pairing of the estimated parameters with the actual parameters would be successful. However, the problem is that pairing cannot be instantaneous with the system working. Various studies have proposed a compromise between the precision of the estimation and the speed of the matching by implementing, more sophisticated algorithms, on specialized platforms of on-board controllers. For this, in automated systems, different types of observers, state filters and controllers are proposed as estimators. The robustness of the controller is supported by the use of adaptive methods. Large capacity microcontrollers can improve the design of the controller board and the software required for estimation, which iteratively targets matching simultaneously [33-40]. Figure 3(a) illustrates a conceptual representation of such iterative real-time matching. Figure 3(b) shows an example of interactive autonomous image guided drug release system. This system is using minimally invasive technology involving precisely restricted drug delivery using an integrated image guided drug release implant [40]. The information data collected by the imager (sensory observation) are processed by sophisticated algorithms and make it possible to provide feedback data retracing (iterative matching) the location necessary for the implant. The feedback control information along with the power is transmitted wirelessly to the implant.

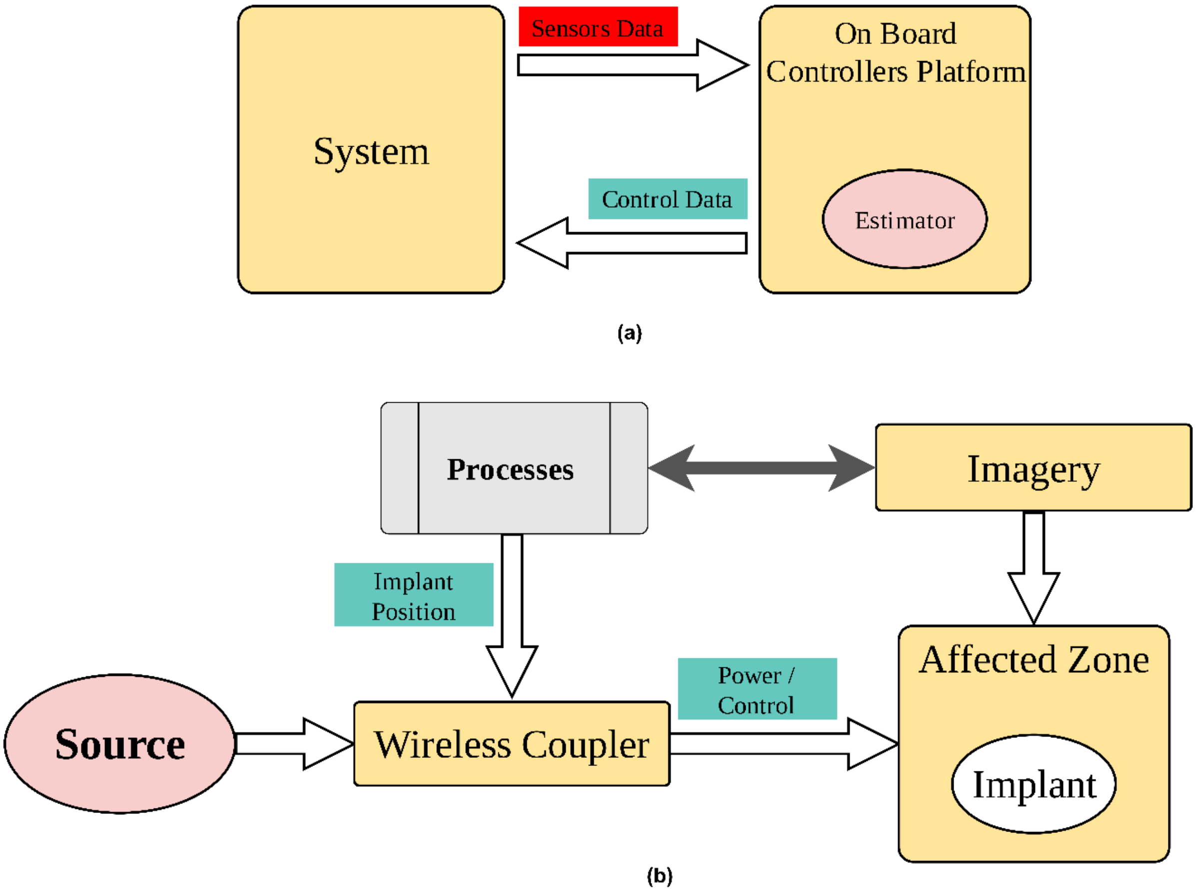

Figure 3. Iterative real-time matching in automated system: (a) Conceptual representation of iterative matching; (b) Example of interactive autonomous image guided drug release system

4. Observation-Modeling Pairing in Complex Procedures

In the last section, we have examined the role of matching of estimated and actual parameters in automated procedures. This permitted to illustrate the necessity of the enhancement of the matching of virtual models to their real procedures. In this section, the matching twins in complex procedures will be examined that allows exposing the concept of digital twin.

4.1. Matching Twins in Complex Procedures

We have seen that the nature of a real system and the uncertainty of the emulation process often make it difficult to build a realistic virtual system (see section 3.1.2.) and that we need a compromise between the estimation precision and matching speed in automated systems (see section 3.2.). These two remarks are related the enhancement of the matching of virtual models to their real procedures. Such action depends on the qualities of the virtual model and its interacting with the real object. The value of the virtual model is associated to its capacity to account for the environmental phenomena involved in the real procedure. The feature of the link "real-virtual" is allied to the abilities of sensing, processing and control.

The weight of the enhancement of the matching becomes particularly crucial in the compound procedures where the complexity concerns the different incorporated components accounting for the physical phenomena involved (the notion of complexity will be approached in section 4.4.3.). To manage such compound procedures, one can practice the Internet of Things (IoT) which deliberates intensely in the physical domain via direct real-time data collection as shown in Figure 4, or computer-aided design (CAD) which focuses exclusively on the digital territory as shown in Figure 5.

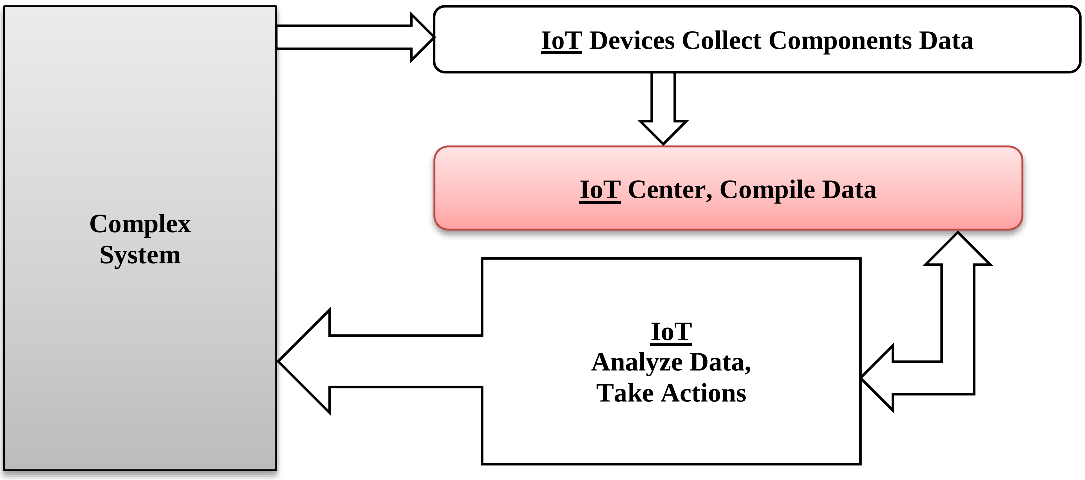

Figure 4. Scheme of IoT integrated in physical system

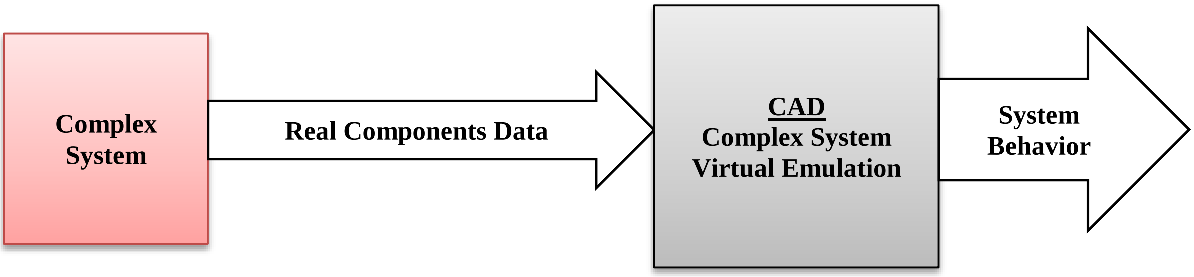

Figure 5. Representation of full digital CAD

However, it is essential to temper and control the irregular and unnecessary behavior that occurs in these complex procedures. Achieving such, a goal requires a paired observation-model twin practiced in the relevant procedure [41]. A coherent representation of such a matched twin is shown in figure 6. Such a twin differs from both IoT and CAD by focusing on both the physical and digital spheres. This twin needs the practice of different skills mainly involving detection (observation side), computation (model side) and information and control link (between observation and model sides). Detection on the observation side concerns the various sensor recognitions. The computation of the model side could involve simulation, optimization, design, diagnosis, prediction and testing. These operations can exploit learned gathered data in addition to sensor data. The link between the observation and the model sides is bidirectional. The observation part delivers sensor measurements in processed form to the model part while the latter sends processes and control information to the observation part.

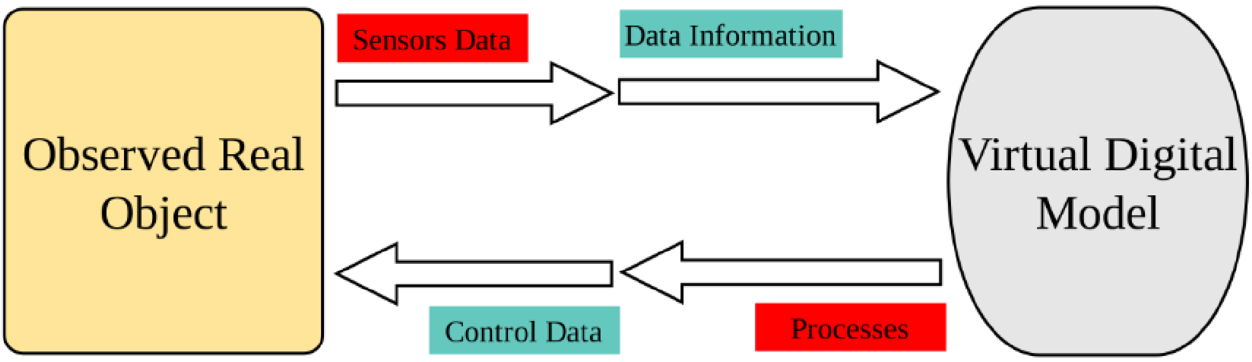

Figure 6. Representation of a real-time bidirectional matched observation-model twin

4.2. Digital Twin Concept

The twin described in the last section (Figure 6) corresponds to the Digital Twin DT. This concept was first introduced in 2002 by Grieves [41], although similar uses previously existed (see section 4.4.2.). It is distinguished by a beneficial two-way communication between the digital and physical spheres. The three components of a DT are a paired physical observable, a real-time replicated digital element, and their sensory, processing, control, and pairing links. The physical element dynamically adjusts its conduct in real time according to the recommendations made by digital element. While the digital article correctly reproduces the real state of the territory of the physical product. Thus, the DT offers an intelligent alliance of the physical and digital domains [42]. Hence, in DT technology, physical observation and virtual modeling are interconnected in a reciprocal exchange in real time. Therefore, we are in the presence of a real-time bidirectional interconnected pairing process. The observed element corrects the virtual error and the virtual element corrects the observed sensory data. This iterative process leads to a more objective and intelligent association. The DT concept is mainly used for fault diagnosis, predictive maintenance, and performance analysis and product design [43]. This concerns various fields and innovative industrial devices such as energy and utilities, aerospace and defense, automotive transport, machinery manufacturing, healthcare and consumer goods.

4.3. Examples of Applications of DT

As mentioned above, the number of publications on DT applications has increased considerably in recent times and it is not possible to, exhaustively cite such a contribution. However, to illustrate the range of such applications from manufacturing to smart cities, we will give several examples in different areas of this work.

One of DT's most widely used activities is industrial manufacturing and product design. For example, one can use physical and virtual product matching for iterative redesign of an existing product or for creation of a new product. Such DT-based product design can guide manufacturers to support the product design process, see e.g. [42, 43]. As well, the integration of manufacturing data and sensory data in the development of DT virtual products that can enhance cyber-physical manufacturing capabilities can valuable [44]. Another DT activity concerns predictive maintenance that is employed in many domains. In the framework of industrial procedures, predictive maintenance has turn into an important attention; the main purpose is to optimize the maintenance calendar by predicting the failures of systems and processes. Such an approach will outcome in a reduction in unforeseen system interruption and serious failures. As well, benefits are the minimization of costs, and the reduction of the substitution of fundamental elements of the system, see e.g. [45-48]. Moreover, we can mention healthcare services using DT technology as an enthusing and encouraging approach that can promote progress endeavors in medical innovations and enhance clinical and society health consequences [49, 50]. In addition, the DT security activity as Cyber DT designed for cybersecurity protection [51] and DT based industrial automation and control system security [52]. As well in control, DT technology for application in power system control centers [53] and in mechatronic systems [54]. Another activity concerns the application of DT technology in intelligent electric vehicles EV. This concerns various aspects such as autonomous navigation control, driver assistance systems, vehicle condition monitoring, battery management systems, electronics and electric drive systems [55, 56]. In addition to the mentioned examples of using DT, we can mention some innovative applications. The application of DT in the livestock sector to improve large-scale precision farming practices, the use of machinery and equipment, as well as the health and well-being of a large variety of animals [57]. In addition, DT's application in smart cities to ensure smart aspects in real property, transportation, construction, health system, building, home, transportation and parking [58].

4.4. Discussion and Remarks on Pairing Twins

Following the previous analysis, we will underline some features of the observation-virtual representation pair. As well, we will highlight the historical aspect the concept of DT and the definition of complex systems or procedures.

4.4.1. Characters of the Observation-Virtual Representation Pair

We will first draw attention to the nature of the observation-theory pair in general and as well DT. We refer to observation mainly, sensory observation, experience or manipulation, while theory mainly refers to virtual analysis, mathematical modeling [59] or prediction [60]. When each of the two members of this duo is considered correct, they are completely matched by definition. So, this matching character can be used for their adjustment. Thus, if one of the two sides is unknown (unverified - uncertain) or has a degree of uncertainty [61], it could be validated or corrected by the other. Therefore, the practice of matching or mirroring can then be judiciously used to remedy the uncertainty. A second evidence can be deduced from the analysis concerns the valuation of each member of the duo by the other. In section 2 for example, we saw how the duo allows actions of validation (or invalidation), explanation or unification. These aspects are practiced from one side to the other. Such a practice allows, in addition to the mentioned actions, enhancing the exercising side itself. Thus, a performing observation becomes more efficient and an acting theory more elegant [62]. This improvement allows a gain in the future work of theoretical research and observation tools.

This analysis illustrates the common behavior of the concept of matching reality to virtual representation in Digital Twin and in different forms in many scientific fields. As well in the behavior, impact and controlling of uncertainties on both sides and link of a matched twin and more generally in the pairing of a real and its virtual representation.

4.4.2. History of the Concept of DT

This section concerns the historical aspect of the concept of DT [57]. As early as 1993, in "Mirror Worlds", David Gelernter evoked, on a similar concept, the possibilities of software models that represent a portion of reality [63]. However, even before that, NASA used complex simulations to control the safety of spacecraft [64]. This was subsequently interrupted by the unexpected explosion in the oxygen tank of the Apollo 13 mission in 1970 [65]. Following this accident, the mission modified several high-fidelity simulators to adapt them to the real conditions of the damaged spacecraft and used them to land safely [66]. This was probably one of the first real applications of a DT. This involved several basic characteristics of a DT, although this was not a familiar concept in 1970.

4.4.3 Complex Procedures Definition

This part relates to the definition of complex systems or procedures concerned in section 4.1. The complexity concerns components and involves physical phenomena. One can define complexity in terms of interactions [67]. These can be classified into three forms: simple, complicated, and complex interactions. The first behaves simply as direct or linear, while complicated interactions are performed linearly and loosely coupled, while complex interactions with tightly coupled links would be the feature of a complex system or procedure.

5. Conclusions

The investigations followed in this article have focused on several questions concerning the practice of matching a real procedure with its virtual model. Its impacts can be summarized in the following points:

- Regarding scientific theories regarding their credibility and universality, this appears through their attributes of validation (or invalidation) of a theory, explanation of an observation, and unification of a number of observations.
- Referring to the introduction of innovative computing tools that mimic physical paradigms such as neuromorphic and quantum computing technologies.
- Corresponding to innovations in functional approaches to matching in theories addressing functions and approaches to industrial design.
- Regarding the matching of estimated and actual parameters in automated procedures.
- Concerning the role of matched twins in complex procedures, which made it possible to expose the concept of digital twin and examples of its applications in different fields, illustrating its relevant range, including energy, mobility, predictive maintenance, production, health, security, smart cities, etc.

The analysis followed in this paper relative to the problem of uncertainty makes it possible to specify certain points that can be summarized as follows. One can often encounter uncertainties on both sides (observation and virtual) of the duo. On the observation side, this may be due to the accuracy of the sensors or the difficulty of detection. On the model side, the problems could stem from the difficulty of mathematically reflecting real behavior. In such a circumstance, the connections between the two parties can effect a significant improvement in both directions of the duo. The observation corrects the virtual error, and the virtual side adjusts the observed sensory data in a reciprocal iterative process that leads to a more factual and intelligent association. Noting that the iterative reciprocal process involved in pairing the duo works according to variations in the observed procedure. The pairing in the link behaves consistently with these variations in addition to the uncertainties on either side of the pair. Reducing these uncertainties greatly helps match behavior. The stakes in such circumstances concern the practice of different skills, mainly involving detection on the observation side, calculation on the model side, and the processing of information, as well as the control by action of the links between the two sides.

In conclusion, this contribution illustrated four important points:

- The first is the prominence in general of the concept of matching reality to virtual representation in both off-line and real-time pairing.
- The second is that the practice of matching, which is central in different forms in many scientific fields, is furthermore fundamental in the management of complex procedures.
- The third concerns the behavior, impact, and administration of uncertainties on both sides and link of a matched twin and, more generally, in the pairing of a real and its virtual representation.
- The last thing is that DT concept applications are very vital in many innovative fields.

Finally, the analysis of the investigations followed in this paper makes it possible to imagine a philosophy of possible future evolution in several questions concerning the practice of pairing of a real procedure with its virtual model.

6. Declarations

6.1. Data Availability Statement

Data sharing is not applicable to this article.

6.2. Funding

The author received no financial support for the research, authorship, and/or publication of this article.

6.3. Institutional Review Board Statement

Not applicable.

6.4. Informed Consent Statement

Not applicable.

6.5. Declaration of Competing Interest

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the author.

7. References

[1] Bates, H. W. (1862). XXXII. Contributions to an Insect Fauna of the Amazon Valley. Lepidoptera: Heliconidae. Transactions of the Linnean Society of London, 23(3), 495–566. doi:10.1111/j.1096-3642.1860.tb00146.x.

[2] Leitão, P., Karnouskos, S., Ribeiro, L., Lee, J., Strasser, T., & Colombo, A. W. (2016). Smart Agents in Industrial Cyber-Physical Systems. Proceedings of the IEEE, 104(5), 1086–1101. doi:10.1109/JPROC.2016.2521931.

[3] Abramovici, M., Göbel, J. C., & Savarino, P. (2017). Reconfiguration of smart products during their use phase based on virtual product twins. CIRP Annals - Manufacturing Technology, 66(1), 165–168. doi:10.1016/j.cirp.2017.04.042.

[4] Kritzinger, W., Karner, M., Traar, G., Henjes, J., & Sihn, W. (2018). Digital Twin in manufacturing: A categorical literature review and classification. IFAC-Pap. Online, 51(11), 1016–1022. doi:10.1016/j.ifacol.2018.08.474.

[5] Jones, D., Snider, C., Nassehi, A., Yon, J., & Hicks, B. (2020). Characterising the Digital Twin: A systematic literature review. CIRP Journal of Manufacturing Science and Technology, 29, 36–52. doi:10.1016/j.cirpj.2020.02.002.

[6] Lévi-Strauss, C. (1958) Structural anthropology. Basic Books, Paris, France.

[7] Maurice Merleau-Ponty. (1964). L'œil et l'esprit (The eye and the spirit). Éditions Gallimard, Paris, France.

[8] Schrödinger, E. (1926). An undulatory theory of the mechanics of atoms and molecules. Physical Review, 28(6), 1049–1070. doi:10.1103/PhysRev.28.1049.

[9] Wineland, D. J., Monroe, C., Itano, W. M., Leibfried, D., King, B. E., & Meekhof, D. M. (1998). Experimental issues in coherent quantum-state manipulation of trapped atomic ions. Journal of research of the National Institute of Standards and Technology, 103(3), 259. doi:10.6028/jres.103.019.

[10] Brune, M., Haroche, S., Raimond, J. M., Davidovich, L., & Zagury, N. (1992). Manipulation of photons in a cavity by dispersive atom-field coupling: Quantum-nondemolition measurements and generation of Schrödinger cat states. Physical Review A, 45(7), 5193–5214. doi:10.1103/PhysRevA.45.5193.

[11] Maxwell, J. C. (1873) A Treatise on Electricity & Magnetism. Dover Publications, New York, ISBN 0-486-60636-8 (Vol. 1) & 0-486-60637-6 (Vol. 2). Available online: https://www.aproged.pt/biblioteca/MaxwellI.pdf (accessed on December 2021).

[12] Hall, E. H. (1879). On a new action of the magnet on electric currents. American Journal of Mathematics, 2(3), 287-292. doi:10.2307/2369245.

[13] Laesecke, A. (2002). Through measurement to knowledge: The inaugural lecture of Heike Kamerlingh Onnes (1882). Journal of Research of the National Institute of Standards and Technology, 107(3), 261–277. doi:10.6028/jres.107.021.

[14] Haykin, S. (2000). Neural Networks: A Guided Tour. Soft Computing and Intelligent Systems, 71–80. doi:10.1016/b978-012646490-0/50007-x.

[15] Burr, G. W., Shelby, R. M., Sebastian, A., Kim, S., Kim, S., Sidler, S., … Leblebici, Y. (2016). Neuromorphic computing using non-volatile memory. Advances in Physics: X, 2(1), 89–124. doi:10.1080/23746149.2016.1259585.

[16] Feynman, R. P. (1982). Simulating physics with computers. International Journal of Theoretical Physics, 21(6–7), 467–488. doi:10.1007/BF02650179.

[17] Castelvecchi, D. (2017). Quantum computers ready to leap out of the lab in 2017. Nature, 541(7635), 9–10. doi:10.1038/541009a.

[18] Fedorov, A. K., Kiktenko, E. O., & Lvovsky, A. I. (2018). Quantum computers put blockchain security at risk. Nature, 563(7732), 465–467. doi:10.1038/d41586-018-07449-z.

[19] Knill, D. C., & Pouget, A. (2004). The Bayesian brain: The role of uncertainty in neural coding and computation. Trends in Neurosciences, 27(12), 712–719. doi:10.1016/j.tins.2004.10.007.

[20] Penny, W. (2012). Bayesian Models of Brain and Behaviour. ISRN Biomathematics, 2012, 1–19. doi:10.5402/2012/785791.

[21] Pouget, A., Beck, J. M., Ma, W. J., & Latham, P. E. (2013). Probabilistic brains: knowns and unknowns. Nature neuroscience, 16(9), 1170-1178. doi:10.1038/nn.3495.

[22] Hohwy, J. (2017). Priors in perception: Top-down modulation, Bayesian perceptual learning rate, and prediction error minimization. Consciousness and Cognition, 47, 75–85. doi:10.1016/j.concog.2016.09.004.

[23] Rodríguez, A. A., Bertolazzi, E., Ghiloni, R., & Valli, A. (2013). Construction of a finite element basis of the first de Rham cohomology group and numerical solution of 3D magnetostatic problems. SIAM Journal on Numerical Analysis, 51(4), 2380–2402. doi:10.1137/120890648.

[24] Ren, Z., & Razek, A. (1993). Boundary edge elements and spanning tree technique in three-dimensional electromagnetic field computation. International Journal for Numerical Methods in Engineering, 36(17), 2877–2893. doi:10.1002/nme.1620361703.

[25] Ying, P., Jiangjun, R., Yu, Z., & Yan, G. (2007). A composite grid method for moving conductor eddy-current problem. IEEE Transactions on Magnetics, 43(7), 3259–3265. doi:10.1109/TMAG.2007.892793.

[26] Rapetti, F., Maday, Y., Bouillault, F., & Razek, A. (2002). Eddy-current calculations in three-dimensional moving structures. IEEE Transactions on Magnetics, 38(2 I), 613–616. doi:10.1109/20.996160.

[27] Sun, Q., Zhang, R., Zhan, Q., & Liu, Q. H. (2019). 3-D implicit-explicit hybrid finite difference/spectral element/finite element time domain method without a buffer zone. IEEE Transactions on Antennas and Propagation, 67(8), 5469–5476. doi:10.1109/TAP.2019.2913740.

[28] Carpes, W. P., Pichon, L., & Razek, A. (2000). 3D finite element method for the modelling of bounded and unbounded electromagnetic problems in the time domain. International Journal of Numerical Modelling: Electronic Networks, Devices and Fields, 13(6), 527–540. doi:10.1002/1099-1204(200011/12)13:6<527::AID-JNM391>3.0.CO;2-V.

[29] Sun, X., Cheng, M., Zhu, S., & Zhang, J. (2012). Coupled electromagnetic-thermal-mechanical analysis for accurate prediction of dual-mechanical-port machine performance. IEEE Transactions on Industry Applications, 48(6), 2240–2248. doi:10.1109/TIA.2012.2226859.

[30] Ren, Z., & Razek, A. (1990). A Coupled Electromagnetic - Mechanical Model for Thin Conductive Plate Deflection Analysis. IEEE Transactions on Magnetics, 26(5), 1650–1652. doi:10.1109/20.104477.

[31] Hafner, M., Finken, T., Felden, M., & Hameyer, K. (2011). Automated virtual prototyping of permanent magnet synchronous machines for HEVs. IEEE Transactions on Magnetics, 47(5), 1018–1021. doi:10.1109/TMAG.2010.2091675.

[32] Razek, A. (2020). The elegant theory, the observed societal reality and the potentialities of coupled models. International Symposium on Numerical Modeling towards Digital Twin in Electrical Engineering. Beijing, China, January 5 to 7, 2020.

[33] Xu, D., Wang, B., Zhang, G., Wang, G., & Yu, Y. (2020). A review of sensorless control methods for AC motor drives. CES Transactions on Electrical Machines and Systems, 2(1), 104–115. doi:10.23919/tems.2018.8326456.

[34] Soto, G. G., Mendes, E., & Razek, A. (1999). Reduced-order observers for rotor flux, rotor resistance and speed estimation for vector controlled induction motor drives using the extended Kalman filter technique. IEE Proceedings-Electric Power Applications, 146(3), 282-288. doi:10.1049/ip-epa:19990293.

[35] Alonge, F., D'Ippolito, F., & Sferlazza, A. (2014). Sensorless control of induction-motor drive based on robust Kalman filter and adaptive speed estimation. IEEE Transactions on Industrial Electronics, 61(3), 1444–1453. doi:10.1109/TIE.2013.2257142.

[36] El Moucary, C., Mendes, E., & Razek, A. (2002). Decoupled direct control for PWM inverter-fed induction motor drives. IEEE transactions on industry applications, 38(5), 1307-1315. doi:10.1109/TIA.2002.803010.

[37] Holtz, J., & Juntao Quan. (2003). Drift- and parameter-compensated flux estimator for persistent zero-stator-frequency operation of sensorless-controlled induction motors. IEEE Transactions on Industry Applications, 39(4), 1052–1060. doi:10.1109/tia.2003.813726.

[38] Ortega, R., Aranovskiy, S., Pyrkin, A. A., Astolfi, A., & Bobtsov, A. A. (2021). New Results on Parameter Estimation via Dynamic Regressor Extension and Mixing: Continuous and Discrete-Time Cases. IEEE Transactions on Automatic Control, 66(5), 2265–2272. doi:10.1109/TAC.2020.3003651.

[39] Mendes, E., Baba, A., & Razek, A. (1995). Losses minimization of a field oriented controlled induction machine. IEEE Conference Publication (Issue 412, pp. 310–314). doi:10.1049/cp:19950885.

[40] Razek, A. (2018). Towards an image-guided restricted drug release in friendly implanted therapeutics. EPJ Applied Physics, 82(3), 31401. doi:10.1051/epjap/2018180201.

[41] Grieves, M., & Vickers, J. (2017). Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems. In Transdisciplinary perspectives on complex systems (pp. 85-113). Springer, Cham. doi:10.1007/978-3-319-38756-7_4.

[42] Tao, F., Sui, F., Liu, A., Qi, Q., Zhang, M., Song, B., Guo, Z., Lu, S. C. Y., & Nee, A. Y. C. (2019). Digital twin-driven product design framework. International Journal of Production Research, 57(12), 3935–3953. doi:10.1080/00207543.2018.1443229.

[43] He, B., & Bai, K. J. (2021). Digital twin-based sustainable intelligent manufacturing: A review. Advances in Manufacturing, 9(1), 1-21. doi:10.1007/s40436-020-00302-5.

[44] Cai, Y., Starly, B., Cohen, P., & Lee, Y. S. (2017). Sensor Data and Information Fusion to Construct Digital-twins Virtual Machine Tools for Cyber-physical Manufacturing. Procedia Manufacturing, 10, 1031–1042. doi:10.1016/j.promfg.2017.07.094.

[45] Selçuk, Ş. Y., Ünal, P., Albayrak, Ö., & Jomâa, M. (2021). A workflow for synthetic data generation and predictive maintenance for vibration data. Information (Switzerland), 12(10), 386. doi:10.3390/info12100386.

[46] Montero Jimenez, J. J., Schwartz, S., Vingerhoeds, R., Grabot, B., & Salaün, M. (2020). Towards multi-model approaches to predictive maintenance: A systematic literature survey on diagnostics and prognostics. Journal of Manufacturing Systems, 56, 539–557. doi:10.1016/j.jmsy.2020.07.008.

[47] Nacchia, M., Fruggiero, F., Lambiase, A., & Bruton, K. (2021). A systematic mapping of the advancing use of machine learning techniques for predictive maintenance in the manufacturing sector. Applied Sciences (Switzerland), 11(6), 2546. doi:10.3390/app11062546.

[48] Liu, Z., Meyendorf, N., & Mrad, N. (2018). The role of data fusion in predictive maintenance using digital twin. AIP Conference Proceedings, 1949. doi:10.1063/1.5031520.

[49] Liu, Y., Zhang, L., Yang, Y., Zhou, L., Ren, L., Wang, F., Liu, R., Pang, Z., & Deen, M. J. (2019). A Novel Cloud-Based Framework for the Elderly Healthcare Services Using Digital Twin. IEEE Access, 7, 49088–49101. doi:10.1109/ACCESS.2019.2909828.

[50] Kamel Boulos, M. N., & Zhang, P. (2021). Digital twins: From personalised medicine to precision public health. Journal of Personalized Medicine, 11(8), 745. doi:10.3390/jpm11080745.

[51] Holmes, D., Papathanasaki, M., Maglaras, L., Ferrag, M. A., Nepal, S., & Janicke, H. (2021). Digital Twins and Cyber Security – solution or challenge? Computer Engineering, Computer Networks and Social Media Conference (SEEDA-CECNSM, 1–8). doi:10.1109/seeda-cecnsm53056.2021.9566277.

[52] Gehrmann, C., & Gunnarsson, M. (2020). A digital twin based industrial automation and control system security architecture. IEEE Transactions on Industrial Informatics, 16(1), 669–680. doi:10.1109/TII.2019.2938885.

[53] Brosinsky, C., Westermann, D., & Krebs, R. (2018). Recent and prospective developments in power system control centers: Adapting the digital twin technology for application in power system control centers. 2018 IEEE International Energy Conference, ENERGYCON 2018, 1–6. doi:10.1109/ENERGYCON.2018.8398846.

[54] Boschert, S., & Rosen, R. (2016). Digital twin-the simulation aspect. Mechatronic Futures: Challenges and Solutions for Mechatronic Systems and Their Designers. Springer. doi:10.1007/978-3-319-32156-1_5.

[55] Bhatti, G., Mohan, H., & Raja Singh, R. (2021). Towards the future of smart electric vehicles: Digital twin technology. Renewable and Sustainable Energy Reviews, 141, 110801. doi:10.1016/j.rser.2021.110801.

[56] Chen, X., Min, X., Li, N., Cao, W., Xiao, S., Du, G., & Zhang, P. (2021). Dynamic safety measurement-control technology for intelligent connected vehicles based on digital twin system. Vibroengineering Procedia, 37, 78–85. doi:10.21595/vp.2021.21990.

[57] Neethirajan, S., & Kemp, B. (2021). Digital twins in livestock farming. Animals, 11(4), 1008. doi:10.3390/ani11041008.

[58] Shirowzhan, S., Tan, W., & Sepasgozar, S. M. E. (2020). Digital twin and CyberGIS for improving connectivity and measuring the impact of infrastructure construction planning in smart cities. ISPRS International Journal of Geo-Information, 9(4), 240. doi:10.3390/ijgi9040240.

[59] Razek, A. (2020). Pragmatic Association of the Two Evaluation Concepts of Operational Observation and Mathematical Modeling. Athens Journal of Sciences, 8(1), 23–36. doi:10.30958/ajs.8-1-2.

[60] Razek, A. (2021). Pertinence of Predictive Models as Regards the Behavior of Observed Biological and Artificial Phenomena. Athens Journal of Health and Medical Sciences, 8(3), 189–200. doi:10.30958/ajhms.8-3-3.

[61] Hamilton, F., Lloyd, A. L., & Flores, K. B. (2017). Hybrid modeling and prediction of dynamical systems. PLoS Computational Biology, 13(7), 1005655. doi:10.1371/journal.pcbi.1005655.

[62] Razek, A. Analysis of the Properties of Smart Theories and Their Revisited Realistic Modeling. International Journal of Cultural Heritage, 6, 1–5. Available online: http://www.iaras.org/iaras/filedownloads/ijch/2021/017-0001(2021).pdf (accessed on December 2021).

[63] Gelernter, D. (1993). Mirror worlds: Or the day software puts the universe in a shoebox... How it will happen and what it will mean. Oxford University Press, Oxford, United Kingdom.

[64] Tao, F., & Qi, Q. (2019). Make more digital twins. Nature, 573(7775), 490–491. doi:10.1038/d41586-019-02849-1.

[65] Boy, G. A. (2020). Human–systems integration: from virtual to tangible. CRC Press, Florida, United States. doi:10.1201/9780429351686.

[66] Zhuang, C., Miao, T., Liu, J., & Xiong, H. (2021). The connotation of digital twin, and the construction and application method of shop-floor digital twin. Robotics and Computer-Integrated Manufacturing, 68, 1–16. doi:10.1016/j.rcim.2020.102075.

[67] Perrow, C. (2011) Normal Accidents: Living with High Risk Technologies - Updated Edition. Princeton University Press, New Jersey, United States. doi:10.2307/j.ctt7srgf.