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REVIEW ARTICLE

Planning and performing image-assisted robotic interventions using personalized, minimally invasive, safe, and precise therapeutics

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Abstract

This review aims to analyze complex medical interventions planned and performed using image-guided robots. Such interventions, which may involve surgical or targeted drug delivery, are minimally invasive, precise, and safe therapies. The accuracy of robotic positioning is improved by reducing uncertainty and complexity, which can be achieved by matching real and virtual interventional procedures involving physical and virtual phantoms of the relevant part of the corresponding living tissues. Such tailored training includes personalized, patient, and interventional tool characteristics, and the results enable a real (with patient) intervention controlled by staff and a possible matched autonomous intervention under staff supervision. This paper discusses considerations for selecting appropriate scanners to control and monitor image-guided interventional procedures, planning personalized medical interventions using physical and virtual phantoms, involving staff in the loop, and employing augmented matched digital twins (DTs) for real interventions. Moreover, the paper positions the image-assisted robotic strategy in comparison to laparoscopic surgery. Each topic covered in this article, while self-contained, is supported by examples from the literature to facilitate a deeper understanding. The outcomes of this review highlight the importance of complex medical interventions involving image-assisted robotics or laparoscopic processes involving minimally invasive, nonionizing, and precise interventions. Furthermore, DTs already integrated into healthcare, combined with digital tools, could offer an effective solution for managing image-assisted robotics. This includes planning interventions with phantoms or patients and involving staff in the loop.

Keywords: Image-guided therapeutics; Living tissues; Surgery and drug delivery interventions; Complexity; Uncertainties; Monitoring paired real–virtual twins

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1. Introduction

Throughout history, the drive for progress has remained constant. Today, many routine processes and technologies contribute to modern well-being, with one of the most critical domains being health-related strategies that prioritize safety, comfort, and curative outcomes. Recent advances in medical sciences have uncovered the causes of numerous illnesses and developed strategies to address them, primarily through surgical and drug delivery interventions. The effectiveness of these interventions is directly linked to factors

such as safety, comfort, and curative outcome of the patient, which rely heavily on the tactile and visual skills of medical staff. These interventions aim to be minimally invasive and precisely targeted, thus protecting healthy tissues surrounding the affected areas. Furthermore, medical staff is expected to deliver personalized patient care, which intensifies the skills required for operational efforts. The concept of personalized medicine involves medical care tailor-made to the specific requirements of each patient, allowing for, in addition to the specific disease to be treated, factors such as hereditary characteristics, daily life, ecological environment, and reaction to treatments.

Based on the above-described information, the least invasive and positional precision tactile and visual skills could be advantageously replaced through dedicated image-guided robotics[1-4] or equivalent strategies such as laparoscopic surgery.[5] In fact, robotic surgery is the daughter of laparoscopic surgery with an evident improvement in technology and also in the fatigue of the surgeon who assumes a more comfortable position for the entire duration of the procedure. Such substitution is particularly further recommended for more complex interventions. Moreover, such interventional complexity that can be encountered during major surgical procedures[6-9] or limited drug delivery[10-12] obligates actions in a restricted area, as mentioned earlier, to protect healthy living tissues bordering the affected area. Hence, closed-loop robotic or laparoscopic processes would enable complex interventions reflecting positioning precision, minimally invasive, and restricted-area medical rulings by assistance using methods that are harmless to healthy living tissues.[4,5] In such closed-loop robotic control processes, different problems may be encountered, related to the management of complexity, uncertainty, and unanticipated dangerous incidents. Such problems can be solved using a control strategy based on matched physical–virtual pairs.[4,13] Therefore, the concept of personalized medicine as well as the last mentioned medical rulings could be planned (predetermined) by monitoring a matched physical–virtual pair (involving a physical phantom and its model) allowing the verification of the intervention result. This supervision can be aided by a human intercession. Furthermore, in expectancy, a monitoring of the real–virtual pair could be autonomous in the presence of the patient and with the medical staff in the loop.

The aim of this review is to analyze complex personalized medical interventions planned and performed using image-guided robotics, ensuring minimally invasive and safe conditions for precise surgical or drug administration procedures. The next sections in this paper are summarized as follows. Section two is dedicated to image-guided medical interventions involving features of adapted interventional scanners. Section three discusses the control and monitoring of image-guided intervention procedures comprising closed-loop control of image-assisted robotics and the reduction of perturbing factors in such control by monitoring real–virtual pairs. Section four discusses the planning of personalized and medical rulings, which incorporate both physical and virtual phantoms, along with integrating prospective individuals (staff) in the loop and using augmented digital twins (DTs) for real (with patient) interventions. A discussion on additional details of notions and concepts involved in the developed analyses is provided in section five. Finally, section six discusses conclusions and future suggestions.

2. Image-guided medical interventions

Traditional invasive interventions pose challenges in surgical procedures and restrict drug administration. At present, minimally invasive, image-assisted robotics enhance patient ease and safety as well as procedural accuracy and therapeutic efficacy. These methods can target almost any area in the body, and controlled release through implants prevents side effects.

2.1. Characteristics of interventional scanners

Most imaging scanners can be used in robotic assistance. However, each of the imaging methods is acceptable for an explicit condition.[14] Those engaging ionizing radiations, such as X-ray and positron emission, would not be appropriate for extensive-duration actions. Consequently, only the two nonionizing scanners, *namely*, magnetic resonance imaging (MRI) and ultrasound imaging (USI), would fit such prolonged actions.[15-18]

An imaging scanner is expected to provide high-resolution, 3D visualization the tissue structure and close-action instrumentation. Robotic assistance works within the imager scaffold alongside the object, enabling closed-loop management of tasks, such as tracking object motion and distortion, tracing robotic tools, and controlling drug release. Due to the increasing use of interdependent scanner–robot actions, a new approach has emerged that allows medical staff to treat patients more efficiently. Placing robotics within the imaging scaffold merges imaging capability with robotic competence, thus developing closed-loop management.

2.2. Features of MRI and USI

Both MRI and USI exhibit the abovementioned features relative to imaging and interventional tasks. However, USI can function only in boneless and airless frames.[3,4] The second distinction is the MRI's requirement for a scaffolding environment devoid of electromagnetic (EM) noise.[19-25] However, MRI appears to be a comprehensive scanner conditional to circumventing EM noise.

In addition to these distinctions, other applications can be identified. MRI is suitable for imaging entire body parts without constraints. Although MRI is universally applicable, USI can serve as a replacement when appropriate for the object being examined. Moreover, USI offers good maneuverability and cost-effectiveness, whereas MRI, although capable of producing high-quality images of soft tissues, is more complex and expensive. Therefore, from the viewpoint of practical use, the choice between the two scanners depends on the situation. USI should be used whenever possible, whereas MRI should be reserved for imaging structures containing bone and/or air, such as the brain and certain other body parts. Typically, clinical centers that perform MRI-guided procedures likely possess surgical imaging facilities, eliminating the need for scanner transport. In terms of cost, when patient well-being is a consideration, MRI-guided interventions, such as brain surgery, are the only nonionizing, minimally invasive treatment options.

In fact, MRI can provide high-level 3D images of the object configuration, neighboring healthy tissues, and involved instruments; however, there are significant challenges in its implementation to successfully guide the intervention. These challenges include the use of three magnetic fields of different characters (magnitude and frequency), presenting allergic responses to EM noise, and imposing a restricted occupation zone inside the imaging structure. The latter problem can be overcome using an open scanner, although it involves tolerating the disadvantage of lower field intensity and therefore a slower process. Nonetheless, MRI may be better than other scanners for several reasons. It has an incomparable contrast allowing the visualization of tumors as well as other abnormalities undetectable by other scanners. It has a true 3D imaging capability, including multimodal detection, *for example*, blood flow, temperature, and biomarker tracking. In these circumstances, the training of robotic assistance by an MRI can allow an excellent intervention.

3. Control and monitoring of image-guided interventions

Intraoperative imaging strategies have created a need for medical tools that address the requirements of different imaging techniques. Developments in image resolution and disconnection capabilities have enabled new interventions. 3D imaging techniques provide realistic and detailed views of living tissues; however, the tool must be activated within a specific area by locating the image coordinates. Moreover, operative drug delivery procedures can deliver drugs to the target site, maintaining therapeutic drug levels with minimal impact on surrounding healthy tissues. This can be facilitated by drug-delivery implants.

3.1. Closed-loop control of image-assisted robotics

As mentioned earlier, for patient comfort and safety, therapy must be limited to the affected area during surgery or drug delivery. Such precision depends on the accuracy of tool actuation and space localization. Accordingly, the prerequisite for such high-performance topological tracking is image-supervised location identification. Such conditions require a collaborative organization working autonomously, as demonstrated in a controlled drug release setting (Figure 1). This system includes the scanner, tissue-affected area, drug delivery implant, control system, and drug supply.[3,4]

The accuracy involved in such a control process related to actuation and spatial localization would be influenced by different disturbing factors, including the degree of complexity of the components of the combined procedure, the associated detection uncertainties, and different unanticipated external hazard incidents. Reliable control could be certified only after reducing these disturbing factors.

3.1.1. Surgical interventions

Image-assisted or laparoscopic intraoperative interventions that meet safety requirements for imaging and interventional actions generally use MRI and USI scanners[3,4,6] or laparoscopic strategies.[5] However, in some cases, MRI scanners are increasingly used in surgical interventions increasingly, particularly for their superior ability to differentiate tumors from normal tissues during surgeries and tumor extractions.[26-29] As mentioned earlier, MRI is sensitive to EM noise; thus, all robotic materials inserted into the scaffold near body tissues must be MRI-compatible (free of magnetic and conductive materials). In such settings, an actuation action is necessary. Few high-performance actuators are MRI-compatible. One possible class of actuation devices is piezoelectric actuators, which come in different categories. More information on their structures, materials, fabrication, testing, and applications is described elsewhere.[30-39] These devices must be tested to confirm their compliance, *that is*, to ensure that they do not disturb the field distribution produced by the radiofrequency (RF) coil used for imaging. Such devices are composed of piezoelectric materials, which are dielectrics and thin electrodes. Although dielectrics are not expected to disturb the field, conductive electrodes, even those of minimal size, must be carefully tested and regulated.

3.1.2. Drug delivery interventions

Conventional drug administration by intermittent oral or intravenous release can cause extraordinary blood drug concentrations immediately after delivery, probably

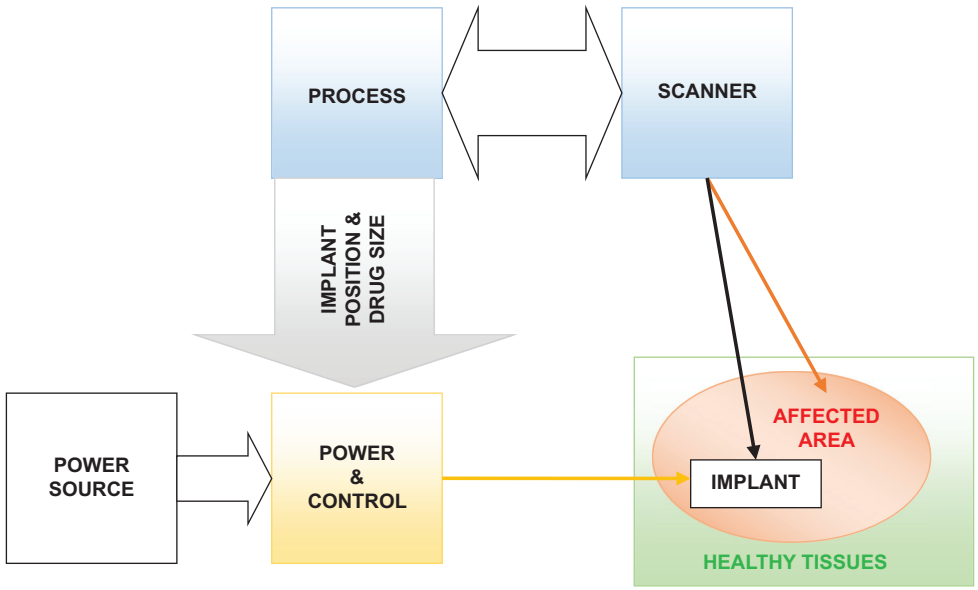


Figure 1. Schematic of an autonomous restricted drug release setting comprising the scanner, tissue affected area, drug delivery implant, control system, and supply

resulting in a dangerous effect in patients. Moreover, these methods undergo first-pass metabolism, causing a substantial concentration decrease in the liver before attaining regular flow, and consequently several doses are often required. Local, sustained, and controlled delivery allowing less hostile effects is possible through implant technology. Two situations regarding the spatial release are concerned. The first is spatially regular with constant drug release and biodegradable static configurations that enable their disposal; more information concerning the structures, materials, composition, and characterization is described elsewhere.[40-50] The second is spatially non-uniform centering only on sick zones and circumventing healthy zones; hence, mobile implants are necessary. The strategy used in the second case is similar to the case of image-assisted surgical interventions discussed in the previous section and satisfies safety features regarding imaging and interventional actions; these implants can involve different cases depending on the required precision, the treatment type, and the concerned placement.[12,51-58]

3.2. Reduction of control-perturbing factors

As mentioned earlier, the accuracy involved in the control process related to actuation and spatial localization is subject to disturbing factors, which include the degree of complexity of the components of the combined procedure, the associated detection uncertainties, and different unforeseen external hazard incidents. It is essential to reduce these possible perturbations and consider personalized patient data, which could be achieved by monitoring such factors and data through matching in physical–virtual pairs as DT tools.[59] DTs could be termed as a simple incorporation of data between a real phenomenon and its digital copy pair, in both ways. DTs are generally used for monitoring procedure conditions, diagnostics, prediction, optimization, scenarios, and risk evaluation.[60] Such tools can be designed at the levels of system, subsystem, and specific components. The concept of DTs is used for the administration of complex processes such as image-assisted robotized interventions; we describe here its central features.[61] A DT is organized as a real–virtual pair that permits self-adapting conduct. The real part provides the processed detected data to the virtual part, and the latter conveys the control instructions to the real part. Such a matching also allows reducing uncertainties and decreasing undesirable and menacing operating singularities.

3.3. DT management

Following the description of the primary features of a DT, this section describes in detail the management of its monitoring. The processed information of the real side provides sensor detections paralleled and amended by outward data (IoT) as well as by acquired history. The resulting product is communicated after training in a data analysis format. These submissions, with a suitable reduced model, are transferred to the virtual side. Rapid matching requires a reliable virtual replica with short computation times, which can be achieved by reducing the comprehensive model – *that is*, a complete coupled model closely resembling the real system – while maintaining the real physical picture. Administration using such a

pair consents an adaptive control for a procedure when functioning.[62] Figure 2 summarizes the topographies of a DT for monitoring an image-guided intervention procedure.

Note that the DT concept is progressively incorporating the healthcare sphere exploiting virtual replicas of bodily individuals that go further than a static situation incorporating the dynamic conduct of a real living tissues entity, many examples have been published in this intention, see for instance.[63-73] As the healthcare sector is gradually exploring the use of DTs, successful proofs of concept in various sectors suggest that, if fully realized, DTs could transform connected care, lifestyle, health, and chronic disease management in the future. However, recognition of the vast capacity of DTs in health care may likely be slowed by hesitation challenges.

4. Planning of personalized and medical rulings

The concept of DT discussed in the previous section could be used in planning a fictive intervention without a patient. In this case, we monitor the fully imaging-assisted robotic intervention procedure, including the scanner, the robot, and the tissue (phantom). This physical phantom of the tissue part of interest will be incorporated into the real physical side of the DT. Similarly, the virtual model side of the DT involving the intervention procedure model will include a digital phantom replica of the physical one. This corresponds to Figure 2, with physical and digital phantoms representing the body part of interest in the living tissue. This planning would include personalized characteristics of the patient and the interventional tool as well as the recommended medical prescriptions to meet the safety features related to imaging and interventional actions for the intervention concerned. Such planning allows confirming the smooth running of the intervention and the possible adaptations required for the medical protocol practiced. Therefore, the real (with patient) image-guided intervention could be performed under good conditions, which could be achieved through an image-assisted collaborative environment, as illustrated in Figure 1, under the supervision of medical staff, or prospectively through an autonomous DT monitoring procedure with involved staff (in the loop).

4.1. Physical and virtual phantoms

Physical and digital phantoms, discussed in the previous section, represent living tissues on both sides of the DT. A major problem with both choices lies in the way of tissue representation. Considering that biological properties allow the erection of these phantoms with static behavior, such a static representation could be suitable for specific parts of body tissues and for particular demands. Nevertheless, as mentioned earlier, these phantoms should represent real body tissues with reasonable biological properties. In general, the mechanical behavior related to the deformation and displacement of living soft tissues, irrigated by fluids allowing their functioning, corresponds to an exhibition of a complex dynamic behaviour.[74-78] Such a complex tissue behavior requires actually evaluated constitutive rules, adapted computational approaches, or both to address this problem. We can only approach this category of representation in an approximate manner. Different tissue models can be found in the literature.[79-82]

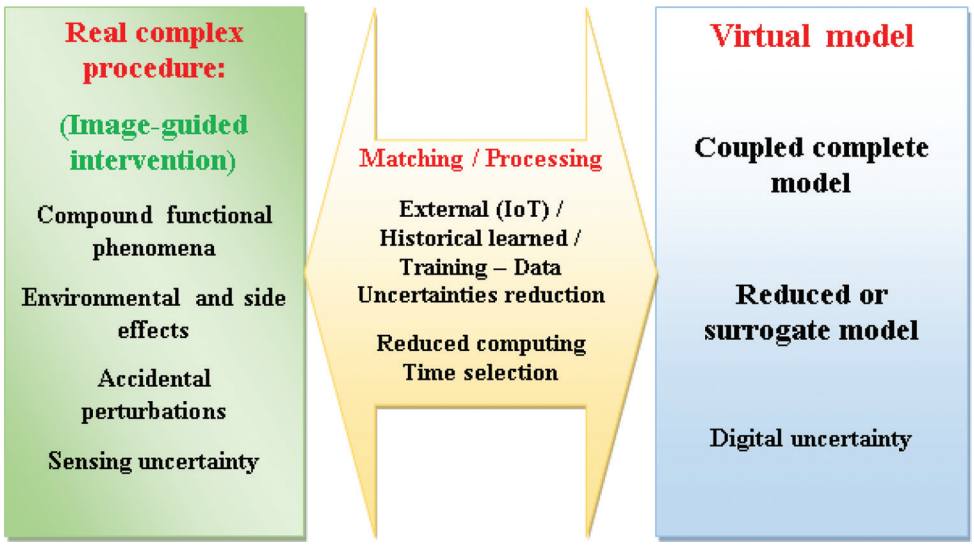


Figure 2. Summarized illustration of a matched monitoring of a complex procedure (image-guided intervention) with its virtual model

4.2. Prospective human in the loop and augmented DTs

The abovementioned human-robot alliance (staff in the loop) related to DT authorizes higher supervision of image-guided interventions, thus reducing the threat for the patient and ensuring a guaranteed outcome for medical staff.[83-85]

Furthermore, the commitment of the practices of artificial intelligence (AI) in such medical therapeutics helps in reducing the complexity of data acquirement and post-processing in MRI through strategy acceleration and providing quicker analysis periods with relaxed image processing.[86,87] AI can also be exploited to perform planned repeated training duties in image-assisted robotics related to the objective of the present paper.

The procedure can be significantly enhanced through augmented human-robot interactions, advancing the overall system with augmented reality (AR)-aided robotic actions. When combined with MRI, AR can reduce risks in complex procedures, such as tissue damage, bleeding, and post-operative trauma. Moreover, DTs can play a significant role in AR-supported robotic procedures. This allows for precise identification of the source of the disorder and the necessary action, using individual patient modeling from deep learning databases. Furthermore, the AR–DT combination enhances accuracy in suturing, knotting, and placement compared to manual operations.[88-92]

5. Discussion

In previous analyses, image-guided interventions have been comprehensively discussed and illustrated. Different necessary concepts or notions have been mentioned and used in these developments, which include complete coupled and reduced models, complexity, and matched real–virtual pairs. These aspects are further developed (extensions, reflections, or connected matters) and discussed in the following points:

- Historically, the concerns related to the minimally invasive surgical approach can be summarized as follows. Since the beginning of the 19th century, open surgery through laparotomy was practiced until the middle of the 20th century based on the argument that "you could see better with open surgery." Then, laparoscopic minimally invasive surgery revolutionized the approach to specific areas of the human body by providing an enlarged view through a tiny video camera and light at the end of a thin tool. Robotic image-assisted surgery is a successor to laparoscopic surgery, offering significant technological advancements and reducing staff fatigue by allowing them to maintain a more comfortable position during the procedure. An intervention, such as partial gastrectomy, whether performed using open, laparoscopic, or robotic image-assisted techniques, involves the same surgical duration, with only the access being different.
- A complex procedure involves several compound-interacting components characterized by different phenomena interacting in an interdependent manner, which is linked to the temporal and spatial behaviors of the involved phenomena. The closer the time constants and the higher the matter local nonlinearities in phenomena, the stronger their interdependence and, consequently, the greater the complexity. For distant time constants and linear matter behaviors, this interdependence and related complexity are greatly reduced. The concept of complexity is present in various natural and artificial occurrences[93] as well as societal issues.
- A complex procedure can be modeled mathematically considering its compound-interacting components through the coupling of the equations governing the different phenomena interacting in an interdependent manner. The more complex the procedure and its related phenomena interdependence, the more will be the complexity of the coupled model. For stronger phenomena interdependence (near time constants and nonlinear matter behavior), the equations would be strongly coupled (solved simultaneously). In the case of low interdependence (distant time constants and linear behavior), the equation coupling would be weak (iterative solution). Furthermore, the solution of the concerned equations should account for diverse topographies of modeled assemblies, which reflect geometrical complexity, variables nonlinear behaviors, and interdependence of phenomena. Satisfying such characteristics inflicts a local solution in the matter suggesting the practice of discretized 3D methods as finite elements (FEM) or comparable methods. More details regarding the types of discretized elements, domain meshing, methods mixing, and numerical methodology are described elsewhere,[94-103] accompanying appropriate strategies for equations coupling, with more details described elsewhere.[104] These coupled solutions would faithfully represent the behavior of the complex procedure. However, they reflect an important computation time and could not be suitable for real-time executions.
- In the case of repetitive or online real-time computations, complete coupled models would be penalizing, and hence reduced models should be used. Reducing a model involves hastening its solution while debasing its accuracy as slight as possible; more details are described elsewhere.[105] The trouble

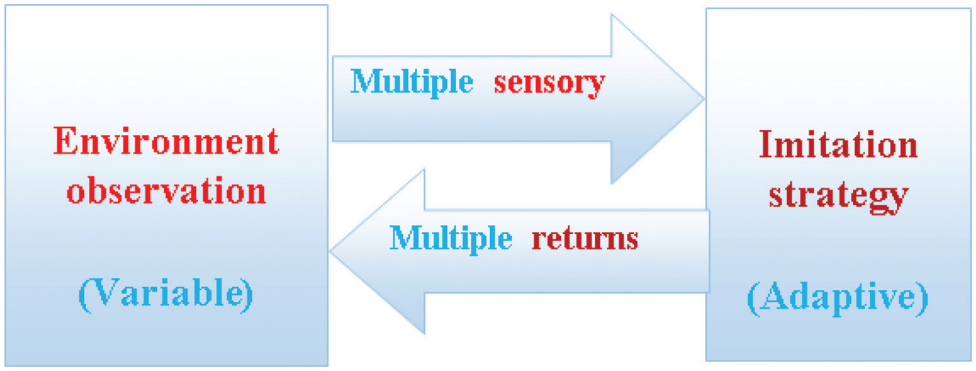


Figure 3. Schematic of camouflage involving the environment observation-imitation strategy pair with its two-way link (sensory–return) for variable environment real-time adaptive matching

is then frequently to obtain the border between sparing time and weakening exactness. The key idea originates from the observation that a superior model is much time-consuming to execute in real time" or consider revising suitably. A model reduction (surrogate model) is therefore substituted[106,107] for the superior model to perform a pre-sizing. Moreover, one can practice stochastic non-intrusive methods (*e.g.*, kriging and polynomial chaos)[108,109] that expend 3D FEM calculations with a restrained group of attainments (learning samples), thus providing efficient metamodels.

- Real-virtual matched pairs are materialized in this review article by the DT concept. This concept was first introduced by Michael Grieves in 2002 [62], although its principle existed earlier. For example, its use by NASA for complex simulations to control the safety of spacecraft following a worrying explosion in the oxygen tank of the Apollo 13 mission in 1970. After this accident, the mission adapted simulators for the real spacecraft conditions; this was possibly one of the first practical applications of a DT, although it was not a common concept in 1970. Moreover, the practice of real–virtual matching is related to virtual modeling or reasoned deduction accounting for the observation of an object or phenomenon. Hence, the matching (or mirroring) of an observable with its virtual image has been and still practiced in numerous natural and artificial circumstances. Humans and other living beings often rely on observation and sensory maneuvers, using deduction and mimicry to ensure self-protection and survival. Deductive reasoning, coupled with observation, is one of the earliest learned natural abilities. For example in wildlife, life security is based on observation, and occurrences of imitation strategy are recurrent, this is materialized by camouflage.[110] This facilitates living beings to blend into their environments through adaptive matching.

Figure 3 illustrates a representation of camouflage, highlighting the link between environmental observation, mimicry strategy, and its bidirectional (sensory–feedback) link for a variable environment using real-time correspondence.

6. Conclusion

This review paper contributed to the analyses of complex medical interventions involving image-assisted robotics (or laparoscopic) processes under conditions of minimally invasive, nonionizing, and precise surgical or drug delivery interventions. The adaptation of scanners for robotic interventions, their control and monitoring, the mitigation of perturbing factors, and the planning of personalized medical decisions with prospective augmented routines have been analyzed and discussed. DTs, which can be readily integrated into healthcare, may offer an efficient solution for managing image-assisted robotics when combined with digital tools. This can be implemented in various forms, including planning and interventions using phantoms and patient involvement, with staff in the loop. A potential future research direction could focus on further exploring the mechanical behaviors of living tissues in real time.

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References

1. Chinzei K, Hata N, Jolesz FA, Kikinis R. Surgical Assist Robot for the Active Navigation in the Intraoperative MRI: Hardware Design Issues. In: *Proceedings of the 2000 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2000) (Cat. No.00CH37113)*, Takamatsu, Japan; 2000. p. 727-732.

   doi: 10.1109/IROS.2000.894690

2. Tsekos NV, Khanicheh A, Christoforou E, Mavroidis C. Magnetic resonance-compatible robotic and mechatronics systems for image- guided interventions and rehabilitation: A review study. *Annu Rev Biomed Eng*. 2007;9:351-387.

   doi: 10.1146/annurev.bioeng.9.121806.160642

3. Razek A. Towards an image-guided restricted drug release in friendly implanted therapeutics. *Eur Phys J Appl Phys*. 2018;82:31401.

   doi: 10.1051/epjap/2018180201

4. Razek A. Image-guided surgical and pharmacotherapeutic routines as part of diligent medical treatment. *Appl Sci*. 2023;13:13039.

   doi: 10.3390/app132413039

5. Marrelli D, Piccioni SA, Carbone L, *et al*. Posterior and para-aortic (D2plus) lymphadenectomy after neoadjuvant/conversion therapy for locally advanced/oligometastatic gastric cancer. *Cancers* (*Basel*). 2024;16(7):1376.

   doi: 10.3390/cancers16071376

6. Faoro G, Maglio S, Pane S, Iacovacci V, Menciassi A. An artificial intelligence-aided robotic platform for ultrasound-guided transcarotid revascularization. *IEEE Robot Autom Lett*. 2023;8:2349-2356.

   doi: 10.1109/LRA.2023.3251844

7. Su H, Kwok KW, Cleary K, *et al.* State of the art and future opportunities in MRI-guided robot-assisted surgery and interventions. *Proc IEEE Inst Electr Electron Eng*. 2022;110:968-992.

   doi: 10.1109/jproc.2022.3169146

8. Padhan J, Tsekos N, Al-Ansari A, *et al*. Dynamic Guidance Virtual Fixtures for Guiding Robotic Interventions: Intraoperative MRI-guided Transapical Cardiac Intervention Paradigm. In: *Proceedings of the 2022 IEEE 22nd International Conference on Bioinformatics and Bioengineering (BIBE)*, Taichung, Taiwan; 2022. p. 265-270.

   doi: 10.1109/BIBE55377.2022.00062

9. Singh S, Torrealdea F, Bandula S. MR imaging-guided intervention: Evaluation of MR conditional biopsy and ablation needle tip artifacts at 3T using a balanced fast field echo sequence. *J Vasc Interv Radiol*. 2021;32:1068-1074.

   doi: 10.1016/j.jvir.2021.03.536

10. Xu L, Pacia CP, Gong Y, *et al*. Characterization of the targeting accuracy of a neuronavigation-guided transcranial FUS system *in vitro, in vivo*, and *in silico*. *IEEE Trans Biomed Eng*. 2023;70(5):1528-1538.

    doi: 10.1109/TBME.2022.3221887

11. Navarro-Becerra JA, Borden MA. Targeted microbubbles for drug, gene, and cell delivery in therapy and immunotherapy. *Pharmaceutics*. 2023;15(6):1625.

    doi: 10.3390/pharmaceutics15061625

12. Delaney LJ, Isguven S, Eisenbrey JR, *et al*. Making waves: How ultrasound-targeted drug delivery is changing pharmaceutical approaches. *Mater Adv*. 2022;3:3023-3040.

    doi: 10.1039/d1ma01197a

13. Razek A. Augmented therapeutic tutoring in diligent image-assisted robotic interventions. *AIMS Med Sci*. 2024;11(2):210-219.

    doi: 10.3934/medsci.2024016

14. Zhang B, Liu L, Meng D, Kue CS. Medical imaging technology: Principles and systems. *INNOSC Theranostics Pharmacol Sci*. 2024;7(3):3360.

    doi: 10.36922/itps.3360

15. Kuah T, Vellayappan BA, Makmur A, *et al*. State-of-the-art imaging techniques in metastatic spinal cord compression. *Cancers* (*Basel*). 2022;14:3289.

    doi: 10.3390/cancers14133289

16. Kraus MS, Coblentz AC, Deshpande VS, *et al*. State-of-the-art magnetic resonance imaging sequences for pediatric body imaging. *Pediatr Radiol*. 2023;53:1285-1299.

    doi: 10.1007/s00247-022-05528-y

17. Sennimalai K, Selvaraj M, Kharbanda OP, *et al*. MRI-based cephalometrics: A scoping review of current insights and future perspectives. *Dentomaxillofac Radiol*. 2023;52:20230024.

    doi: 10.1259/dmfr.20230024

18. Chianca V, Vincenzo B, Cuocolo R, *et al.* MRI quantitative evaluation of muscle fatty infiltration. *Magnetochemistry*. 2023;9:111.

    doi: 10.3390/magnetochemistry9040111

19. Sato Y, Takeuchi T, Fuju A, *et al*. MRI safety for leave-on powdered hair thickeners under 1.5-T and 3.0-T MRI: Measurement of deflection force, MRI artifact, and evaluation of preexamination screening. *Phys Eng Sci Med*. 2023;46:915-924.

doi: 10.1007/s13246-023-01267-y

20. Akdogan G, Istanbullu O. Analysing the effects of metallic biomaterial design and imaging sequences on MRI interpretation challenges due to image artefacts. *Phys Eng Sci Med*. 2022;45:1163-1174.

doi: 10.1007/s13246-022-01183-7

21. Germann C, Nanz D, Sutter R. Magnetic resonance imaging around metal at 1.5 Tesla: Techniques from basic to advanced and clinical impact. *Investig Radiol*. 2021;56:734-748.

doi: 10.1097/RLI.0000000000000798

22. Germann C, Falkowski AL, von Deuster C, *et al*. Basic and advanced metal-artifact reduction techniques at ultra-high field 7-T magnetic resonance imaging-phantom study investigating feasibility and efficacy. *Investig Radiol*. 2022;57:387-398.

doi: 10.1097/RLI.0000000000000850

23. Inaoka T, Kitamura N, Sugeta M, *et al*. Diagnostic value of advanced metal artifact reduction magnetic resonance imaging for periprosthetic joint infection. *J Comput Assist Tomogr*. 2022;46:455-463.

doi: 10.1097/RCT.0000000000001297

24. Haskell MW, Nielsen JF, Noll DC. Off-resonance artifact correction for MRI: A review. *NMR Biomed*. 2023;36:e4867.

doi: 10.1002/nbm.4867

25. Spronk T, Kraff O, Kreutner J, *et al*. Development and evaluation of a numerical simulation approach to predict metal artifacts from passive implants in MRI. *MAGMA*. 2022;35:485-497.

doi: 10.1007/s10334-021-00966-5

26. Jia X, Zhang Y, Du H, Yu Y. Experimental study of double cable-conduit driving device for MRI compatible biopsy robots. *J Mech Med Biol*. 2021;21:2140014.

doi: 10.1142/S0219519421400145

27. Li X, Young AS, Raman SS, *et al*. Automatic needle tracking using Mask R-CNN for MRI-guided percutaneous interventions. *Int J Comput Assist Radiol Surg*. 2020;15:1673-1684.

doi: 10.1007/s11548-020-02226-8

28. Wartenberg M, Schornak J, Carvalho P, *et al*. Closed-loop Autonomous Needle Steering during Cooperatively Controlled Needle Insertions for MRI-guided Pelvic Interventions. In: *The 10th Hamlyn Symposium on Medical Robotics, 33--34, Imperial College*. London, UK; 2017.

29. Wu D, Li G, Patel N, *et al*. Remotely Actuated Needle Driving Device for MRI-Guided Percutaneous Interventions: Force and Accuracy Evaluation. In: *Proceedings of the 2019 41st Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC)*, Berlin, Germany; 2019.

doi: 10.1109/ismr.2019.8710176

30. Mohith S, Upadhya AR, Navin KP, *et al*. Recent trends in piezoelectric actuators for precision motion and their applications: A review. *Smart Mater Struct*. 2020;30:013002.

doi: 10.1088/1361-665X/abc6b9

31. Gao X, Yang J, Wu J, *et al*. Piezoelectric actuators and motors: Materials, designs, and applications. *Adv Mater Technol*. 2020;5:1900716.

doi: 10.1002/admt.201900716

32. Qiao G, Li H, Lu X, Wen J, Cheng T. Piezoelectric stick-slip actuators with flexure hinge mechanisms: A review. *J Intell Mater Syst Struct*. 2022;33:1879-1901.

doi: 10.1177/1045389X211072244

33. Liu J, Gao X, Jin H, *et al*. Miniaturized electromechanical devices with multi-vibration modes achieved by orderly stacked structure with piezoelectric strain units. *Nat Commun*. 2022;13:6567.

doi: 10.1038/s41467-022-34231-7

34. Fu DK, Fan PQ, Yuan T, Wang YS. A novel hybrid mode linear ultrasonic motor with double driving feet. *Rev Sci Instrum*. 2022;93:025003.

doi: 10.1063/5.0057254

35. Li Z, Guo Z, Han H, Su Z, Sun H. Design and characteristic analysis of multi-degree-of-freedom ultrasonic motor based on spherical stator. *Rev Sci Instrum*. 2022;93:025004.

doi: 10.1063/5.0074049

36. Wang S, Zhou S, Zhang X, *et al*. Bionic stepping motors driven by piezoelectric materials. *J Bionic Eng*. 2023;20:858-872.

doi: 10.1007/s42235-022-00313-x

37. Hernandez C, Bernard Y, Razek A. Design and manufacturing of a piezoelectric traveling-wave pumping device. *IEEE Trans Ultrason Ferroelectr Freq Control*. 2013;60:1949-1956.

doi: 10.1109/TUFFC.2013.2779

38. Zhang SJ, Liu Y, Deng J, *et al*. Piezo robotic hand for motion manipulation from micro to macro. *Nat Commun*. 2023;14:500.

doi: 10.1038/s41467-023-36243-3

39. Yang Z, Li X, Tang J, *et al*. A bionic stick-slip piezo-driven positioning platform designed by imitating the structure and movement of the crab. *J Bionic Eng*. 2023;20:2590-2600.

doi: 10.1007/s42235-023-00411-4

40. Traverson M, Heiden M, Stanciu LA, *et al. In vivo* evaluation of biodegradability and biocompatibility of Fe30Mn alloy. *Vet Comp Orthop Traumatol*. 2018;31:10-16.

doi: 10.3415/VCOT-17-06-0080

41. Wang Y, Venezuela J, Dargusch M. Biodegradable shape memory alloys: Progress and prospects. *Biomaterials*. 2021;279:121215.

doi: 10.1016/j.biomaterials.2021.121215

42. Li H, Lin G, Wang P, Huang J, Wen C. Nutrient alloying elements in biodegradable metals: A review. *J Mater Chem B*. 2021;9:9806-9825.

doi: 10.1039/D1TB01962G

43. Rabeeh VPM, Hanas T. Progress in manufacturing and processing of degradable Fe-based implants: A review. *Prog Biomater*. 2022;11:163-191.

doi: 10.1007/s40204-022-00189-4

44. Babacan N, Kochta F, Hoffmann V, *et al*. Effect of silver additions on the microstructure, mechanical properties and corrosion behavior of biodegradable Fe-30Mn-6Si. *Mater Today Commun*. 2021;28:102689.

doi: 10.1016/j.mtcomm.2021.102689

45. Tai CC, Lo HL, Liaw CK, Huang, *et al*. Biocompatibility and biological performance evaluation of additive-manufactured bioabsorbable iron-based porous suture anchor in a rabbit model. *Int J Mol Sci*. 2021;22:7368.

doi: 10.3390/ijms22147368

46. Bakhsheshi-Rad HR, Najafinezhad A, Hadisi Z, *et al*. Characterization and biological properties of nanostructured clinoenstatite scaffolds for bone tissue engineering applications. *Mater Chem Phys*. 2021;259:123969.

doi: 10.1016/j.matchemphys.2020.123969

47. Sun Y, Chen L, Liu N, *et al*. Laser-modified fe–30 mn surfaces with promoted biodegradability and biocompatibility toward biological applications. *J Mater Sci*. 2021;56:13772-13784.

doi: 10.1007/s10853-021-06139-y

48. Hao S, Yang T, Zhang A, *et al*. Evaluation of biodegradable alloy Fe30Mn0.6N in rabbit femur and cartilage through detecting osteogenesis and autophagy. *Biomed Res Int*. 2023;18:3626776.

doi: 10.1155/2023/3626776

49. Biffi CA, Fiocchi J, Bregoli C, *et al*. Ultrashort laser texturing for tuning surface morphology and degradation behavior of the biodegradable Fe-20Mn alloy for temporary implants. *Adv Eng Mater*. 2022;24:2101496.

doi: 10.1002/adem.202101496

50. Putra NE, Leeflang MA, Taheri P, *et al*. Extrusion-based 3D printing of ex situ-alloyed highly biodegradable MRI-friendly porous iron-manganese scaffolds. *Acta Biomater*. 2021;134:774-790.

doi: 10.1016/j.actbio.2021.07.042

51. Williams RP, Karzova MM, Yuldashev PV, *et al*. Dual-mode 1-D linear ultrasound array for image-guided drug delivery enhancement without ultrasound contrast agents. *IEEE Trans Ultrason Ferro Freq Cont*. 2023;70:693-707.

doi: 10.1109/TUFFC.2023.3268603

52. Williams RP, Karzova MM, Yuldashev PV, *et al*. Microbubble-mediated ultrasound drug-delivery and therapeutic monitoring. *Expert Opin Drug Deliv*. 2017;14:1031-1043.

doi: 10.1080/17425247.2017.1266328

53. Nazary Abrbekoh F, Salimi L, Saghati S, *et al*. Application of microneedle patches for drug delivery, doorstep to novel therapies. *J Tissue Eng*. 2022;13:20417314221085390.

doi: 10.1177/20417314221085390

54. Arno MC, Simpson JD, Blackman LD, *et al*. Enhanced drug delivery to cancer cells through a pH-sensitive polycarbonate platform. *Biomater Sci*. 2023;11:908-915.

doi: 10.1039/D2BM01626E

55. Chen W, Cheng CA, Zink JI. Spatial, temporal, and dose control of drug delivery using noninvasive magnetic stimulation. *ACS Nano*. 2019;13:1292-1308.

doi: 10.1021/acsnano.8b06655

56. Huang J, Xiao K. Nanoparticles-based strategies to improve the delivery of therapeutic small interfering RNA in precision oncology. *Pharmaceutics*. 2022;14:1586.

doi: 10.3390/pharmaceutics14081586

57. Jia M, Zhang D, Zhang C, Li C. Nanoparticle-based delivery systems modulate the tumor microenvironment in pancreatic cancer for enhanced therapy. *J Nanobiotechnol*. 2021;19:384.

doi: 10.1186/s12951-021-01134-6

58. Zhao JF, Zou FL, Zhu JF, *et al*. Nano-drug delivery system for pancreatic cancer: A visualization and bibliometric analysis. *Front Pharmacol*. 2022;13:1025618.

doi: 10.3389/fphar.2022.1025618

59. Tao F, Sui F, Liu A, *et al*. Digital twin-driven product design framework. *Int J Prod Res*. 2019;57:3935-3953.

doi: 10.1080/00207543.2018.1443229

60. Fuller A, Fan Z, Day C, Barlow C. Digital twin: Enabling technologies, challenges and open research. *IEEE Access*. 2020;8:108952-108971.

doi: 10.1109/ACCESS.2020.2998358

61. Grieves M, Vickers J. Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems. In: *Trans-disciplinary Perspectives on Complex Systems*. Cham, Switzerland: Springer; 2017. p. 85-113.

doi: 10.1007/978-3-319-38756-7_4

62. Razek A. Monitoring complexity in clean energy systems applications. *Clean Energy Sustain*. 2024;2:10007.

doi: 10.35534/ces.2024.10007

63. Sun T, He X, Li Z. Digital twin in healthcare: Recent updates and challenges. *Digit Health*. 2023;9:20552076221149651.

doi: 10.1177/20552076221149651

64. Sun T, He X, Song X, *et al*. The digital twin in medicine: A key to the future of healthcare? *Front Med*. 2022;9:907066.

doi: 10.3389/fmed.2022.907066

65. De Benedictis A, Mazzocca N, Somma A, Strigaroet C. Digital twins in healthcare: An architectural proposal and its application in a social distancing case study. *IEEE J Biomed Health Inform*. 2022;27:5143-5154.

doi: 10.1109/JBHI.2022.3205506.

66. Haleem A, Javaid M, Singh RP, Suman R. Exploring the revolution in healthcare systems through the applications of digital twin technology. *Biomed Technol*. 2023;4:28-38.

doi: 10.1016/j.bmt.2023.02.001

67. Mohamed N, Al-Jaroodi J, Jawhar I, Kesserwan N. Leveraging digital twins for healthcare systems engineering. *IEEE Access*. 2023;11:69841-69853.

doi: 10.1109/ACCESS.2023.3292119

68. Mohamed N, Al-Jaroodi J, Jawhar I, Kesserwan N. How Healthcare Systems Engineering Can Benefit from Digital Twins? In: *Proceedings of the 2023 IEEE International Systems Conference (SysCon)*, Vancouver, BC, Canada; 2023. p. 1-6.

doi: 10.1109/SysCon53073.2023.10131101

69. Ricci A, Croatti A, Montagna S. Pervasive and connected digital twins-a vision for digital health. *IEEE Internet Comput*. 2022;26:26-32.

doi: 10.1109/MIC.2021.3052039

70. Okegbile SD, Cai J. Edge-Assisted Human-to-Virtual Twin Connectivity Scheme for Human Digital Twin Frameworks. In: *Proceedings of the 2022 IEEE 95th Vehicular Technology Conference: (VTC2022-Spring)*, Helsinki, Finland; 2022. p. 1-6.

doi: 10.1109/VTC2022-Spring54318.2022.9860619

71. Das C, Mumu AA, Ali MF, *et al*. Toward IoRT collaborative digital twin technology enabled future surgical sector: Technical innovations, opportunities and challenges. *IEEE Access*. 2022;10:129079-129104.

doi: 10.1109/ACCESS.2022.3227644

72. Carbonaro A, Marfoglia A, Nardini F, Mellone S. CONNECTED: Leveraging digital twins and personal knowledge graphs in healthcare digitalization. *Front Digit Health*. 2023;5:1322428.

doi: 10.3389/fdgth.2023.1322428

73. Strobel G, Möller F, van der Valk H. *Healthcare in the Era of Digital Twins: Towards a Domain-Specific Taxonomy. Technical Report Healthcare IT, European Conference on Information Systems*; 2022. Available from: https://api.semanticscholar.org/CorpusID:251034187 [Last accessed on 2024 Jul 01].

74. Humphrey JD. Biological soft tissues. In: Sharpe W, editor. Springer Handbook of Experimental Solid Mechanics. Springer Handbooks. Boston, MA., USA: Springer; 2008.

doi: 10.1007/978-0-387-30877-7_7

75. Kallin S. *Deformation of Human Soft Tissues: Experimental and numerical aspects. Licentiate Thesis,* Jönköping University, School of Health and Welfare, HHJ, Department of Rehabilitation; 2019. Available from: https://hj.diva-portal.org/smash/get/diva2:1344790/FULLTEXT01.pdf [Last accessed on 2024 Mar 17].

76. Al-Dirini RMA, Reed MP, Hu JW, Thewlis D. Development and validation of a high anatomical fidelity FE model for the buttock and thigh of a seated individual. *Ann Biomed Eng*. 2016;44(9):2805-2816.

doi: 10.1007/s10439-016-1560-3

77. Fung YC. *Biomechanics: Mechanical Properties of Living Tissues*. 2nd ed. New York, Berlin: Springer-Vlg; 1993.

doi: 10.1007/978-1-4757-2257-4

78. Henninger HB, Reese SP, Anderson AE, Weiss JA. Validation of computational models in biomechanics. *Proc Inst Mechan Eng H*. 2010;224(7):801-881.

doi: 10.1243/09544119JEIM649

79. Gabriel S, Lau RW, Gabriel C. The dielectric properties of biological tissues: II. measurements in the frequency range 10 Hz to 20 GHz. *Phys Med Biol*. 1996;41:2251-2269.

doi: 10.1088/0031-9155/41/11/002

80. Barchanski A, Steiner T, De Gersem H, Clemens M, Weiland T. Local grid refinement for low-frequency current computations in 3-D human anatomy models. *IEEE Trans Magn*. 2006;42:1371-1374.

doi: 10.1109/TMAG.2006.871449

81. Noetscher GM. The CAD-Compatible VHP-Male Computational Phantom. In: Makarov SN, Noetscher GM, Nummenmaa A, editors. *Brain and Human Body Modeling 2020: Computational Human Models Presented at EMBC 2019 and the BRAIN Initiative® 2019 Meeting*. Cham, Switzerland: Springer; 2020. p. 309-323.

doi: 10.1007/978-3-030-45623-8_19

82. Makarov SN, Noetscher GM, Yanamadala J, *et al*. Virtual human models for electromagnetic studies and their applications. *IEEE Rev Biomed Eng*. 2017;10:95-121.

doi: 10.1109/RBME.2017.2722420

83. Song Y. Human digital twin, the development and impact on design. *J Comput Inf Sci Eng*. 2023;23:060819.

doi: 10.1115/1.4063132

84. Burattini S, Montagna S, Croatti A, *et al*. An Ecosystem of Digital Twins for Operating Room Management. In: *Proceedings of the 2023 IEEE 36th International Symposium on Computer-Based Medical Systems (CBMS),* L'Aquila, Italy; 2023. p. 770-775.

doi: 10.1109/CBMS58004.2023.00317

85. Hagmann K, Hellings-Kuß A, Klodmann J, *et al*. A digital twin approach for contextual assistance for surgeons during surgical robotics training. *Front Robot AI*. 2021;8:735566.

doi: 10.3389/frobt.2021.735566

86. Katsoulakis E, Wang Q, Wu H, *et al*. Digital twins for health: a scoping review. *NPJ Digit Med*. 2024;7:77.

doi: 10.1038/s41746-024-01073-0

87. Cusumano D, Boldrini L, Dhont J, *et al*. Artificial intelligence in magnetic resonance guided radiotherapy: Medical and physical considerations on state of art and future perspectives. *Phys Med*. 2021;85:175-191.

doi: 10.1016/j.ejmp.2021.05.010

88. Seetohul J, Shafiee M, Sirlantzis K. Augmented reality (AR) for surgical robotic and autonomous systems: State of the art, challenges, and solutions. *Sensors* (*Basel*). 2023;23:6202.

doi: 10.3390/s23136202

89. Avrumova F, Lebl DR. Augmented reality for minimally invasive spinal surgery. *Front Surg*. 2023;9:1086988.

doi: 10.3389/fsurg.2022.1086988

90. Long Y, Cao J, Deguet A, Taylor RH, Dou Q. Integrating Artificial Intelligence and Augmented Reality in Robotic Surgery: An Initial dVRK Study Using a Surgical Education Scenario. In: *Proceedings of the International Symposium on Medical Robotics (ISMR)*, Atlanta, GA, USA; 2022. p. 1-8.

91. Fu J, Rota A, Li S, *et al.* Recent advancements in augmented reality for robotic applications: A survey. *Actuators*. 2023;12:323.

doi: 10.3390/act12080323

92. Qian L, Wu JY, DiMaio SP, *et al*. A review of augmented reality in robotic-assisted surgery. *IEEE Trans Med Robot Bionics*. 2020;2:1-16.

doi: 10.1109/TMRB.2019.2957061

93. Razek A. Matching of an observed event and its virtual model in relation to smart theories, coupled models and supervision of complex procedures-A review. *Comptes Rendus Phys.* 2024;25:1-16.

doi: 10.5802/crphys.184

94. Nunes AS, Dular P, Chadebec O, Kuo-Peng P. Subproblems applied to a 3-D magnetostatic facet FEM formulation. *IEEE Trans Magnet*. 2018;54(8):7402209.

doi: 10.1109/TMAG.2018.2828786

95. Cicuttin M, Geuzaine C. Numerical investigation of a 3D hybrid high-order method for the indefinite time-harmonic Maxwell problem. *Finite Elements Anal Des*. 2024;233:104124.

doi: 10.1016/j.finel.2024.104124

96. Piriou F, Razek A. Numerical simulation of a nonconventional alternator connected to a rectifier. *IEEE Trans Energy Convers*. 1990;5:512-518.

doi: 10.1109/60.105275

97. Bernard L. *Electrical Characterization of Biological Tissues and Computing of Phenomena Induced in the Human Body by Electromagnetic Fields Below 1 GHz. PhD Thesis,* Universities of Ecole Centrale de Lyon, France and Universidade federal de Minas Gerais, Brazil; 2007. Available from: https://theses.hal.science/tel-00179791v3 [Last accessed on 2024 Nov 20].

98. Ren Z, Razek A. Force calculation by Maxwell stress tensor in 3D hybrid finite element-boundary integral formulation. *IEEE Trans Magnet*. 1990;26(5):2774-2776.

doi: 10.1109/20.104869

99. Freschi F, Giaccone L, Cirimele V, Canova A. Numerical assessment of low-frequency dosimetry from sampled magnetic fields. *Phys Med Biol.* 2018;63(1):015029.

doi: 10.1088/1361-6560/aa9915

100. Li C, Ren Z, Razek A. An approach to adaptive mesh refinement for three-dimensional eddy-current computations. *IEEE Trans Magn*. 1994;30:113-17.

doi: 10.1109/20.272523

101. Piriou F, Razek A. Calculation of saturated inductances for numerical simulation of synchronous machines. *IEEE Trans Magn*. 1983;19(6):2628-2631.

doi: 10.1109/TMAG.1983

102. Madani SS, Schaltz E, Kær SK. Thermal analysis of cold plate with different configurations for thermal management of a lithium-ion battery. *Batteries*. 2020;6:17.

doi: 10.3390/batteries6010017

103. Urdaneta-Calzadilla A, Galopin N, Niyonzima I, *et al*. FEM-BEM modeling of nonlinear magnetoelectric effects in heterogeneous composite structures. *IEEE Trans Magn*. 2024;60(3):7401704.

doi: 10.1109/TMAG.2023.3339088

104. Razek A. Coupled models in electromagnetic and energy conversion systems from smart theories paradigm to that of complex events: A review. *Appl Sci*. 2022;12:4675.

doi: 10.3390/app12094675

105. Razek A. Strategies for managing models regarding

environmental confidence and complexity involved in intelligent control of energy systems - A review. *Adv Environ Energies*. 2023;2(1):aee020104.

doi: 10.58396/aee020104

106. Kudela J, Matousek R. Recent advances and applications of surrogate models for finite element method computations: A review. *Soft Comput*. 2022;26:13709-13733.

doi: 10.1007/s00500-022-07362-8

107. Koziel S, Pietrenko-Dabrowska A. *Fundamentals of Data-driven Surrogate Modeling*. Europe: World Scientific Publishing Europe Ltd.; 2022. p. 1-37.

doi: 10.1142/9781800610750 0001

108. Lebensztajn L, Marretto CAR, Caldora Costa M, Coulomb JL. Kriging: A useful tool for electromagnetic device optimization. *IEEE Trans Magn*. 2004;40(2):1196-1199.

doi: 10.1109/TMAG.2004.824542

109. Gaignaire R, Scorretti R, Sabariego RV, Geuzaine C. Stochastic uncertainty quantification of eddy currents in the human body by polynomial chaos decomposition. *IEEE Trans Magn*. 2012;48(2):451-454.

doi: 10.1109/TMAG.2011.2171925

110. Bates HW. Contributions to an insect fauna of the amazon valley. *Lepidoptera*: Heliconidae. *Trans Linnean Soc London*. 1862;23(3):495-566.

doi: 10.1111/j.1096-3642.1860.tb00146.x