REVIEW ARTICLE

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Digital Monitoring of Electromagnetic Radiation Associated with Biodiversity (One Health) in Natural Parks: A Narrative Review

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Abstract

Up to date technologies, created by humans and utilizing electromagnetic fields (EMFs), present both anticipated benefits and undesirable side effects. These effects can influence the living tissues of all exposed biodiversity, in accordance with the "One Health" principle. The operation of modern natural parks encourages Internet connections via antennas, linked to park management, security, and telecommunications. These connectivity needs are tied to the functioning of all living organisms within the park, which depend on environmental conditions, according to the time and season. The antenna providing Internet access is a source of EMF; this coverage/exposure relationship can be monitored and controlled, thus enabling appropriate temporal and spatial emissions. The central scientific question of this narrative review is to analyze and highlight the continuous monitoring of emission intensity in relation to the behavior of different living tissues within the park's biodiversity, using an autonomous EMF source control procedure. The article addresses issues related to natural parks and biodiversity, the behavior of living tissues in response to environmental conditions, transmitting antennas and exposure to EMFs, autonomous control procedures, and intelligent management of emissions/exposure and biodiversity-related concerns involving an artificial intelligence-assisted autonomous procedure and digital twin-based monitoring of connected biodiversity. These are the review's contribution to this research field. In addition, other aspects related to plants and exposure to electromagnetic fields are addressed succinctly in the discussion, for example the electrophysiology of plants, their position and relationship with the biodiversity of the park, the electromagnetic environment and plant performance and ecosystem stability, and more. Further details, focusing on plant electrophysiology and directly related to the subject of JPE, are being written for a future article. The various themes addressed in this article are supported by literature reviews that facilitate understanding.

Keywords: electromagnetic fields, antennas exposures, One Health, biodiversity, natural parks, environmental conditions, autonomous procedures, artificial intelligence, digital twins.

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1 Introduction

Recently, ecological transformations have gradually influenced urban planning considerations, leading to a reorientation of design practices towards regenerative and nature-based situations. This change has resulted in the management of places as living ecosystems closely resembling nature. Furthermore, strategies that take into account the contextual nature of human-environment interactions are being implemented to highlight adaptive planning accounting for biodiversity [1, 2]. Simultaneously, human society has increasingly sought well-being through new technologies. A significant category of recently manufactured tools, utilizing electromagnetic fields (EMFs), has enabled numerous advanced applications and services. These devices present both anticipated benefits and harmful side effects. These effects can harm all exposed biodiversity, including humans, in accordance with the "One Health" concept [3].

Many ecosystems, such as nature parks, support humans surrounded by diverse flora and fauna. These parks can accommodate adults and children, wild and domestic animals, birds, fish, wild and ornamental plants, and many other species. They are considered a kind of ecological bedrock, providing humans with rich biodiversity through their infrastructure [4, 5]. They typically include a children's playground or a biodiversity-enhancing garden, thus contributing to personal well-being. They can serve as zoos, hiking trails, campsites and recreational spaces, promoting comfort and health by offering a quiet respite from the stress of modern urban life and providing protection from thermal risks [6–8].

The modern management of these spaces can take advantage of Internet connections via antennas, thus ensuring the operation and security of the park, as well as the telecommunication needs of staff and visitors. The use of such connectivity, of obvious importance [9, 10], nevertheless requires some special precautions regarding its coexistence with the park's biodiversity, including humans. Actually, the impacts of such connectivity are closely linked, on the one hand, to the presence of humans in the park, and on the other hand, to the functioning of all the living organisms in the park. The behaviors of these organisms are linked to environmental conditions such as daylight and weather conditions, which vary according to the time of day and the season [11]. To meet these challenges, it is necessary to manage the park area and monitor the emissions from the connected antennas in space and time. In reality, the antennas of connected base stations that provide Internet access emit electromagnetic (EM) radiation at high frequency (HF); this coverage/exposure duality can be supervised and controlled, thus enabling coherent spatiotemporal emissions.

The behavior of living tissues in organisms across biodiversity is linked to life situations in animals or plants. Indeed, tissue endeavors and temperatures are influenced differently by external stress conditions [12] such as EM radiation stress [13].

The adverse biological effects (BEs) of exposure to EM fields affect living tissues and the fluids that nourish them: blood in animals and sap in plants. These effects are primarily thermal and result from the dissipation of EM energy, mathematically described by Maxwell's EM equations. This dissipation causes the irrigated tissues to heat up, according to a bioheat phenomenon modeled by a bioheat (BH) equation, where the source corresponds to the dissipated EM energy. These exposure effects, which correspond to EM-BH coupling [14], can be mitigated by optimized organization of park areas, promoting biodiversity, and by an autonomous management procedure for antennas and exposed objects, taking environmental conditions into account.

This type of autonomous procedure, involving the emission of antennas onto exposed objects, can be digitally controlled in real time, taking into account spatiotemporal emissions and environmental conditions. This complex procedure can be assisted by artificial intelligence (AI) algorithms known for their ability to make effective decisions in this type of autonomous process [15–18]. Furthermore, monitoring of such AI-augmented autonomous procedures can be achieved through digital twins (DTs), which are recognized for their skill to reduce the complexity, uncertainties, and external risks of procedures [19–22].

The present paper aims to investigate and emphasize the monitoring of the exposure to EMFs emitted by a base station of antennas on the biodiversity of a natural park. This monitoring takes into account the behavior of different organisms within the park's biodiversity, using a controlled autonomous system. This system can be assisted by AI tools and supervised by a DT implement, thus augmenting decision-making and reducing the system associated complexity, uncertainties, and risks. These are the present review's contribution to EMF and park's biodiversity. Furthermore, additional aspects related to plants and exposure to EMFs are addressed in the discussion, As mentioned previously, further details, focused on plant electrophysiology and directly related to the subject of this journal (JPE), are being written for a later article. This narrative review includes:

- Natural parks and biodiversity: One Health approach, park adapted infrastructure;
- Behavior of living tissues in response to environmental conditions: plants environmental behaviors, general animal adapted comportments;
- Emitting antennas and EMF exposure: EMF source emission control, EMF exposure effects;
- Autonomous controlled procedures for transmission infrastructures: emission coverage and exposure dual management, closed loop transmission procedure;
- Smart managing of emission/exposure and biodiversity concerns: AI-assisted autonomous procedure, DT-monitoring of biodiversity exposure;
- Discussion of other aspects related to plants and exposure to EMFs and future works perspectives;
- Conclusions.

2 Natural Parks and Biodiversity

Appreciating how land-utilize variations influence the ecosystem facilities delivered by urban green areas is central to valuing the worth of such places. An ecosystem facility is characterized as the occurrences and instruments which allow natural ecosystems with their organisms to maintain and take care of human life. This view has become a basis of contemporary environmental policy, particularly in urban backgrounds. The facilities of an ecosystem fall into several categories: unpolluted atmosphere, control of parasites and infections, prevention of natural catastrophes, guaranteed harvests and cross-fertilization of plants, improved health of inhabitants, treatment and decomposition of wastewater, climate regulation, preservation of soil fertility and acting as a checking of the proliferation of disease vectors.

One can rationalize how the urban development distresses the relative significance of distinctive ecological facilities. Ecosystem facilities are often menaced by growing expansion or shifting the use of land. All those dependent on these facilities could suffer the consequences of this alteration. Assessing such menaces can be possible by rating the spatiotemporal modification of the facility value next to such alteration.

Based on the above, the link between ecological transformations, urban planning, natural spaces, and human-environment interactions, as well as the harmful effects of new technologies, suggests considering the "One Health" approach, which takes biodiversity into account. This link relates to the biodiversity of natural parks [23, 24] exposed to EMFs, studied within the framework of this work.

2.1 One Health Approach

The "One Health" concept [25] is a cohesive and merging line of defense that focuses on ecological balance, optimizing the health of humans, animals (domestic and wild), plants (ornamental and natural) and the broader natural world (counting ecosystems), all intimately joined and behaving interdependently [26]. This approach deals with the mutual requirement for clean air, water and energy, as well as secure and healthful nutrition, while advancing the protection of biodiversity and sustainable expansion [3]. In the situation of urban background such approach includes the health of people, animals, birds, aquatic living organisms, and plants, all menaced by perturbations created by artificial manmade undertakings.

2.2 Park Adapted Infrastructure

The spatial planning of a nature park's infrastructure can promote the protection of biodiversity against the man-made pollution mentioned earlier [11–13]. For example, activities requiring an Internet connection (through a base station (BS) antennas), such as park administration, security, and telecommunications, should be concentrated in a restricted area. Similarly, it is important to define zones based on activity schedules, taking into account the sleep-wake cycles of species, the seasonal hibernation of animals, and the sap flow of plants. Figure 1 illustrates such spatial park's planning.

3 Behavior of Living Tissues in Response to Environmental Conditions

All living things (plants, animals, and microorganisms) respire. Respiration allows autotrophs (which produce their own food from inorganic sources) and heterotrophs (which consume other organisms) to obtain energy from carbohydrates.

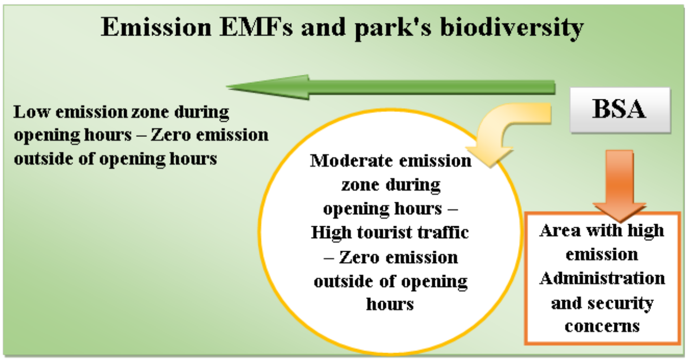

Figure 1. Illustrative schematics of spatial planning of a nature park's infrastructure accounting for park and BSA operational conditions.

This energy is essential for their growth, movement, and the execution of their vital functions.

3.1 Plants Environmental Behaviors

Plant life processes rely on two essential functions: photosynthesis and respiration. They respire both day and night. However, photosynthesis only occurs during the day, in the presence of light. These functions adapt to different natural environmental conditions, such as temperature, light intensity, and humidity. Any environmental stress, such as water or nitrogen stress, can disrupt these functions [12, 13].

Actually, photosynthesis is the process by which plants, in the presence of light, produce their food and energy reserves. Several factors enhance photosynthesis, such as higher temperatures (20 to 35 °C), CO_2 concentration, light intensity, leaf surface area exposed to light, and water availability in the soil (transpiration allows for CO_2 absorption). Respiration is approximately the reverse of photosynthesis in terms of overall reactants and products, though the two processes occur via distinct enzymatic pathways in different organelles. It consumes oxygen (oxidation of sugars) and releases CO_2 and water. The key factors influencing respiration in plants include: temperature (min. below 0 °C and max. between 45 and 50 °C), stage of development, and plant type (woody plants respire less than herbaceous plants).

It is important to note that photosynthesis and respiration in plants are also linked to the intrinsic electrical activity of plant organs. This activity is indeed connected to the existence of ions and electrons associated with the cell membrane and the electron transport chain carrying out in the course of photosynthesis and respiration processes. This is related to the general motor activity of living tissues, involving not only the nervous and muscular systems of humans and animals, but also the living tissues of plants [27, 28] (see section 7.1 for more details).

3.2 General Animal Adapted Comportments

Animals, like humans, exhibit specific physiological behaviors: social, kinetic, reproductive, feeding, exploratory, territorial, reactive, comfort-related behaviors (including excretion, thermoregulation, and grooming), in addition to behaviors related to rest and sleep. Each type of behavior manifests itself through different, constantly evolving activities. These can be apparent, through direct observation, for instance walking, sleeping, vocalizing, feeding, etc., and invisible activities, detectable by functional processes related to the brain, heart, and other organs managed by the nervous system, for example variations in blood pressure.

A change in behavior can be temporary or continuous and constitutes the body's reaction to intrinsic or extrinsic stimuli. A negative stimulus, in turn, induces behavioral changes that appear as stressors. These include all life-threatening situations that the body cannot control or anticipate, such as a sudden noise or an attack. These stressors trigger stress responses involving the activation of neurological, endocrine, and immunological tracks. This results in behavioral and physiological changes that allow the body to adapt to the new conditions. Depending on the nature, intensity, and quantity of simultaneous stressors, the duration of exposure, and the body's state, the body's response can be detrimental.

Behavioral alterations may also be caused by pollution exposures, which can be chemical or geochemical, biological, or physical (light, heat, EMF radiation, sound waves), these exposures are environmental stressors [13, 29] and can affect humans, animals, birds, aquatic organisms, insects, etc. [30–32].

4 Emitting Antennas and EMF Exposure

As mentioned previously, in urban areas such as nature parks, operations and security, as well as telecommunications needs, require an Internet connection for transmission and reception via antennas using EM signals. These antennas are installed in BSAs near urban areas serving different users, and they employ different technologies depending on their application. They can be, for example, directional [33, 34], omnidirectional [35], array [36, 37], multiport [38], multiple input multiple output (MIMO) [39–41] and more. These multiple and different structures allow for scalable use, which can be adjusted according to demands.

4.1 EMF Exposure Effects

As previously mentioned, exposure to EMFs from BSA affects the various living tissues of species found in urban environments. This exposure can generate BEs in tissues, characterized by the specific absorption rate (SAR) in watts/kg, which measures the energy absorbed per unit mass by the tissue over a given time interval. These BEs are primarily thermal and result from the dissipation of EM energy, which causes heating of the irrigated tissues. These thermal effects, at excessive SAR values and durations, can be dangerous. Non-thermal electrophysiological effects, which manifest at lower exposure levels, lie beyond the scope of this article; they will be addressed in a later article.

The EM energy dissipated in the tissue and its thermal behavior correspond to physical phenomena that can be mathematically represented by Maxwell's EM equations and a BH equation, respectively. The EM equations (see reference [3] [equations 6 to 9]) characterize the integrated electric and magnetic fields, taking into account the EM properties of the material, its electrical conductivity, dielectric permittivity, and magnetic permeability. The BH equation (see reference [3] [equation 10]) characterizes the temperature rise due to heat transfer, taking into account the bioheat properties of the material, its specific heat, thermal conductivity, density, and heat transfer by convection via the tissue irrigation fluid. The source terms in these equations are the exposure EM field for the EM equation and the EM power dissipation (see [3] [equation 11]) for the BH equation. The solution of the EM and BH equations is coupled by the dissipation of EM power, which results from the former and constitutes the source of the latter. Such coupling behaves like an interdependence where the different parameters involved can be mutually affected between EM and BH phenomena [3, 14].

Other effects of EMF exposure are related to the possible perturbation of electronic devices in general and in particular wearable devices used for health observation and assistance. These can be protected through adapted design or shielding, both can be controlled by EM compatibility (EMC) routines [42].

It is worth noting, as stated in Section 3.1, that another type of effect of EMF exposure is related to the possible disruption of the intrinsic electrical activity of living tissues. Indeed, the electrical phenomena that occur in living organisms are produced, as previously mentioned, by ions and electrons associated with the components of the cell membrane and electron transport chains during natural life processes such as photosynthesis and respiration. This is linked to motor activity, involving not only the human and animal nervous and muscular systems, but also various plant tissues [27, 28].

4.2 Thermal Tissues BE Evaluation

As abovementioned the interdependent coupled phenomenon related to EM and BH behaviors permits the evaluation of the tissue temperature rise following to an EMF exposure. In the case of exposure on different biodiversity species, the evaluation should account for the features of the involved tissues related to their topological complexity, inhomogeneity, nonlinear behaviors and the mentioned interdependence. Satisfying such actual features requires a tissue local evaluation. Thus the solution of the EM-BH equations suggesting the practice of discretized 3D techniques such as finite elements method or equivalent schemes. The coupling of the locally discretized EM-BH equations would be weak due to the distant values of the time constants of the two phenomena [42–44]. Thus, the execution of an iterative procedure gives the local distributions in the tissue of the EM fields induced, dissipated power, SAR and temperature rise. These local values can be verified by comparing them to the thresholds set by safety standards [45–47].

A summarized treatment of EMF exposure effects on biodiversity with their control strategies are shown on Figure 2.

5 Autonomous Controlled Procedures for Transmission Infrastructures

The effects of exposure to EMFs mentioned above can be mitigated by an autonomous, digitally controlled, real-time procedure that considers antenna emissions and exposed objects, as well as spatiotemporal coverage and environmental conditions. This procedure involves complex behaviors related to the scalability of the base station, the conduct of exposed tissues, the relationship between coverage and exposure, the multiplicity of environmental conditions, and the heterogeneity of the collected sensor data.

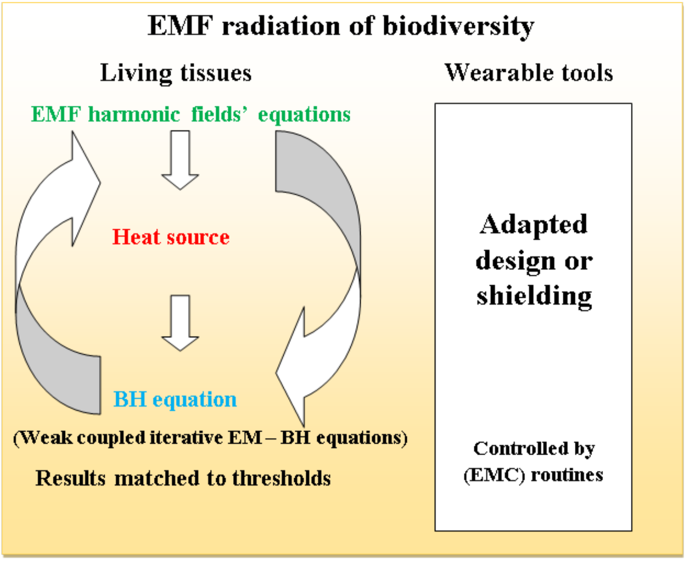

Figure 2. Managing the effects of exposure to EMFs on biodiversity through control strategies.

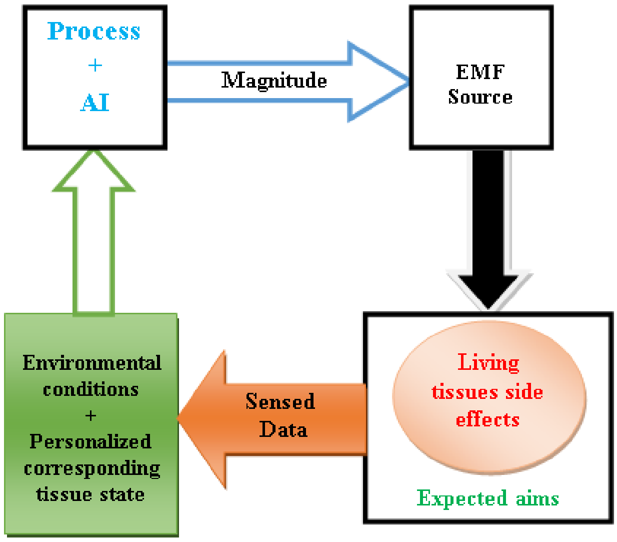

Figure 3. Schematics of autonomous procedure including the EMF source antennas, expected emissions, exposed living tissues, environmental conditions, and AI-assisted antenna processing and control.

5.1 Emission Coverage and Exposure Dual Management

As abovementioned the antennas in the base station related to the concerned area can be multiple and different and hence scalable, allowing the management of coverage and signal strength, by increasing or decreasing different parts of the infrastructure according to the demand of the base station. Thus, the previously mentioned coverage/exposure duality can be supervised and controlled, thereby enabling coherent spatiotemporal emissions that take into account the spatial organization of the area and the temporal behavioral activities of biodiversity species. It should be noted that a coverage with good signal strength allows for convenient and safe use of telecommunication tool.

5.2 Closed Loop Transmission Procedure

The autonomous, digitally controlled, real-time procedure operates in a closed loop and takes into account the source of EMFs from the antennas, expected emissions, exposed living tissues, environmental conditions related to the state of the tissues, and AI-assisted antenna processing and control. Thus, this complex procedure considers targeted emissions, unwanted exposures, and spatiotemporal coverage related to environmental conditions, all with the help of AI for optimal decision-making (see the next section). This closed loop transmission procedure is illustrated in Figure 3.

6 Smart Management of Emission/Exposure and Biodiversity Concerns

The complex closed-loop emission/exposure – biodiversity procedure mentioned, including targeted emissions, undesired exposures and spatiotemporal coverage related to environmental conditions, must be administered. In the background of supervising such autonomous procedures, including complex and interdependent constituents, two classes of smart digital instruments are specifically adapted for handling such involvedness: AI [15–18] and DT [19–22]. Many details concerning these digital tools could be found in the cited literature; in this article, we are mainly interested in the possibilities of the strategies employed. AI, empowers decision-making of autonomous and automated procedures across data utilization, while its committed twig, machine learning (ML), permits data analysis in such procedures. Actually, AI leverages data to make learned decisions, while ML processes data to learn from it and continuously improve predictive models. DT on the other hand, assists diminish uncertainties and peripheral hazards contained by complex systems [19].

6.1 AI-Assisted Autonomous Procedure

AI is mainly a large assembly of tools that allow computers to operate elegantly, mimicking human being brainpower and performing routinely, for instance, in autonomous robotic interventions [48]. It uses data to attain knowledgeable conclusions and can come to be more effective as it accumulates further data [49, 50]. ML, as abovementioned, is a dedicated branch inside the extensive ground of AI. Its principal objective is to build and refine algorithms that develop into further consistent and proficient as they interact with data throughout time. It supplies computers to assess data, and create informed judgments or forecasts, all free of requiring particular programming for such tasks [51]. It definitely follows to lessen human interfering as much as feasible, schematizing the exercise of learning from data. Various implications of AI tools in general in green energy applications can be found for instance in predicting regional energy consumption [52] and green energy penetration [53].

Generally, AI and big data are necessary for generating real-time insights that permit decision-making in complex developments [15–17]. Blending sizable data flows and AI algorithms extends substantial capacity for obtaining utilizable data with remarkable rapidity and exactitude. AI can be expended for intricate decision-making, especially in the framework of autonomous procedures with high accuracy, and create decisions in the order of a second to avoid any problem. AI, via a series of guidelines, can administer various issues such as adaptive control, thus permitting heterogeneous, real-time decision-making. AI hence lets autonomous procedures to be achieved steadily and proficiently, thus decreasing the risk of error [54].

ML operated to data-driven forecasts allows the practice of prognostic analytics on data. Such algorithms continuously learn and update their predictions as added data raise to be handy, allowing tailored and proactive approaches. Thus, the employ of ML lets well-timed identification of threatened disorder, helping better outcomes, more consistent and reduced costs.

6.2 DT-Monitoring of the Autonomous Procedure

As mentioned earlier, a DT facilitates complexity management and reduces parametric uncertainties and peripheral threats in controlled composite systems [19, 20]. It embraces a real physical element, its virtual copy, and an interface permitting near-instantaneous bidirectional data transfer and synchronization. This physical-virtual pair enables inherent self-correction and adaptive updating, thus supporting the abovementioned management and reductions through control of the composite system. The correct matching operation in the DT involves transferring data from the real component and adapting it using external data such as the Internet of Things (IoT) and the system's learned operational history. The adapted result, after training via data analysis, is then directed to the virtual replica [55, 56]. The intrinsic complexity resulting from the interaction of the physical system's components is correlated with a complex coupled model in the virtual replica. The near-instantaneous correspondence in a DT suggests avoiding significant computation time, such as that required by a fully coupled model. Thus, the complete model must be replaced by a reduced-order model or a surrogate model, however retaining a faithful image of the real system [57, 58].

In general biodiversity management requests multidisciplinary methodologies reflecting problems related to spatial and temporal data, as well as shattered and disjointed datasets. In such background, the DT concept can play a potential solution in forwarding data model incorporation defies. As mentioned above DTs allow for dynamic near-instantaneous simulations combining different data flows, models, and decision-support responses [59, 60]. They are especially valued in investigating biodiversity and ecosystems under stresses associated to environmental conditions requiring various databases and models to enhance prognostic truthfulness [61]. These integrative approaches involve a complex technical environment [62]. These complexities are stressed by the discrepancy between the monitoring data and the increasing size of adjustable and automatic observations, two factors that complicate the elaboration of powerful models for forecast and simulation [63].

DT tools are progressively introduced in many fields such as healthcare [64–66], smart industries [67], fault detection and diagnosis [68], safety and reliability [69], manufacturing [70], human-robot collaborative assembly and construction [71, 72], and sustainable development [73, 74].

6.3 Combined AI-DT Monitoring of Biodiversity Exposure

Considering the two digital treatments discussed above, AI-assisted autonomous procedure along with its administration by a DT, Figure 4 illustrates such combined smart deed.

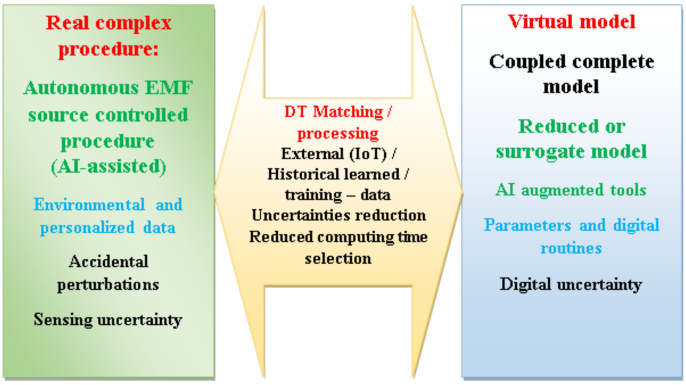

Figure 4. AI-assisted autonomous procedure along with its administration by a DT.

7 Discussion

In the investigations and analyses developed in the previous sections, a number of points deserve added discussion.

7.1 Intrinsic Electric Activity in Plants – Electrophysiology

Plants constitute a fraction of environmental biodiversity, from which they obtain and process nutrients and stimuli. They thus exhibit induced and natural activity that modifies their environment. The physiological processes that take place within them interact with one another. Plant electrophysiology studies the influence of electricity on plant physiology, comprising organ motion, extension and evolution processes [75].

As mentioned before an electric event happening in a living entity is produced by the tissue-present ions and electrons associated to the cell membrane properties as well as electron carriers involved in photosynthetic and respiratory processes. Such phenomenon is associated with human or animal nervous and muscular coordination responsible of motor activity, which is similar to different plant tissues [27, 28].

Actually, single-celled organisms, plants and animals encounter many of the same problems. A fundamental challenge is ensuring energy supply, reproduction, protection and acclimation. Augmenting the hopes of subsistence and proliferating, creatures at all levels of arrangement require to transmit inside and outside signals to regulate energy level in changing background. The electrical interaction at the simplest level serves universally for intra / inter-cellular, tissue-to-tissue and creature-to-creature communication. Solar energy is essential for plant functioning and therefore the association of electrical signals and other indications related to energy absorption presents an influential means that globally controls plant homeostasis. Different involvements of plant electrophysiology including effects of ionizing radiation, excess energy absorption, as well as problems related to plant acclimatization, precision agriculture, and infection can be found in the literature [76–81]. In addition, various disturbances can be observed, for example, EMFs disrupt ion channels, membrane potential or Ca^{2+} signaling [82], electrical signaling and long-distance communication in plants [83], disturbances related to the photosynthetic rate on light respiration and adaptive responses of plants to light stress [84, 85], and ecosystem-level effects of long-term low-level EMFs [86].

7.2 Position and Relationship of Plants with Park Biodiversity

In general, living organisms included in the biodiversity interact all together. Such interactions can be mutually beneficial or negatively harmful. The role of plants in park biodiversity is mostly beneficial for human adults and children, birds, insects, etc.

Relating to EMF exposure, this can enhance plant conditions in case of moderate field strengths, specific frequencies, and short exposure duration. However for higher field strengths, frequencies and durations, the EMF exposure could be harmful, provoking plant stress; this is the case for most telecommunication BSA.

7.3 EM Environment and Plant Performance and Ecosystem Stability

In plants, the effects of EM radiation, particularly that from sunlight, are essential for photosynthesis, the process by which they convert sunlight into energy. Different wavelengths of light exert specific effects on plant development. Photosynthesis can therefore be optimized through the use of artificial light sources with controlled characteristics, intensity, and exposure intervals, thus stimulating plant growth. Furthermore, various studies are investigating the effects of EM radiation and its significant impact on seed robustness and germination, mineral nutrition, ant nutritional factors, and pest prevention [87, 88]. All these advantageously EMF exposure effects help significantly ecosystem stability.

7.4 Animal and Plant Living Tissues under HF-EMF Exposure

In previous sections, the term "living tissues" refers to tissues composed of solid substances associated with soft matter, irrigated by fluids that ensure their function. The main living tissues studied here are those of animals and plants. The corresponding irrigated soft matter are, respectively, the veins and arteries that contain blood in animals, and the xylem and phloem that contain sap in plants. The correlation of xylem and phloem enclosing the sap in plants and veins and arteries enveloping the blood in animals is shown in Figure 5.

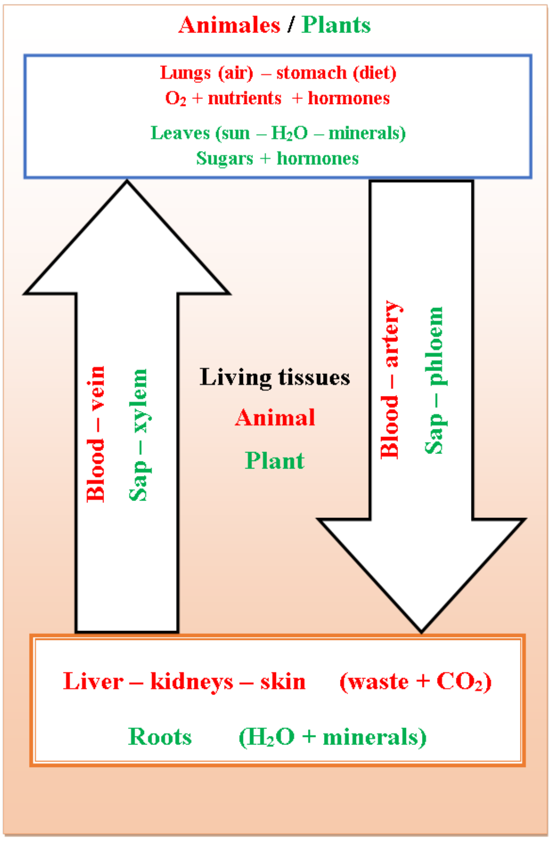

Figure 5. Schematic illustration of the correspondence of xylem and phloem enclosing the sap in plants (Green color) and veins and arteries enveloping the blood in animals (Red color).

These living tissues are protected by a thin outer layer against natural aggressions such as the sun, wind, frost, etc. Faced with natural heating due to the sun, characterized by heat transfer by conduction through this outer layer and by convection in the irrigating fluids, the tissues' self-protection is well adapted. On the other hand, this self-protection proves ineffective against the thermal BEs induced by exposure to HF-EMF, as the tissues are not intended for such exposure [89–93]. Indeed, HF-EMF radiation has two particular characteristics: the dissipation of EM energy directly in the internal layers of tissues and its strong capacity to instantaneously heat tissues [42, 43]. It should be noted that in the event of disproportionate heating of the internal layers, only fluid irrigation of the tissues can remedy this, and that insufficient irrigation would be harmful to the affected tissue.

The tissues locally induced fields (as mentioned in section 4) subsequent to HF-EMF exposure, can be checked matched to safety thresholds [45–47]. Estimating these thresholds for non-human tissues such as plants or insects, is difficult due to the narrow number of research accomplished in this topic and the substantial morphological and anatomical diversity amongst species [94].

Indeed, manmade HF-EMF sources are environmentally ever-present. Consequently, the putting into practice of standardized regulations has come to be a priority to guard humans from risky radiation. Evaluating the possible effects of HF-EMF on plants rests intricate, however, as it hinge on species- individual factors [95].

7.5 Future Works Perspectives

Relating to plant electrophysiology discussed in section 7.1, a potential effect of EMF exposure is linked to the disturbance of the intrinsic electrical activity of living tissues, an occurrence that deserves further exploration.

As specified in Section 7.4, protection thresholds for non-human species are not determined, due to the wide-ranging morphological and anatomical diversity between species [94]. It is crucial to estimate classified thresholds for diverse species to control the influences of EMF exposure and therefore preserve biodiversity.

8 Conclusion

The present paper investigated and emphasized the monitoring of the exposure to EMFs emitted by antennas on the biodiversity of a natural park. This monitoring takes into account the behavior of different organisms within the park's biodiversity, using a controlled autonomous system. The main conclusions of this paper can be recapitulated as follows:

- One Health approach, park adapted infrastructure, behavior of living tissues in response to environmental conditions, emitting antennas and EMF exposure, autonomous controlled transmission procedures, smart managing of emission/exposure, are essential and closely related topics in the supervision of EM radiation associated with biodiversity in natural parks;

- Administration of spatiotemporal emission coverage related to environmental conditions, is crucial for reliable functioning of ecological natural parks;
- Innovative digital tools such as AI and DT keep promise for managing connected green natural parks;
- Research perspectives are recommended to assess the effect of EMF exposure related to the disruption of the intrinsic electrical activity of living tissues, and to estimate classified thresholds for various species in order to control the influences of EMF exposure and thus preserve biodiversity.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

Adel Razek serves as an Associate Editor of *Journal of Plant Electrobiology*. To ensure the integrity of the peer-review process, Adel Razek had no involvement in the editorial review, peer review, or decision-making process for this manuscript. The manuscript was handled independently by another editor in accordance with the journal's editorial policies. The remaining authors declare that they have no conflicts of interest.

AI Use Statement

The author declares that no generative AI was used in the preparation of this manuscript.

Ethical Approval and Consent to Participate

Not applicable.

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