Remote sensing archaeology: The next century

Lei Luo,[1,2,3] Xinyuan Wang,[1,2,3,*] and Huadong Guo[1,2,3,*]

[1]International Research Center of Big Data for Sustainable Development Goals (CBAS), Beijing 100094, China
[2]Key Laboratory of Digital Earth Science, Aerospace Information Research Institute (AIR), Chinese Academy of Sciences (CAS), Beijing 100094, China
[3]International Centre on Space Technologies for Natural and Cultural Heritage (HIST) Under the Auspices of UNESCO, Beijing 100094, China
*Correspondence: wangxy@aircas.ac.cn (X.W.); hdguo@radi.ac.cn (H.G.)

THE SCIENCE OF REMOTE SENSING ARCHAEOLOGY

The science of remote sensing archaeology (RSA) is a traditional yet innovative sub-discipline of archaeology that studies how to use general remote sensing technology to capture and interpret the characteristics of data taken from physical remains related to human activities, then using these findings to understand human history and culture. The theoretical and practical basis for aerial photography archaeology, the principle behind RSA, was first described by Crawford in 1923.[1] Over the past decades, although RSA has already led to significant breakthroughs in archaeological prospecting and mapping at a wide range of scales (Figures 1A and 1B), it is still crucial to consider fresh perspectives on the advantages of maintaining the influence of remote sensing technology and emerging cutting-edge technologies (artificial intelligence [AI], big data [BD], cyber infrastructure [CI], and digital twin [DT], etc.), which deserve detailed analysis as they may be able to serve as reference points for promoting the future development of RSA (Figure 1C).

REMOTE SENSING ARCHAEOLOGY: THE NEXT CENTURY

Recently, AI-based opportunities to interpret multimodal data collected by various remote sensing systems have been increasing, and training on how to employ AI technology and demonstrate its promise for application in archaeology is a realistic way of filling the gap between AI technology and the archaeological community. While the amount of AI-based research is limited at present, we
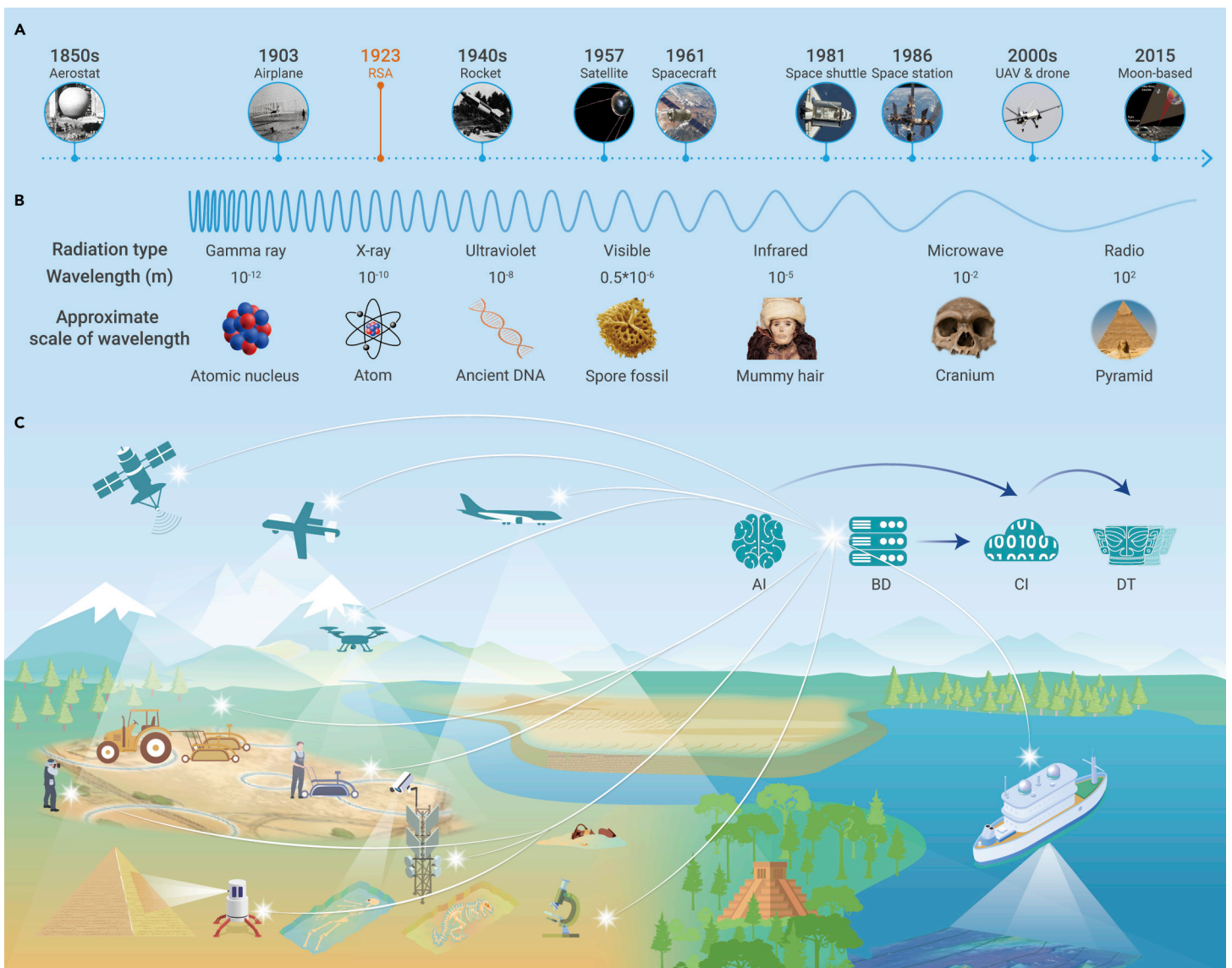

Figure 1. Remote sensing archaeology (RSA) (A) The development of remote sensing platforms. (B) The electromagnetic spectrum and approximate scale of the wavelength for RSA. (C) The schematic diagram of combing remote sensing networks (includes airborne and spaceborne sensing, proximal sensing, *in situ* sensing, and laboratory instrumental measurement and observation) with emerging cutting-edge technologies (AI, BD, CI, DT) for archaeological applications over the next century.

argue that the successes achieved by these recent attempts offer a way for AI archaeology to become more fully integrated with archaeological research beyond the detection of specific subtle features from massive amounts of remote sensing data.[1,2] The deep integration of AI algorithms and big remote sensing data is among the technologies that hold the most promise in terms of application to RSA and to archaeology in general over the next century.

Currently, remote sensing archaeologists are collecting and employing big remote sensing data to conduct their studies. We argue that the integration of big remote sensing data with other types of BD should be employed to provide novel insights to aid our understanding of the past. BD-driven archaeological research aims to find hidden correlated networks within massive datasets and provides the possibility of discovering and understanding past human activities as well as interactions between humans and the environment without any loss of complexity or dimensionality. It can be seen that recent and future advances in the use of BD in RSA will trigger a paradigm shift from model-driven to data-driven research, as well as the establishment of a data-intensive archaeological research approach.

It is important to note that, over the next century, while prospecting, preserving, and recording archaeological objects, RSA will need to consider not only the social benefits and the cultural interests of the public, but also how archaeologists can increase active public participation in archaeological research. The booming development and popularization of CI along with the free availability of remote sensing imagery have brought about a major turning point for RSA and unprecedented opportunities for public archaeology.[3] The integration of BD with CI will help promote the transition of RSA, and archaeology in general, from a specialized science to a citizen science in the next century. These are among the major ethical and moral questions that must be grappled with more effectively as citizen science-powered RSA advances further.

Over the next century, one of the great challenges that RSA will face is the countless tangible archaeological remains still poorly documented even as archaeological heritage sites face unprecedented and unpredictable threats from global climate change and the intensification of anthropogenic activities. Fortunately, the rapid development of DT technology now allows RSA specialists to document the remains and physical records as multidimensional digital datasets. At the same time, DT technology has the potential to provide the capacity and standard protocols that will allow the storage and processing of local, regional, and global massive data as well as offer access to both specialists and the public. CI, together with DT technology, will thus facilitate a shift in RSA from physical remains in the real world to digital heritage.

Over the past century, research in RSA has focused on the surveying and mapping of archaeological sites and landscapes by spatially processing and analyzing remote sensing data of the physical space. However, the use of remote sensing technologies (such as imaging spectrometry, imaging radar and lidar) alone does not make an RSA specialist a spatial thinker who understands the physical, mental, and social space of the past.[4] Thus, a move from spatial analysis to spatial thinking is needed in RSA over the next century. This transformation will trigger a paradigm shift toward space archaeology. The integrated application of remote sensing technologies and emerging cutting-edge technologies will be expected to provide new information about the relationship between the humans and environment of the past, as well as to improve the quality and accuracy of information.

SPACE ARCHAEOLOGY: A NEW PARADIGM

In this paper, we define the concept of "space archaeology" as a new and advanced stage in the science of RSA. Space archaeology comprises all aspects of our understanding of human-environment interactions, combining advanced remote sensing technologies with emerging technologies and covering the range from physical space or spatial practices to mental space or representations of space, social space or representational space, and cyber space. Space archaeology highlights the quaternity of physical, mental, social, and cyber spaces, so

as to understand the evolution of human society and interactions between humans and the environment.

In the new paradigm of space archaeology, it will be through the process of engaging with evidence or information derived from BD that representations of space will be conceived. These representations will include the AI-powered interpretations of survey and excavation plans, distribution maps, spatial patterns and models, and digital heritage that are used to represent and interpret spatial and social relationships. At the same time, through these representations of space, attempts will be made to link past spatial practices with the lived spaces of the people of the past in both physical and cyber space. It should be clearly pointed out that cyber space is a spatial metaphor applied to real places in the digital environment that will become, for RSA specialists in the next century, an essential aspect of archaeological discovery and of their understanding of the past human-environment interactions.

Space archaeology constitutes a paradigm shift away from archaeological prospecting, primarily using BD captured by remote sensing technologies, which involves understanding and thinking from a space-based view and an attempt to explain the relationships between culture (human) and space (environment) using remote sensing technologies and emerging cutting-edge technologies. The distinctive features of space archaeology include multi-disciplinary integration and cross-innovation. This method allows the strengths and values of the natural, applied, and formal sciences, as well as the social sciences and humanities, to be combined. It should also be pointed out that the fundamental purpose of space archaeology is the same as that of archaeology: that is, to help humans understand the past, address the major social and environmental challenges of the present, and search for a sustainable roadmap toward the future.[5]

CONCLUSIONS

In the next century, the general public, together with space archaeology specialists in the multi-disciplinary field, will form new groups that can jointly tackle key issues, broaden the spatial and temporal scope and coverage of archaeological research, and answer major scientific questions, such as those related to the basic picture and internal mechanisms behind the origin, formation, and development of human civilization, as well as analyze the relationship between changes in the geographical environment and the evolution of human civilization. In addition, galactic archaeology and cosmic archaeology, which use sensing-based observation technology to study the origin, formation, and evolution of the universe and extraterrestrial intelligence, have been classified as generalized space archaeology, and we look forward to future discussions on galactic archaeology and cosmic archaeology with astrophysicists and cosmologists.

REFERENCES

1. Luo, L., Wang, X., Guo, H., et al. (2019). Airborne and spaceborne remote sensing for archaeological and cultural heritage applications: a review of the century (1907–2017). Remote Sens. Environ. **232**, 111280.
2. Davis, D. (2021). Theoretical repositioning of automated remote sensing archaeology: shifting from features to ephemeral landscapes. J. Comput. Appl. Archaeol. **4**, 94–109.
3. Snow, D.R., Gahegan, M., Giles, C.L., et al. (2006). Cybertools and archaeology. Science **311**, 958–959.
4. Inomata, T., Triadan, D., Vázquez López, V.A., et al. (2020). Monumental architecture at Aguada Fénix and the rise of Maya civilization. Nature **582**, 530–533.
5. Stephens, L., Fuller, D., Boivin, N., et al. (2019). Archaeological assessment reveals Earth's early transformation through land use. Science **365**, 897–902.

DECLARATION OF INTERESTS

The authors declare no competing interests.