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Utilizing Remote Sensing for the Investigation of North Korean Cultural Heritage: A Case of Unregistered Royal Tombs of the Joseon Dynasty in North Korea

Hyunwoo Kim [1]

[1] Institute of Humanities, Seoul National University, Seoul, Republic of Korea - akhw01@snu.ac.kr

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Abstract

This study explores the potential of remote sensing as a method for investigating North Korean cultural heritage, which remains largely inaccessible to South Korean researchers despite its critical importance for understanding the Korean Peninsula’s past. In particular, it focuses on the use of Google Earth, which provides easy and extensive access to very high-resolution satellite imagery at no cost. North Korea is home to two royal tombs of the Joseon Dynasty that are excluded from South Korea’s UNESCO World Heritage inscription. A preliminary survey using Google Earth revealed that although detailed structures were difficult to discern, key elements such as burial mounds, platforms, and their spatial layout were identifiable. These findings suggest that Google Earth can be effectively utilized as a preliminary survey tool for North Korean heritage. However, due to its limitations in identifying unknown or poorly located sites, this study proposes future research utilizing AI-based methods—specifically Convolutional Neural Networks (CNNs)—to enhance automated detection capabilities.

1. Introduction

North Korean cultural heritage constitutes a shared cultural asset that holds critical value for understanding the historical and contemporary transformations of the Korean Peninsula. Spanning from prehistoric settlements to ancient states and historical kingdoms, the region of North Korea contains numerous sites that are vital for reconstructing Korea’s cultural evolution. Despite its significance, access to this heritage is extremely limited due to the closed nature of North Korean society and the fragile political relationship between the two Koreas. This has left substantial gaps in archaeological and historical narratives, with North Korean data forming a conspicuous “missing link” in Korean heritage studies.

Scholars in South Korea have made considerable efforts to overcome this barrier, primarily through indirect means such as analyzing North Korean publications or utilizing defectors’ testimonies. However, these sources are fraught with challenges: North Korean publications are often ideologically framed and lack detail, while legal restrictions limit the circulation of such materials in South Korea. Furthermore, the ideological foundation of North Korean scholarship—the “Juche” ideology—raises questions regarding the objectivity and reliability of their interpretations.

Given these constraints, it is imperative to explore alternative strategies for the investigation of North Korean heritage. One promising avenue is remote sensing, a method originally developed for military reconnaissance but now widely used in archaeological research. Since the 1980s, remote sensing has supported the discovery and monitoring of archaeological features, particularly in politically or geographically inaccessible regions (Lasaponara and Masini, 2011). Its utility spans site detection, landscape analysis, and long-term monitoring, making it an ideal non-intrusive tool for heritage studies.

This study examines the applicability of remote sensing to North Korean cultural heritage, with a particular focus on Google Earth—a freely accessible platform providing very high-resolution satellite imagery. Despite certain limitations in spectral range and metadata, Google Earth offers an unprecedented opportunity for South Korean researchers to conduct preliminary site assessments across North Korean territory. Through a focused case study on the royal tombs of the Joseon Dynasty located in the Gaeseong region, this paper evaluates the effectiveness of Google Earth as a tool for cultural heritage reconnaissance and proposes a future research agenda incorporating AI-assisted analysis for undocumented sites.

2. Remote Sensing for the Investigation of North Korean Cultural Heritage

Remote sensing, originally developed for military reconnaissance, has emerged as a valuable tool in archaeological research (Lasaponara and Masini, 2011), enabling the detection and monitoring of sites even in politically or physically inaccessible regions. These technologies are broadly categorized by altitude into terrestrial (ground-based), airborne, and spaceborne platforms, each offering distinct advantages and limitations in terms of spatial resolution, data availability, operational cost, and accessibility.

Ground-based remote sensing using UAVs and drones has gained popularity due to its high precision and cost-effectiveness. However, such platforms are not feasible for research on North Korea due to political and logistical restrictions. Consequently, spaceborne sensing via satellite imagery represents the only realistic method for remotely observing North Korean cultural heritage from South Korea.

Several sources of satellite imagery are available, each with specific strengths and weaknesses in the context of archaeological survey (Lindsay and Mkrtchyan, 2023). For example, the CORONA reconnaissance imagery offers high spatial resolution (approximately 1.83m) and has been successfully used to identify archaeological features in the Near East. However, its utility is limited in the Korean context due to its restricted geographic coverage of North Korea (Figure 1).

The Sentinel-2 satellite, part of the European Space Agency’s Copernicus program, provides free multispectral optical imagery that is ideal for tracking vegetation and landscape changes. It offers frequent image acquisition at five-day intervals, but its 10-

meter resolution is insufficient for detecting small-scale heritage features such as individual tomb structures or architectural remains.

Very high-resolution (VHR) commercial satellite imagery, such as those from KOMPSAT-3A (0.55m resolution) or WorldView-3 (0.31m resolution), can offer excellent detail for archaeological purposes. However, the high acquisition costs and licensing restrictions associated with such imagery pose significant limitations—especially in preliminary research phases, where the expected return on investment is uncertain and broad regional coverage is often required.

In contrast, Google Earth provides a highly accessible and cost-effective alternative. Although limited to RGB composite imagery and inconsistent in terms of metadata and spatial resolution, it integrates VHR satellite data from commercial providers, making it possible to visually assess a wide range of cultural heritage sites (Table 1). For researchers conducting preliminary surveys under budget constraints and political limitations, Google Earth emerges as the most practical and immediately usable tool (Luo et al., 2018).

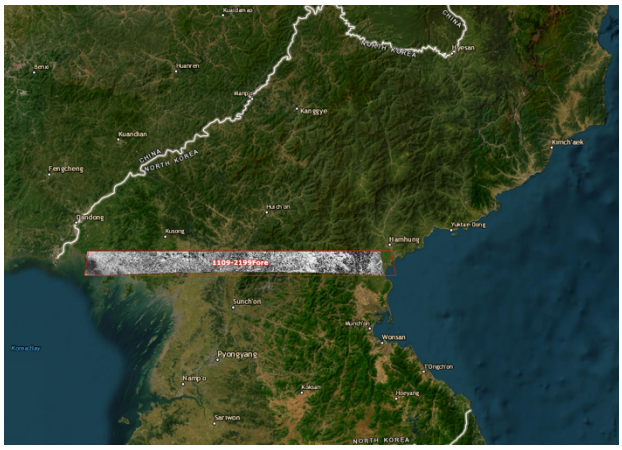

Figure 1. Screenshot showing coverage of georeferenced CORONA imagery in the North Korea available for free download from the CORONA Atlas website (1), developed at the University of Arkansas (Casana and Cothren, 2013)

Merits	Limitations
· User-friendly software with an easy-to-use interface · Sufficient horizontal positional accuracy · Freely accessible multi-temporal and multi-resolution remote sensing imagery · Easy visualization · Up-to-date thematic layers	· Inconsistency of remote sensing image quality · Lack of quantitative measurements and spatial analysis · Ethical issues related to the use of Google Earth

Table 1. Merits and limitations of Google Earth for archaeological research and cultural heritage survey (Luo et al., 2018, 19-21)

Previous study comparing Google Earth and KOMPSAT-3A imagery for heritage sites in North Korea have shown minimal difference in detection capacity (Kim and Yi, 2021). For example, features of the Lelang (樂浪, 108 BCE–313 CE) Fortress in Pyeongyang, including the west wall (Figure 2-3) and adjacent burial mounds (Figure 4-5), could be identified with similar clarity in both platforms. While commercial imagery may offer advantages in spectral analysis and geolocation accuracy, Google Earth suffices for visual identification and spatial context assessment—especially for large-scale features such as tomb platforms, ramparts, and spatial layouts.

Given these considerations, this study adopts Google Earth as the principal tool for preliminary investigation of cultural heritage in North Korea. Its wide availability, ease of use, and sufficient resolution make it particularly suited for exploratory research aimed at identifying the current condition and spatial characteristics of heritage sites, pending further detailed analysis or ground verification in the future.

Figure 2. West wall of Lelang fortress as seen on Google Earth (© Image Copyright 2025, Maxar Technologies)

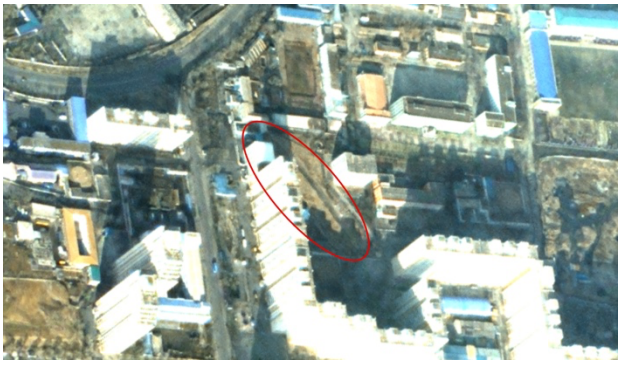

Figure 3. West wall of Lelang fortress as seen on KOMPSAT-3A (© Image Copyright 2020, Korea Aerospace Research Institute)

(1) corona.cast.uark.edu

Figure 4. The burial mounds located south of Lelang fortress as seen on Google Earth (© Image Copyright 2025, Maxar Technologies)

Figure 5. The burial mounds located south of Lelang fortress as seen on KOMPSAT-3A (© Image Copyright 2020, Korea Aerospace Research Institute)

3. Case: Detecting Royal Tombs of the Joseon Dynasty in North Korea using Satellite Imagery

Given the spatial resolution of available satellite imagery, the types of North Korean cultural heritage that can be identified from spaceborne platforms are limited to large-scale features such as fortresses, monumental buildings, and burial mounds. Among these, two royal tombs of the Joseon Dynasty located in present-day North Korea—Je-reung [齊陵] and Hu-reung [厚陵]—serve as ideal test cases. Although they are part of the broader category of Joseon royal tombs inscribed on the UNESCO World Heritage List, these two tombs are not included because they are located in North Korea. Moreover these tombs are significant not only from a heritage recognition perspective but also in terms of ideological context, as the North Korean regime has historically maintained a dismissive stance toward the Joseon Dynasty (Jeong, 1994). Studying their preservation state may thus offer insights into the cultural politics of heritage management in North Korea.

Je-reung, the tomb of Queen Sineui [神懿王后], consort of King Taejo [太祖], is located in Sangdo-ri, Panmun-gun, Gaeseong-si. Hu-reung, the joint tomb of King Jeongjong [定宗] and Queen Jeongan [定安王后], is situated in Ryeongjeong-ri. While access to the sites is restricted, previous documentation from the National Institute of Cultural Heritage (NICH) of South Korea provides useful information, including floor plans and structural descriptions. In the case of Je-reung, key architectural elements such as the Jeongjagak [丁字閣] shrine, stele pavilion, and three-tiered platforms are described in the reports (Figure 6). These components, including the arrangement of the burial mound and stone figures, are partially visible in high-resolution imagery on Google Earth (Figure 7).

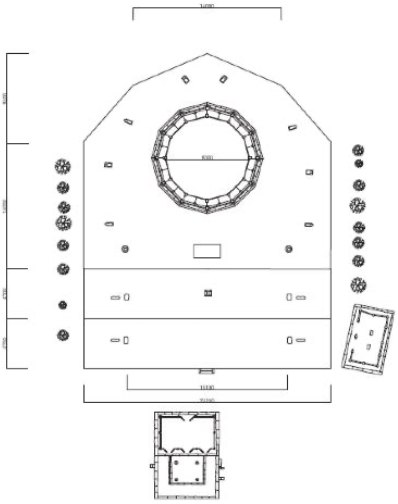

Figure 6. Floor plan of Je-reung (NICH, 2009, 184)

Figure 7. Je-reung as seen on Google Earth (© Image Copyright 2025, Airbus)

Hu-reung presents a more deteriorated condition, with the shrine and stele pavilion no longer standing. However, foundational stones of the shrine, the twin mounds, and tiered platforms are faintly observable (Figure 8). Google Earth imagery allows for basic recognition of the overall layout, despite challenges posed by tree cover and weathering (Figure 9).

The comparative analysis suggests that both tombs are relatively well preserved. Despite North Korea’s ideological disregard for the Joseon period, it appears that these sites have received a degree of conservation, likely due to their historical rarity.

While the visual data confirm that both tombs remain largely intact, limitations in resolution and spectral information hinder detailed observation of surface artifacts or design. For example, individual stone figures and decorative motifs cannot be confidently identified, and vegetative obstructions reduce image clarity.

These constraints underscore the methodological limitations of relying solely on Google Earth for cultural heritage detection. Its RGB composite imagery lacks multispectral depth, and image quality varies by region and update cycle. Thus, while Google Earth proves highly useful for preliminary surveys of known

sites, it is less effective for detecting unknown or undocumented features. These limitations point to the need for supplementary methods, such as AI-assisted automated detection, which are addressed in the next section.

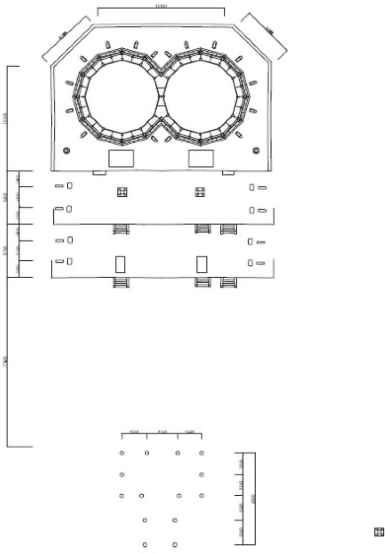

Figure 8. Floor plan of Hu-reung (NICH, 2009, 306)

Figure 9. Hu-reung as seen on Google Earth (© Image Copyright 2025, Airbus)

4. Conclusion and Future Research

This study has demonstrated that Google Earth, despite its known limitations, serves as a practical and accessible platform for the preliminary investigation of cultural heritage sites in North Korea. Through a comparative analysis of satellite imagery and historical documentation, the study confirmed that the spatial configuration of two Joseon royal tombs—Je-reung and Hu-reung—could be effectively identified using Google Earth. These findings suggest that the platform holds considerable value for reconnaissance-level surveys, especially in politically restricted areas where conventional archaeological methods are unfeasible.

However, several limitations must be acknowledged. Google Earth imagery relies primarily on RGB composites, lacks consistent metadata, and varies in spatial resolution depending on location and update cycles. While sufficient for identifying large-scale features such as tomb mounds and platforms, Google Earth does not allow for detailed analysis of sculptural elements, inscriptions, or the detection of previously undocumented sites. For instance, although historical records confirm the existence of royal tombs for King Taejo's four ancestors—also noted during the Japanese colonial period—their current precise locations are unknown, rendering conventional satellite review ineffective (Figures 10–13).

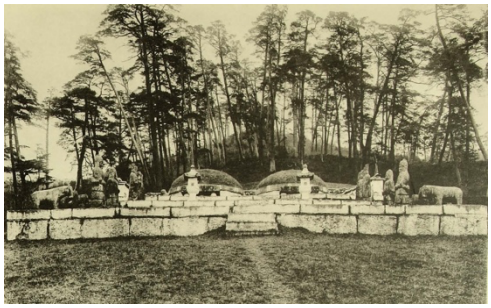

Figure 10. Deok-reung [德陵] and An-reung [安陵], the royal tombs attributed to the great-great-grandparents of King Taejo (Government-General of Korea, 1931, 1608)

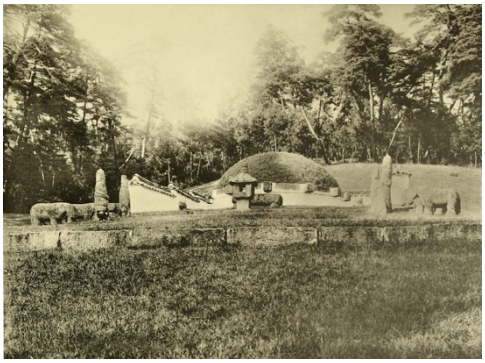

Figure 11. Eui-reung [義陵], the royal tomb attributed to the grandfather of King Taejo (Government-General of Korea, 1931, 1610)

Figure 12. Eui-reung and Jeongjagak shrine (Government-General of Korea, 1931, 1609)

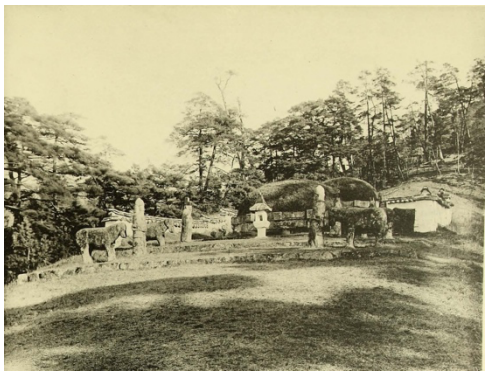

Figure 13. Jeong-reung [定陵] and Hwa-reung [和陵], the royal tombs attributed to the parents of King Taejo (Government-General of Korea, 1931, 1611)

To overcome these limitations, this study proposes the application of convolutional neural networks (CNNs) trained on RGB satellite imagery for semi-automated detection of potential royal tombs in North Korea. While recent methods such as semantic segmentation (e.g., Casini et al., 2023) require large amounts of pixel-level annotated data, such datasets do not exist for Joseon royal tombs due to the limited number of confirmed examples (40 in South Korea and 2 in North Korea). Therefore, we adopt a classification-based approach similar to that proposed by Caspari and Crespo (2019), which is better suited for contexts with scarce training data.

In this approach, a CNN model is trained using small RGB image patches centered on known royal tombs, labeled simply as “tomb” or “non-tomb” according to presence. The model learns to differentiate tomb-resembling terrain and vegetation patterns from ordinary landscapes. Once trained, the CNN is applied in a sliding-window fashion across broader regions of North Korea, generating a probability-based heatmap that highlights areas most likely to contain undocumented tombs. These high-likelihood areas are then reviewed manually by researchers using contextual knowledge and historical records, following a “human-in-the-loop” approach as emphasized by Casini et al. (2023), where expert validation plays a critical role in refining predictions and improving model reliability.

The proposed workflow proceeds as follows (Figure 14):

1. Training Data Collection: RGB satellite image patches are extracted from the vicinity of confirmed Joseon royal tombs in South Korea. Patches without tomb features are also sampled as negative cases.
2. CNN Model Training: A binary classifier is trained to distinguish tomb versus non-tomb patches using standard CNN architectures.
3. Heatmap Generation: The trained model is applied across satellite imagery of North Korea to produce a continuous heatmap of predicted probabilities for tomb presence.
4. Candidate Site Identification: High-probability zones (“hotspots”) are identified and visually compared against known tomb layouts and terrain configurations.
5. Expert Review and Feedback Loop: Researchers examine the candidate sites and incorporate newly validated or rejected locations to refine the training dataset for subsequent model iterations.

This RGB-based CNN methodology has the advantage of requiring only coarse location labels rather than precise contour annotations, making it feasible under current data constraints. The resulting heatmaps do not directly delineate architectural elements but provide valuable guidance in narrowing down areas for further archaeological investigation.

Should Digital Elevation Model (DEM) data of sufficient resolution become available, it could be integrated in future work to complement the RGB-based analysis. DEMs would enable the model to incorporate terrain elevation characteristics—such as mound height or symmetry—further enhancing classification accuracy and robustness. This hybrid approach combining surface texture and topography holds particular promise for detecting low-relief tombs in complex landscapes.

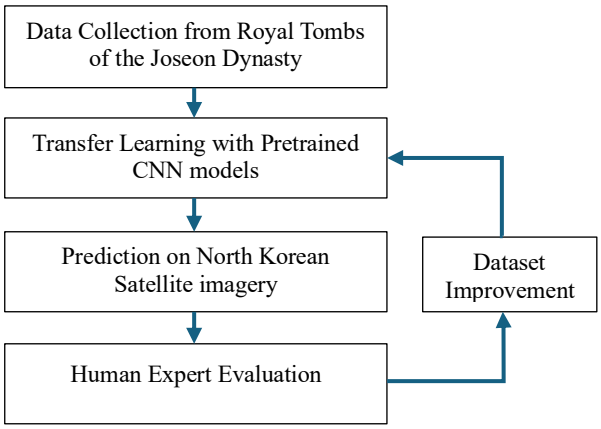

Figure 14. Workflow for CNN-based detection of undocumented royal tombs of Joseon Dynasty in North Korea

References

Casana, J., Cothren, J., 2013. The CORONA Atlas Project: Orthorectification of CORONA Satellite Imagery and Regional-Scale Archaeological Exploration in the Near East. In (eds. Comer, D. C., Harrower, M. J.) *Mapping Archaeological Landscapes from Space*. Springer, New York, 33-43. doi.org/10.1007/978-1-4614-6074-9_4.

Casini, L., Marchetti, N., Montanucci, A., Orrù, V., Roccetti, M., 2023, A human-AI collaboration workflow for archaeological sites detection. *Scientific Reports*, 13, 8699. doi.org/10.1038/s41598-023-36015-5

Caspari, G., Crespo, P., 2019. Convolutional neural networks for archaeological site detection – Finding “princely” tombs. *Journal of Archaeological Science*, 110, 104998. doi.org/10.1016/j.jas.2019.104998.

Government-General of Korea [朝鮮總督府], 1931, *Illustrated Catalogue of Korean Antiquities* [朝鮮古蹟圖譜], Vol. 11. [In Japanese]

Jeong, D., 1994, North Korea’s Historical Perception as Reflected in *Joseon Tongsa*. *Seogang Journal of the Humanities*, 3, 191-224. [In Korean]

Kim, H., Yi, S., 2021. On the Use of Satellite Imagery for Researching Historical Sites in North Korea: A Comparison of Google Earth and Arirang Satellite Imagery. *Journal of Humanities*, 78(2), 273-313. [In Korean] doi.org/10.17326/jhsnu.78.2.202105.273

Lasaponara, R., Masini, N., 2011, Satellite remote sensing in archaeology: past, present and future perspectives, *Journal of*

Archaeological Science, 28(9), 1995-2002. doi.org/10.1016/j.jas.2011.02.002.

Lindsay, I., Mkrtchyan, A., 2023. Free and Low-Cost Aerial Remote Sensing in Archaeology. *Advances in Archaeological Practice*, 11(2), 164-183. doi.org/10.1017/aap.2023.3.

Luo, L., Wang, X., Guo, H., Lasaponara, R., Shi, P., Bachagha, N., Li, L., Yao, Y., Masini, N., Chen, F., Ji, W., Cao, H., Li, C., Hu, N., 2018. Google Earth as a Powerful Tool for Archaeological and Cultural Heritage Applications: A Review. *Remote Sensing*, 10(10), 1558. doi.org/10.3390/rs10101558.

National Institute of Cultural Heritage (NICH), 2009: *Synthesize Investigation Report on the Royal Tombs of Joseon Dynasty*, Vol. I. National Institute of Cultural Heritage, Daejeon. [In Korean]