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Thermal Infrared Satellite Imagery for Countering Nuclear Proliferation : A Recommendation

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1. Introduction

The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) has been the backbone of the international nuclear nonproliferation regime with the participation of all of the United Nations (UN) member states excluding India, Pakistan, Israel, South Sudan and North Korea. Except for South Sudan, which became the UN in 2011, the former three states have not joined the NPT and are deemed as the de facto nuclear weapon states. North Korea, the only nuclear-testing state in the 21st century, has been a subject of controversy in nuclear proliferation for more than two decades.

North Korea's controversial membership of the NPT remains somewhere between the "announcement of withdrawal without any agreed statement " and "return to the treaty," which are officially included as members [1]. Technically, as of April 16, 2009, IAEA inspectors have been expelled from North Korea [2], therefore currently unable to access nuclear-related facilities therein. With this background, the guardians of the nuclear nonproliferation regime, justifiably including the IAEA, are monitoring and analyzing North Korea's nuclear activities making the most use of information to determine whether it is nuclear activities in the proliferation concerns.

In the case of direct events such as nuclear tests, the location and scale of the test, the type of material used, and the type of explosive devices are estimated such as by analyzing satellite imagery in the test site, by capturing relevant neutrons released in air particulate and by evaluating waveform of the artificial earthquake. Since the sixth nuclear test in 2007, (except for the short periods of dramatic peaceful movements,) simmering tensions on the Korean Peninsula have been maintained, and the linkages between North Korea's potential nuclear activities and proliferation risks have been controversial. Meanwhile, remote sensing, especially satellite imaging, has been playing an important role in observing areas of interest for countering nuclear proliferation. Satellite imagery converted from satellite imaging is typically classified into three categories: electro-optical (EO), thermal infrared (TIR), and synthetic aperture radar (SAR) and each has pros and cons due to the nature of the electromagnetic radiation [3].

This paper derives findings for use in thermal infrared satellite imagery, investigating the cases of application for countering nuclear proliferation. There have been discussions on the relationship between nuclear nonproliferation and countering nuclear proliferation in the framework of international regimes on weapons of mass destruction (WMD), and this work adopts the definitions of the US Nuclear Regulatory Commission [4] and the UK Foreign, Commonwealth & Development Office [5] as an active means of strengthening and supporting nuclear nonproliferation regimes. Based on the findings from the case study, recommendations on the reference data are presented.

2. Use of Thermal Infrared Satellite Imagery for Countering Nuclear Proliferation

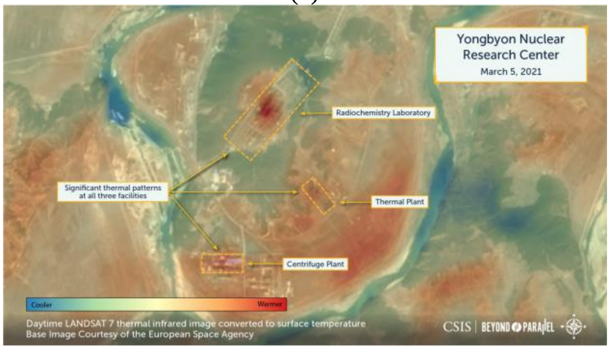
Table I shows the characteristics of three representative types of satellite imaging. Compared to EO and SAR, TIR satellite information has a coarse spatial resolution (ranging from tens of meters to kilometres) due to its wavelength. Since energy decreases as the wavelength increases, the TIR sensor requires more energy than the EO sensor for ensuring a reliable measurement [6]. Thus, it has been widely used in macro-analysis such as the urban heat island and monitoring active volcanoes, etc.

In nuclear nonproliferation, on the other hand, for facilities in restricted access areas such as North Korea, all-source analysis (or all-source intelligence) is being carried out which is to utilize all available information to identify unknown phenomena and activities [7]. In this regard, TIR satellite imagery provides a useful indicator for identifying potential nuclear activities in that it pertains uniqueness of containing temperature information, even though the spatial resolution is lower than others.

Among the nuclear fuel cycle facilities, some inevitably pertain to an increase in temperature due to chemical, radiological, and mechanical reactions. If the internal heat sources are transferred to the external of the structure (outside of the building), remote sensing can detect them. This is evidenced by many pieces of literature [8,9,10] describing the use of TIR satellite imaging that confirms the operation of nuclear-related facilities.

Figure 1 [11,12] shows visually identifiable geographic information converted by electro-optical satellite imaging (Fig. 1a), and overlaps TIR satellite image (Fig. 1b), qualitatively confirming that the temperature of a specific area is higher than that of the surroundings. To confirm quantitative temperature changes, the conversion from thermal imaging data to temperature requires surface radiance (via emissivity),

(a)



(b)

Fig. 1. Reference of Satellite images for the Yongbyon Nuclear Research Center: (a) an electro-optical image and (b) a thermal infrared image transparently overlapped with (a). (excerpt from CSIS Beyond Parallel [11, 12])

which is selectively obtainable depending on wavelength, in that the radiance can be regarded as constant or a function of wavelength [13]. There are several thermal signatures directly indicating an operational status such as discharged water from reactors, and vapor plumes from the cooling tower; however, these are rather momentary phenomena to be captured by satellites. For this reason, the local variation in temperature at target facilities is much more commonly addressed for imagery interpretation. These analyses sometimes refer to quantitative figures showing higher temperatures than surroundings when the conversion is available; otherwise, they only present qualitative results without reasonable guidelines on whether the nuclear-related facility is operational. Although these analyses discuss noticeable and qualitative gradients in temperature or provide temperature differences of a few degrees in Celsius, they are occasionally cited in the major news media [14-17], implying that there is potential nuclear proliferation.

3. Findings and Recommendations

From the investigation of the use of thermal infrared satellite imagery, the findings derived for countering nuclear proliferation are given below:

1. The suspected nuclear-related facilities showing higher temperatures than their surroundings are regarded as an indicator to estimate the location and operation of the facilities from the potential nuclear nonproliferation standpoint.
2. Open-source information for this purpose is very limited, presumably due to the low spatial resolution of currently available thermal infrared satellite images, unabling analysis of specific temperature changes in target facilities.
3. Similar to the other types of satellite imaging, the spatial resolution of thermal infrared satellite images also has been improved, opening the transition period from tens of meters to less than ten meters [3], and enabling analysis of specific temperature changes in target facilities.
4. As the quantitative analysis of temperature changes is available more precisely, the criteria for evaluating potential nuclear activities also need to be established.

Based on the findings, recommendations to enhance the reliability and utilization of thermal infrared satellite imagery for countering nuclear proliferation are derived below:

1. In terms of the heat sources, internal to external structures and materials of the nuclear fuel cycle facilities, reference information (e.g.,

Table I: Characteristics of Satellite Imaging

	Sensing Type	Wavelength	Pros	Cons
Electro-optical (visible)	Passive	0.4 ~ 0.7 μm	· colour perception · high spatial resolution (sub-meter)	· cloud obstruction · daytime only
Thermal Infrared	Passive	3 ~ 14 μm (Medium: 3–5 μm) (Long: 8–14 μm)	· temperature · all-day acquisition	· low spatial resolution (30 m to km)
synthetic aperture radar	Active	1 mm to 1 m	· all-day acquisition · high spatial resolution (sub-meter) · surface altitude/deformation (interferometric)	· demanding processing

graphs or lookup tables of external temperature) shall be established by the heat transfer analyses.

2. Since design information for restricted access facilities may not be obtainable, heat source, structure and material information need to be obtained by all-source analysis, determining a range of upper and lower bounds of the temperatures.

Grafting state-of-the-art technology (i.e., thermal satellite imagery) onto the countering nuclear proliferation creates challenges due to newly given conditions which have not been required or considered ever before. Simultaneously, it can lead to opportunities for reaching robust and reliable conclusions. As increasing remote sensing applications in nuclear nonproliferation, facility-level analysis becomes important. It is necessary to fill the gap for use of thermal satellite data in nuclear nonproliferation.

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