ELECTRIC POWER RESEARCH INSTITUTE

TECHNOLOGY INSIGHTS

A Report from EPRI's Innovation Scouts

EYES IN THE SKY: SATELLITE REMOTE SENSING AND DATA ANALYTICS FOR ELECTRIC UTILITIES

THE TECHNOLOGY

Satellite-based sensors capture remote imagery which, when combined with data analytics, can be applied to perform observation, mapping, and inspection tasks to support electric utility planning, operations, and maintenance functions.

THE VALUE

Use of satellite remote sensing and advanced analytics could deliver economic, safety, and other utility industry benefits in areas such as vegetation management, disaster response, and asset monitoring.

EPRI'S FOCUS

EPRI is evaluating and will continue to explore diverse, near- and longer-term use cases of satellite imaging integrated with additional data sources to address critical challenges faced by electric utilities.

INTRODUCTION

Thousands of satellites orbit the Earth each day, capturing and relaying imaging data with a wealth of information and knowledge to be tapped. These satellites are tasked to perform observation and mapping, communications, weather and atmospheric monitoring, navigation, astronomical and planetary surveys, defense support, and other functions.[1] Decreasing design and launch costs, driven by standardization and miniaturization and the emergence of a commercial reusable rocket industry, have spurred rapid growth in satellite launches as shown in Figure 1, as well as in uses by the private sector. For example, the U.S. Federal Communications Commission (FCC) accepted SpaceX's application to launch and operate Starlink, a "megaconstellation" of broadband communications satellites.[2] A single launch vehicle, the SpaceX Falcon 9, boosted the first 60 out of a total of 4,425 satellites in to orbit on May 24, 2019.[3]

Diverse industries are using satellite data to enhance worker and public safety, create digitized maps, track forest and land use changes, identify watersheds and floodplains, plan and implement construction projects, monitor infrastructure, quantify emissions, determine weather forecasts, respond to natural disasters, identify and fight wildfires, etc. This brief introduces remote sensing technology, potential electric utility applications, and planned EPRI work.

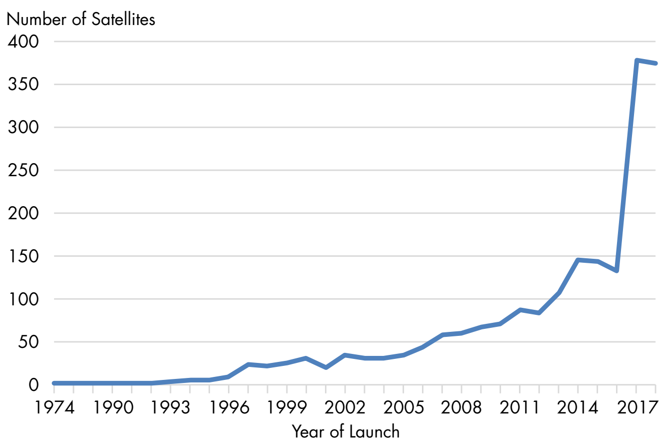

Figure 1. Number of Satellites Placed into Orbit by Year (Data Source: Union of Concerned Scientists[4])

Interesting Facts

- The first publicly available satellite images were published in 1972 from Landsat 1.[5]
- In 2011, the satellite industry accounted for 61% of space industry revenues but only 4% of overall global telecom industry revenues.[6]
- 80% of U.S. Department of Defense communications are provided by U.S. commercial satellites companies.[6]
- U.S. Department of Homeland Security designates satellites as critical infrastructure.[6]
- The cost of building and launching a satellite with the same capabilities dropped from $200,000,000 to $200,000 in a 10-year span.[7]
- Approximately 63% of operational satellites are for Earth observation or telecommunications.[4]
- Wildfires could be detected to greater than 99.9% accuracy using a simple neural network running on the on-board processors of cube satellites[8] (miniaturized satellites often built from off-the-shelf components).

TECHNOLOGY OVERVIEW

Remote sensing satellites use active and passive onboard sensors and instruments to detect, measure, and analyze energy that is reflected, backscattered, or emitted by observed objects or areas.[9] Individual sensors operate on specific bands of the electromagnetic spectrum, collecting data viewable as pixelated imagery.

Active sensors transmit energy to illuminate targets and then detect and measure what's reflected or backscattered. Most operate in the microwave portion of the electromagnetic spectrum. They include LiDAR, laser altimeter, radar, ranging instrument, scatterometer, and sounder devices.[9] Conversely, passive sensors or instruments detect energy—typically sunlight—reflected off observed objects or landscapes. They use the microwave, visible, infrared, and thermal portions of the spectrum. Examples include accelerometers, radiometers, hyperspectral radiometers, imaging radiometers, sounders, spectrometers, and spectroradiometers.[9]

The type, quality, and use of remote sensing data collected by individual satellites and sensors are influenced by three different types of resolution—spatial, spectral, and temporal—as detailed in Table 1. Collecting data for specific use cases involves a balancing act, as high spatial resolution requires low spectral resolution and vice versa.[10] A sensor with high spatial resolution has a small instantaneous field of view, which reduces its ability to distinguish differences in energy level. To counter this, the sensor must collect data on fewer spectral bands.[11]

Figure 2 illustrates how a given spatial resolution influences a satellite's capacity to discern and characterize common transmission and distribution (T&D) equipment via remote sensing. At a resolution of 10 m, pixels are too large to display even a 500 kV transformer. At higher resolutions, smaller objects can be imaged and characterized for a broader array of use cases. The maximum spatial resolution available from commercial satellite image providers is roughly 30 cm, a limit reflecting government regulation but not sensor technology.[12] This corresponds to about the same size as a standard piece of paper.

Figure 3 illustrates remote sensing capabilities across portions of the electromagnetic spectrum, displaying a mix of general uses plus applications specific to the operational land Imager (OLI) and thermal infrared sensor (TIRS) onboard the Landsat 8 satellite launched in 2013. Even at low spatial resolutions of 30 m for the OLI sensor and 100 m for the TIRS,[13,14] the data captured are useful in addressing the applications noted.

Satellite data typically are unusable when transmitted from the satellite, creating a need to process raw data into imagery. At present, raw data generally is transmitted to Earth for processing, but advancing technologies create the potential to shift some of the processing to onboard computers. The following factors are some of the major impacts on imagery captured:

- Viewing angle of sensor in orbit
- Spatial resolution at distance from nadir
- Angle of sunlight, based on Earth's curvature
- Atmosphere and cloud cover
- Topographical distortions
- Environmental effects
- Shadows due to sun blockage
- Time between data capture
- Sensor aging

Some of these factors can be addressed by algorithms, while others require more labor-intensive work to remove distortions and generate useful imagery. Maintaining sensor reliability once in orbit poses additional challenges. Satellite-based sensors include onboard calibration units, but both sensing and recalibration capabilities are subject to degradation due to electrical, mechanical, and thermal effects over time or exposure to UV radiation.[18] Intercalibration—the calibration of a sensor to a

Table 1. Aspects of Satellite and Sensor Resolution[10]

Type	Definition	Low	Medium	High
Spatial	Refers to the size of the pixels in the satellite image	30 to < 1000 m	4 to 30 m	25/30 cm to 4 m
Spectral	Refers to the number of spectral bands for which a sensor collects data	< 3 bands	3 to 15 bands	>220 bands
Temporal	Reflects the time between successive passes over an area by a satellite, as well as the ability of its sensor(s) to refresh imagery/data of that area	>16 days	4 to 16 days	<24 hours to 3 days

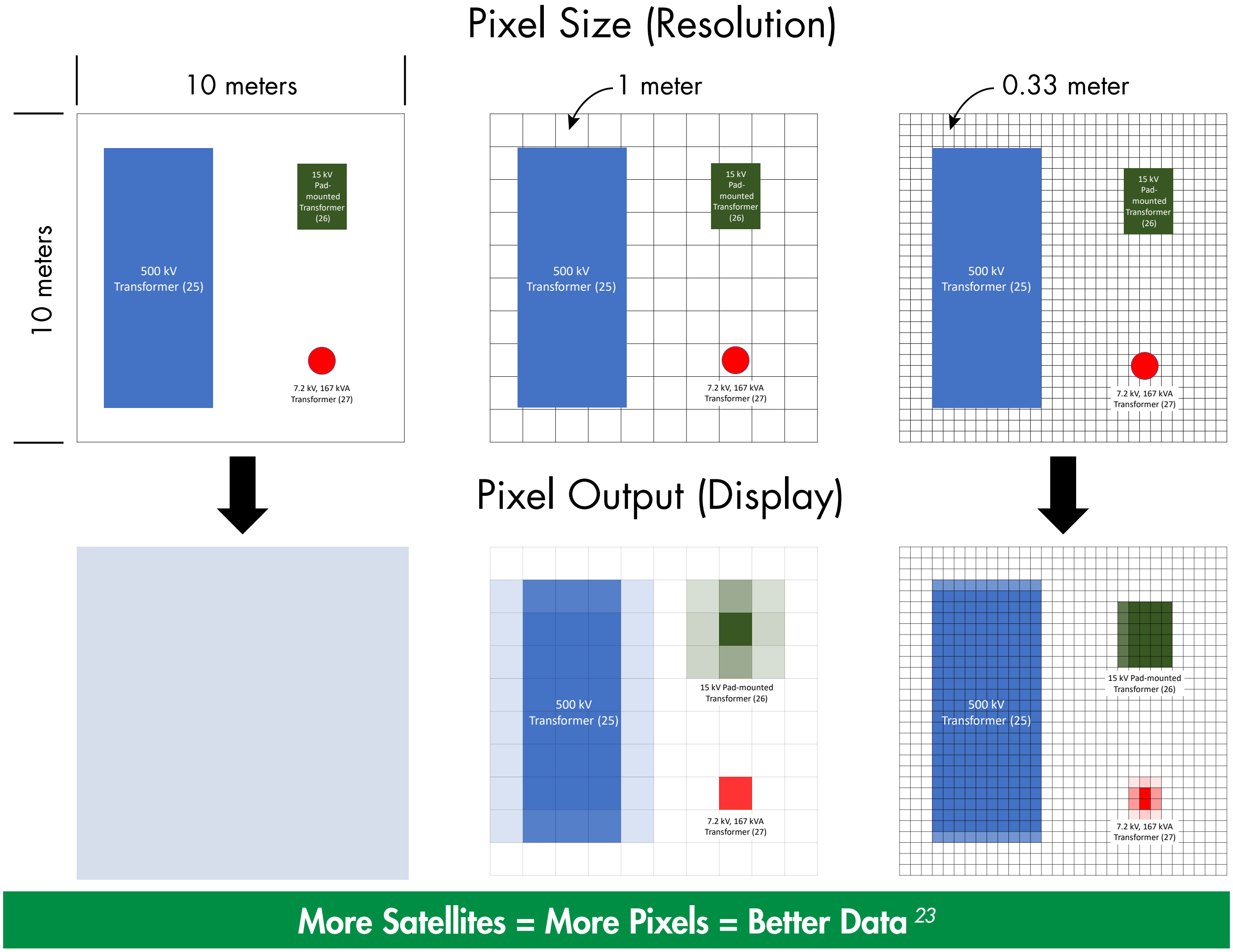

Figure 2. Examples of Spatial Resolution for Common Transmission and Distribution Assets

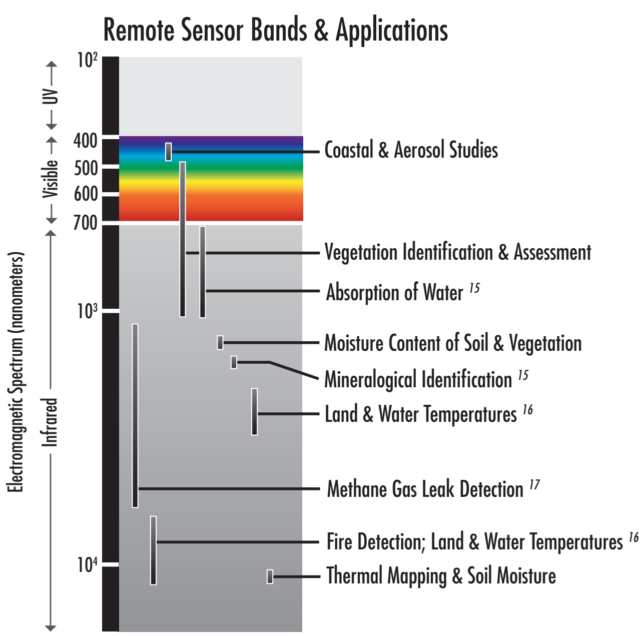

Figure 3. Sample Sensor Bands and Remote Sensing Applications for the Landsat 8 Satellite and More Broadly[13,14]

reference of either a well-calibrated sensor or two sensors viewing the same target—provides a means to calibrate remote sensors deployed on multiple satellites to thereby obtain enough interoperable data within a defined timeframe to solve a variety of use cases.[19]

VALUE TO INDUSTRY

As the number of satellites increases, their onboard intelligence grows, and sensor payloads become more sophisticated, electric utilities have opportunities to immediately implement some uses by leveraging experiences in other industries. Tasks associated with repetitive observation and inspection, especially over large areas, are some of the "lowest-hanging fruit" to be supplemented or replaced with remote sensing and analytics. The magnitude of area that can be assessed at one time and the reduction in evaluation time are important advantages. Table 2 captures the potential benefits and costs from using remote sensing data combined with the required analytics to address a variety of use cases in utility operations and maintenance (O&M).

Longer term, the availability of satellite data—combined with the sophistication of artificial intelligence and data analytics—will drive exploration of new and innovative ways to tackle age-old challenges

Table 2. Costs and Benefits of Remote Sensing

Cost/Benefit Analysis Categories	Favorable / Unfavorable In/Decrease	Comments
Utility Operations (Non-Fuel O&M)	↓	Labor costs to perform inspections and assessments.
Utility Operations (Non-Production Assets)	↑	Cost of data acquisition. Cost of algorithm and application development and implementation or cost of third-part provided analytics services.
Capital Revenue Requirements	↓	Reduction in number of required sensors.
Reliability	↓	Avoided costs from outage or asset failure.
Environment	↓	Reduction in or elimination of truck rolls for inspection.
Security Impacts	✓	Recognizes positive impacts of avoided miles driven.
Safety Impact	✓	Analytics reduces or eliminates the need of field inspection of asset.
Adjacent Possibilities	✓	Realization of things not yet discovered in the data or uses of the technology.

Notes: GREEN or RED text or symbol indicates a favorable or unfavorable change, respectively. ✓ indicates a change that may be difficult to quantify with precision. Arrows (↑↓) indicate an increase or decrease. These are estimated potential effects, but the magnitude of any costs/benefits relative to incumbent processes will vary.

and address emerging issues facing utilities. Step-change improvements in situational awareness and operational and workforce efficiency are anticipated through future use cases that could employ satellite data to automate inspection and other functions and aggregate remote sensing imagery with existing data sets.

COMPARISON OF IMAGE CAPTURE PLATFORMS

Table 3 provides a general qualitative comparison of three image capture platforms: satellites, piloted aircraft (fixed-wing aircraft and helicopters), and unmanned aerial systems (drones). It highlights advantages for remote sensing in a number of areas, as well as some key limitations.

Table 3. General Comparison of Image Capture Platforms

Category	Image Capture Platform		
	Satellites	Piloted Aircraft	Drones
Broad Field of View	+		
Automated Data Transfer	+		
High Spatial Resolution/Close Observation		✓	+
Archived Historical Data Available	+		
Ability to Capture Data Continuously	+		
Limited Expense for Small, Infrequent Missions		+	+
Changeability of Sensors		✓	+
Avoided Nuisance to Customers	+		
Limits Danger to Pilots, Public, Property, and/or Assets	+		
Proven Analytics/Accepted Methodology	✓	+	+

Notes: + Indicates better or best platform; ✓ indicates good or viable option.

At present, the two primary business models for gaining intelligence using satellite data are to acquire the data for use or to contract for analytic services to be provided. High-quality imagery, from near-real-time data to historical data going back decades, can be obtained for free from various governmental agencies such as the U.S. Geological Survey, National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration; the European Space Agency; the Japan Aerospace Exploration Agency; and even some commercial suppliers. Both archived and on-demand imagery are available for commercial sale. On-demand imagery provides controllability, such as across the different types of resolutions, to achieve data optimized to assist with solving particular use cases.

Satellite imagery typically is more cost-effective than other image capture methods, especially as the area of coverage increases. A study performed in 2015 captured images from all three platforms at a vineyard. With a data capture area limited to only 0.5 km^2, the cost of acquiring image data was 20% higher using an aircraft and 60% higher using a drone, as compared to a satellite.[20]

While low-resolution imagery (30 m) from the Landsat 8 satellite is available at no cost, a January 2018 price sheet[21] offered a base cost as low as \$1.28/km^2 for medium-resolution imagery from RapidEye satellites. High-resolution imagery (50 cm) started at \$12.50/km^2 for the Pleiades 1A/1B satellites. Costs for equivalent stereo imaging, such as 3D images that provide depth, doubled from these values. Additional data acquisition cost adders include tasking satellites to capture specific images, guaranteed cloud cover percentage, angle of data capture, and other requests involving new tasking and proactive monitoring. An example of the potential costs of analytic services is from Satshot, which for processed images from Landsat (low-resolution imagery) charged \$61.75/km^2 and from RapidEye (medium-resolution imagery) charged \$123.50/km^2.[20]

THE ART OF THE POSSIBLE: UTILITY USE CASES

The use cases below highlight the potential advantages of remote sensing and analytics over traditional utility approaches to resolving challenging issues across T&D systems. The appendix, presented at the end of this brief, summarizes these and other T&D applications; uses cases for fossil, nuclear, and renewable generation; and use cases with cross-cutting capability, including environmental resource management and protection.

Right-of-Way Vegetation Management [22]

Driver: Remote sensing data and predictive analytics may permit automated detection of vegetation encroachment in T&D rights-of-way (ROWs) and help facilitate the implementation of optimal cutting cycles.

Past/Current Practice: Vegetation management is a continuous, costly, and mission-critical process for utilities whose service territories have abundant forest areas and trees. In general, ROWs are cleared periodically, on a time-based schedule; herbicides also may be applied. Because different species of trees grow at different rates, additional trimming, sometimes called hotspot trimming, may be conducted mid-cycle on an as-needed basis. Manual inspections are conducted prior to clearing and trimming activities to determine the amount of and location of tree growth and potential impacts to grid reliability.

As part of the IlluminationLAB Innovation Challenge, EPRI is working with startup LiveEO to test the applicability and accuracy of satellite imagery in vegetation management applications. By leveraging high-resolution satellite imagery and artificial intelligence (AI) image analysis, EPRI and LiveEO will analyze a portion of the a utility's distribution network, use LiveEO's AI-enabled SaaS platform to assess vegetation incursion, and highlight specific locations in need of attention. The project will compare the results of the image analysis with other imaging and ground data to test accuracy and efficacy.

Future Practice: Vegetation management based on remote sensing data and algorithms is a relatively mature use case for the forestry industry and diverse government agencies. Trees and ground cover can be differentiated, and trees can be speciated. Tree height as well as crown characteristics can be extracted using multispectral imagery.[21] Additionally, the health and growth rate of trees can be derived by comparing data from multiple passes over the same forest area.

Available tools can assist utilities in determining how far limbs of trees have encroached in a ROW, identifying dead or dying trees, and assessing proximity to energized conductors. By knowing height, branch length, and other crown characteristics, a volumetric assessment of the debris to be removed from clearing or spot trimming can be completed. Geospatial information system (GIS) data and historical vegetation management and climate data are needed to supplement the satellite data. GIS data help to determine the location of T&D assets, as well as the defined ROW boundaries. Insights on recent and future tree growth can be extracted by combining image data with historical vegetation management activities, such as trimming, cutting, and chemical treatment, and by correlating growth with climate data to illustrate trends per distance of line.

Figure 4. Satellite Image Highlighting Vegetation Growth Area in ROW Since Last Pass (Credit: Satelytics)

Figure 4 provides a sample satellite image showing recent vegetation growth within a ROW. Challenges in using satellite data for ROW management primarily involve spatial resolution and locational accuracy, which represents an essential prerequisite. Power lines have been constructed over many decades, and many utilities struggle with the precise location of infrastructure. Can satellite technology accurately determine the location of poles, towers, and other structures and, more importantly, conductors? While promising, the accuracy of the analytics used to determine tree species, height, and health need to be evaluated and verified for T&D applications. Further research and demonstration are needed to ascertain the accuracy of the predictions and the value of supplementing or even replacing current vegetation management tasks with remote sensing.

ROW Encroachment

Driver: Remote sensing data and artificial intelligence may allow utilities to detect and characterize non-permitted encroachments, such as construction or dumping, over large swaths of ROWs or service territories with a single analysis.

Past/Current Practices: Human or natural encroachments can impede daily O&M practices and even impact safety of utility employees and/or the public, creating the need for quick identification and resolution of unauthorized activities or structures. ROW encroachment is primarily detected by observation during the course of routine or scheduled O&M activities or through dedicated inspections. Once discovered, additional visits to the encroached area may be required to determine the extent and the risks, as well as to implement solutions.

Future Practice: Periodic satellite image capture of a ROW paired with change detection via artificial intelligence can provide an early warning indicator that encroachment has or is about to occur, thus supporting monitoring and guiding intervention. Land clearing, site preparation, construction vehicles, debris, road crossing, fencing, etc. are examples of activities that could be identified by comparing new and previous images. Figure 5 provides an example. By building an imagery database, utilities could analyze previous encroachments for patterns consistent with urban sprawl, population growth, and other trends, supporting proactive management and prevention strategies.

Figure 5. Satellite image of construction beginning to encroach on the ROW (Credit: Satelytics)

Storm Damage Assessment and Response

Driver: Utility assessments of and responses to hurricanes, tornado outbreaks, and other large natural disasters must be quick and efficient. Detailed information is needed as soon as the immediate danger has passed to assess extent of damage and how best to respond and restore service. Ongoing evaluations are made throughout the power restoration effort to determine local conditions.

Past/Current Practices: The traditional response to a major storm starts days in advance to secure equipment, crews, and assets and to stage resources in areas away from danger yet close enough for rapid deployment. Once danger has ended, small teams of scouts and local linemen deploy immediately to ascertain the extent of damage. As conditions improve, scout teams assess damage to individual assets. The assessment is then translated into work orders or jobs assigned to line and tree crews to organize and expedite repairs. Legions of crews and support teams often work for days to restore power.

Future Practice: Satellites and analytics assist during and in the minutes following the storm (or other event) to survey and obtain a high-level, aerial assessment of the damage for response planners, to provide intelligence for routing scouts and crews to accessible areas, and to assign crews to downed trees and other problems. This future state is almost within reach. The image shown in Figure 6 was captured after Hurricane Michael in Florida in 2018 by a fixed-wing aircraft flying at an altitude below 1500 m using a digital sensor system offering spatial resolution comparable to that available today from satellite-based sensors. At 25 cm resolution, downed trees can be located, the extent of damage to transmission structures can be assessed, and flooded areas of ROWs can be distinguished.

The primary issues with this use case include positioning the right satellites in the best orbit at the appropriate time; developing analytics required for specific needs; and having systems in place to relay time-sensitive intelligence. Satellites with the appropriate sensing capabilities could be staged to provide images before, during, and after a storm. For example, technologies that can "see" through clouds and rain could provide the earliest and high-level assessments relative to pre-event conditions. Once rain and clouds move out of the area, other images could be captured to identify damaged assets and downed trees. Continuous passes could provide updates on road openings, receding waters, and other parameters to assist with efficient service restoration. As more satellites are placed into orbit, tasking satellites with critical missions will become easier.

Figure 6. Aerial Image of Damage by Hurricane Michael in October 2018 (Credit: NOAA Remote Sensing Division)

THE PATH FORWARD

The intelligence gathered from remote sensing data has the potential to grow at a rapid rate. Data is expected to become more plentiful and cheaper as more satellites are placed into orbit. Further development and deployment of advanced sensors will feed the continuing need for more precise and ubiquitous data. The supporting analytics will lead the charge to extract more intelligence. The sky's the limit.

Research and demonstrations are needed to validate current methods and algorithms. New sensors, algorithms, and analytical techniques must be developed and tested to expand remote sensing capabilities. Novel approaches for overcoming technical limitations, such as image resolution and data processing speed, need to be explored. Given EPRI's deep subject matter expertise in inspection, EPRI and its collaborators have the capabilities for objective assessment of use cases and analytical techniques for satellite data through case studies and demonstrations.

APPENDIX: SAMPLE UTILITY USE CASES

The use cases in the table below provide a glimpse of the possibilities of using satellite remote sensing data to solve challenges faced by utilities. The table is intended to highlight some of the important utility use cases within various sectors of the industry but does not serve as an all-inclusive list of use cases. Input from EPRI subject matter experts and data analytics companies using remote sensing data, namely Satelytics and LiveEO, helped to inform the maturity level of each use case.

Use Cases	Description	Level of Maturity
	T&D Infrastructure	
Right-of-Way Encroachment (Vegetation)	Vegetation grows into the rights-of-way. Trimming or clearing usually is performed on a cycle of a few years. Satellite remote sensing data may be used to help assess timing and amount of required clearing/cutting. Easier to implement for transmission.	🟢
Right-of-Way Encroachment (Construction, Dumping, etc.)	Unauthorized activity on the rights-of-way can impede utility work. Detection of encroachment usually occurs during a routine inspection. Change detection using remote sensing data may alert utilities more quickly.	🟢
Geo-Location Confirmation of Assets – T&D	The location of utility assets logged in GIS can be off by as much as tens of meters from their actual locations. Automated methods to provide more precise geo-location of these assets are needed. Analytics that use satellite data may be developed to assist with the identification and geo-location of utility assets.	🟡
Storm Damage Assessment	Assessing damage to utility assets after a major storm historically has been a manual process carried out by utility staff. Satellite data may be used to assess damage to assets, required tree removal, flooded roads, etc.	🟡
Storm Damage Recovery	Recovery from major storms can last days if not weeks. Data from various utility systems and information from the field is gathered and processed to track restoration efforts. Data from satellites gathered quickly for large areas could provide information to supplement or free up the workforce from reporting on the progress of restoration efforts.	🟡
Structural Integrity of Towers and Poles	Periodic inspections of poles and towers are used to assess the integrity. Manual and/or aerial inspections typically are required to assess rust, broken structures, damaged insulators, etc. Satellite remote sensing may be used to complement or replace other types of inspections.	🟠
	Cross-sector	
Land Cover Classification	Land cover classification using satellite remote sensing data has been practiced for years by other industries. For utilities, a key issue is whether the algorithms can be modified to classify land cover at the highest levels of available resolution needed for ROW management.	🟢
Erosion and Land Movement Detection	Land movement can be gradual and may go unnoticed by manual inspections and be missed by flyover inspections. Advanced analytics using data from frequent satellite passes of an area can help discover areas of change over time and alert utility staff of potential damage to infrastructure that could be caused by earthquakes or landslides. Thousands of miles of ROW may be assessed quickly.	🟢
Flooding: Water Levels	Flooding typically is a part of major storms and impacts storm restoration efforts. Satellite remote sensing data and analytics can support detection, monitoring, and response to flood areas.	🟢
	Key	
🟢	Solutions are available, and demonstrations have been performed (TRL 8-9). Commercial deployment achieved. Validation of present solutions and continuous algorithm improvements may warrant additional demos.	
🟡	Basic solution is available but additional demos needed (TRL 7-8). Pre- or early-commercial deployment attained.	
🟠	Algorithm and/or technology advancement or specific demos needed (TRL 1-7).	

Use Cases	Description	Level of Maturity
Land and Water Surface Temperature	Sensors on multiple satellites detect land and water surface temperatures.	●
Time-Lapse Construction Assessment	Satellite images may be "stitched together" in a time-lapse animation to illustrate progress of major construction projects. Video from satellites is becoming an option as well.	●
Physical Security	Satellite remote sensing data with supporting analytics may indicate changes in an observed area, such as vehicles, persons, or storage of material, that pose a physical threat. At issue is whether images and videos from satellites provide enough coverage in sufficient time intervals to protect against physical threats. Societal and privacy issues may need to be considered.	●
Telecommunications Network Optimization	Satellite data, such as terrain, environmental, and land use imagery, can be used as inputs into telecommunications planning tools to optimize network capacity.	●
Pre-construction Planning/ Survey	Prior to construction, the options for a transmission line route are carefully considered. Satellite remote sensing data and artificial intelligence can be used to help optimize routing from a technical standpoint.	○
Solar Energy Potential	Based on the characteristics of roofs and structures and land use and terrain presented in satellite remote sensing data, the potential for solar energy development within specific areas can be calculated using advanced analytics.	○
	Energy and Environment	
Forest Health and Damage Causation	Remote sensing data and analytics have been used to determine the health of forested areas for years by other industries and government agencies. Predictive algorithms can support early identification and more proactive management of factors causing forest damage.	●
Fuel and Fire Mapping	Fuel supply assessments, as well as active fire mapping, are developed using satellite data and supporting analytics by other industries and government agencies.	●
Fire Monitoring	Wildfires and brush fires have impacts on lands owned and managed by utilities and also on their infrastructure. Satellite data serving advanced algorithms can potentially guide utilities in implementing protective measures to help increase public safety and mitigate potential impacts to infrastructure.	○
Fire Starter Detection	Satellite data may be used in combination with or independent from other data sources related to a fire to help determine where and when a fire started.	○
Vegetation Species Identification and Classification	Species of trees, brush, grasses, weeds, and other vegetation can be identified using satellite data. An issue is whether the algorithms can be adapted and relied upon to accurately predict different types and species within the footprints of ROWs and other utility-managed and utility-owned properties.	○
Wetlands Delineation	Satellite data has been used to help identify and assess wetlands. Satellite data and analytics can provide details of the hydrologic, soil, and plants characteristics of the ecosystem, known as wetland delineation, or supplement UAV data and other site visits to the wetlands required.	○
	Key	
●	Solutions are available, and demonstrations have been performed (TRL 8-9). Commercial deployment achieved. Validation of present solutions and continuous algorithm improvements may warrant additional demos.	
○	Basic solution is available but additional demos needed (TRL 7-8). Pre- or early-commercial deployment attained.	
○	Algorithm and/or technology advancement or specific demos needed (TRL 1-7).	

Use Cases	Description	Level of Maturity
Forest Fire Danger Rating	Vegetation type, structure, and water content in plant matter, as well as climate data obtained from satellites, can be fed into prediction models to help assess the danger of a fire starting over various time frames. These techniques may be applied to ROWs and other properties to determine how to potentially change the operating characteristics of the grid to reduce fire danger.	🟠
	Generation and Nuclear	
Leak Detection	Leak detection is critical for safe, reliable production and transportation of gas and liquid substances. Leakage of substances relevant to utilities may be detectable by satellite remote sensing using hydrocarbon signatures.	🟢
Coal Combustion Product Pile Monitoring	Estimating the size of coal and combustion by-product piles is a task carried out by plant technicians. Satellite remote sensing data may allow accurate determination of the amount of material as compared to current methods.	🟡
Pre-Construction Planning	Satellite remote sensing data and artificial intelligence can be used to select optimal plant locations based on terrain and other geographic considerations, as well as transmission ties and load centers.	🟡
Thermal Plume Analysis	Temperatures for bodies of water are regularly captured by satellite measurement. The data may be further refined to show and continuously monitor the thermal plume from discharge points at power plants; an issue is whether results using satellite data would be acceptable by regulatory bodies. There is currently no method for measuring temperature at depth (only surface measurements) so while satellites could be used to provide near-continuous monitoring of surface temperatures, the data is limited in ability to provide a full three-dimensional characterization of the thermal plume in the water body.	🟡
Water Constituent Detection and Measurement	Biological, chemical, metal, and other constituents can be detected and measured by satellite sensing in bodies of water over time to determine an increase or decrease in their presence. Methods of satellite data analysis, if allowed for use in regulatory reporting, may prove favorable in accuracy and cost compared to sensor-based methods used to take and analyze water samples today.	🟡
Water Resource Management	Traditional means of collecting water resource data for hydro plant operations include sensors and manual measurements. Satellite remote sensing data may be used in combination with complex water management algorithms and applications to complement or, if proven, even replace traditional methods.	🟡
Debris/SAV/HAV Monitoring	Satellites could provide near continuous monitoring of debris fields, the growth and movement of submerged aquatic vegetation, harmful algae blooms and other water-borne sources of intake fouling. Accurate detection of these impacts may require development of new analysis capabilities (spectral analysis) and may be limited by factors such as depth of water body and water clarity. For example – satellite imagery may be very helpful in identifying and monitoring of jellyfish blooms, but it may be difficult to find spectral differences between jellyfish and the surrounding seawater that would allow for accurate detection.	🟠

Key	
🟢	Solutions are available, and demonstrations have been performed (TRL 8-9). Commercial deployment achieved. Validation of present solutions and continuous algorithm improvements may warrant additional demos.
🟡	Basic solution is available but additional demos needed (TRL 7-8). Pre- or early-commercial deployment attained.
🟠	Algorithm and/or technology advancement or specific demos needed (TRL 1-7).

Use Cases	Description	Level of Maturity
Snowpack Depth and Melt	The accumulation or snow and the rate at which it melts is important to utilities in estimating future water resources and the flow of water in rivers and into lakes. Data from satellites may support more accurate forecasting for hydro plant operations.	
Structural Monitoring of Containment Ponds	Mining industry studies show promise in the use of satellite data and analytics to detect land movement and erosion for tailings and holding ponds. Similar approaches may be applicable for utility containment ponds and also may be a reliable measurement method.	
	Integrated Grid and Energy Utilization	
Solar Energy Installations and Production	Solar installations can be detected using satellite remote sensing data and based on their location the amount of average solar energy production can be calculated using already developed maps such as the Global Horizontal Irradiance map.	
Solar Installation Inspections and Solar Energy Fraud	Tax incentives have been and continue to be paid out to individuals and companies that install PV systems. The number of audits that can be conducted to confirm the installation parameters by government officials is limited. Satellite remote sensing may be used to confirm installations for entire states or countries and to minimize risk of fraud.	
	Key	
	Solutions are available, and demonstrations have been performed (TRL 8-9). Commercial deployment achieved. Validation of present solutions and continuous algorithm improvements may warrant additional demos.	
	Basic solution is available but additional demos needed (TRL 7-8). Pre- or early-commercial deployment attained.	
	Algorithm and/or technology advancement or specific demos needed (TRL 1-7).	

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