Spatial Survey

Mapping Alaskan Oilfield Infrastructures Using Drones

Ila Tyagi

In the fall of 2013, the drone manufacturer AeroVironment teamed up with the oil company BP to conduct an experiment in northern Alaska. AeroVironment set out to demonstrate the usefulness of its Puma drone to oil operations by using the drone's Light Detection and Ranging (LiDAR) equipment to survey the condition of BP's extensive oilfield infrastructure in Prudhoe Bay. The AeroVironment Puma drone created three-dimensional (3D) maps of Prudhoe Bay's roads, offered 3D volumetric analysis of the oilfield's gravel pits, delivered visual and 3D pipeline analysis, and provided general wildlife and environmental monitoring. This information was crucial to maintaining the integrity of BP installations, and to sparing employees from working outdoors gathering comparable data in the harsh Alaskan climate (AeroVironment 2014).

Drones—or Unmanned Aerial Vehicles, as they are formally known—make up an enormous, valuable global market, which is slated to grow even bigger over the next decade. Annual worldwide drone expenditures currently stand at $6.4 billion, a figure projected to increase to $11.5 billion by 2024, totaling almost $91 billion. A majority of that drone market, 89 percent, consists of military applications (Teal Group Corporation 2014). However, drones' nonmilitary applications are expanding. Within the United States, law enforcement agencies have expressed strong interest in deploying drones. The Customs and Border Protection Agency (CBP) and police forces in a handful of American states have made tentative forays into capitalizing on drones' cheapness relative to manned aircraft surveillance. For instance, the CBP uses Predator drones to remotely patrol the entire length of the U.S.-Mexico border, and the Pentagon has sent Global Hawk drones capable of flying higher than 60,000 feet and surveying 40,000 square miles of territory per day into Mexico to counter drug trafficking (Mazzetti & Thompson 2011). The Texas Department of Public Safety uses drones for certain police operations. For example, in 2011, fears that an Austin resident suspected of holding drugs and weapons might try to shoot down a manned helicopter surveilling his property led agents to survey it instead using a bird-sized "Wasp" beaming a live video feed to them on the ground (Finn 2011).

The Federal Aviation Administration (FAA), which is responsible for safeguarding the nation's airspace, has carefully restricted the domestic use of drones use so far. Entities wishing to operate drones must obtain FAA permission, which usually comes with stringent conditions attached (American Civil Liberties Union (ACLU), 2016). However, the FAA is gradually capitulating to pressure from industry and Congress to relax its regulations and allow broader proliferation of drone technology everywhere. In 2016, the FAA released new rules authorizing small commercial drones (weighing less than 55 pounds) to be flown under 400 feet without a pilot's license, rules that could generate $82 billion for the U.S. economy and create 100,000 jobs in 10 years (Newman 2016). As nonmilitary drones are poised to play an increasingly prominent role in industry, there is a growing need to investigate how their use may revise our understanding of aerial image-making, automation, Cartesian perspective, privacy, safety, surveillance, spatiality, and vision, among a host of other issues.

To that end, in this essay I tackle one nonmilitary application of drones in the Alaskan oil and gas industry, homing in on discourses of large-scale spatiality and extended vision in particular. The global oil industry pervades land and sea, yet only small slices of the industry's operations lend themselves to viewability. I am interested in how images harnessed by drones meet the challenge of representing massive space. Footage captured by LiDAR-equipped drones provides an unprecedented ability to visually access the oil industry's sprawl more thoroughly than any other available technology, allowing the industry to map ever-greater swaths of its spread across the Earth's surface. I argue that while drones' military uses are fraught because of the way they are used to dominate and destroy human beings, drones' civilian uses are more complicated: on one hand, the technology is used to extend the oil industry's neocolonialist control over the natural world; on the other, drones in the civilian sphere help to remove human bodies from the mortal danger to which bodies in the military sphere are exposed.

In what follows, I first offer a brief history of drone technology, as well as an overview of the tug-of-war between utopian and dystopian impulses characteristic of existing perspectives on drones. I then turn my attention to the oil industry's use of civilian drones in Alaska, the product of a long battle to exploit the natural resources of the North Slope despite significant challenges posed by its climate. Automated vision within the oil industry uniquely demonstrates the interplay between risks and benefits afforded by civilian drones' visual power, but ultimately makes a persuasive case for their benefits, particularly their potential to limit bodily harm. The civilian sphere extends concerns about the abuse of visual power, but can be framed in a manner more utopian than dystopian, allowing us to move away from these extreme ends of the spectrum and approach a more measured understanding of drone technology.

Predators, Privacy, Photography

Remote-controlled aircraft were first deployed in the United States during the Second World War, when the Army used the Radioplane OQ-2 for target practice. The Radioplane OQ-2 was launched by catapult and recoverable by parachute. Over the course of the Cold War, unmanned reconnaissance aircraft became more sophisticated in design and began to play a more prominent role in military strategy. Israel's Tadiran Industries developed the Mastiff Unmanned Aerial Vehicle following the 1973 Yom Kippur War in order to aid ground forces with eyes in the sky. The Predator, which along with the Reaper is now one of the two most common combat drone models, owes its existence to an expatriate Israeli engineer based in California. Abraham Karem developed the Gnat 750 in his garage in the 1980s: an unmanned glider with a small engine whose design was eventually bought by the American defense contractor General Atomics in 1990. General Atomics and Karem later modified the Gnat 750's design in order to meet specifications requested by the Central Intelligence Agency, including supplying it with a satellite antenna and a quieter engine. These refinements resulted in the first generation of Predators (Gettinger et al. 2014). Today, drones can be guided in real time by human navigators, or fly "autonomously," meaning that their route, speed, and height are preprogrammed ahead of flight. They can be as small as birds or as colossal as Boeing 737s. The Nano Hummingbird, for instance, designed for stealth surveillance on behalf of the Pentagon's Defense Advanced Research Projects Agency, has a wingspan of 6.5 inches and weighs less than an AA battery (ACLU 2016). Predators and Global Hawks, on the other hand, are bulky enough to require manned aircraft to escort their takeoffs and landings (Cunningham et al. 2014).

Since drones have largely been limited to battlefields until now, academic scholarship on drones focuses overwhelmingly on the military sphere, investigating the physical and psychological damage of conducting warfare at a distance. In his article "Drone Encounters," Matt Delmont uses the Pakistani photojournalist Noor Behram's photographs of drone attack scenes in Waziristan to show the supposed precision of drone strikes to be spurious: drone strikes cause a large number of civilian casualties, which are routinely downplayed by government officials. Delmont suggests that drones have become favored weapons in the "war on terror" because of their "twin claims to visual superiority: the ability to see and to resist being seen" (2013, 193-4). Delmont's interest in photographs and film is reflected in Jessy J. Ohl's article on drones in visual culture, "Nothing to See or Fear." Ohl examines drone imagery in U.S. news media between 2008-11 to argue that its "boring" nature undermines a viewer's capacity to "sense the material consequences of war" (Ohl 2015, 612). Delmont and Ohl's work shares an interest in the blind spots that all-seeing drones create: they limit the visibility of military action and obscure the destruction of foreign bodies (Ohl 2015, 613). Their articles reveal vision—visual acuity, visual obfuscation—to be central to drone studies, an approach further developed in Grégoire Chamayou's book *A Theory of the Drone*.

Chamayou suggests that the history of military drones is that of "an eye turned into a weapon" (2015, 11). This eye is no ordinary eye. Like the eye of God, it does more than simply see what is plainly visible. If the eye of God is capable of searching invisible hearts and minds "beneath the skin of phenomena," a drone's eye can likewise see what lies well beyond the reach of ordinary human vision (Chamayou 2015, 37). Predators and Reapers come equipped with color and black-and-white television cameras, radar, infrared imaging for dim lighting conditions, and image intensifiers, enabling them to send full-motion video to pilots who can use their lasers to target people or structures below (Delmont 2013). These drones' eyes, according to Chamayou, are human eyes amplified. Drones revolutionize seeing in a number of ways. Firstly, they can watch more continuously than a human pilot making a comparatively short flight in a plane could. In Chamayou's words, "a mechanical eye has no lids" (2015, 38). In addition to watching all the time without blinking, spatially they can see everything, following the notion of "wide area surveillance" (Chamayou 2015, 38). Finally, the images drones yield are more advanced than the still photographs, or even filmed footage, produced by human-piloted reconnaissance missions of old. The AeroVironment Puma integrates elevation values with information from the drone's Global Positioning System (GPS) and orientation measurements to produce a dense "point cloud," or set of data points, showing the location of topographic features like glaciers, bare ground, or buildings. Operators can zoom in and out of the 3D maps that the Puma creates, adding and subtracting different layers of information at will.

Why does it matter that drones can see so much more powerfully than people can? In the military sphere, drones' extended vision matters because "omniscience implies omnipotence" (Chamayou 2015, 37). Chamayou, like the other authors cited above, canvasses the ethical ramifications of sharp eyes killing from a distance at length, arguing that drones troublingly eliminate any kind of reciprocity, turning two-way combat into one-way slaughter. What about seeing powerfully in the nonmilitary sphere? The fact that drones can see so extensively and intensively has generated a popular discourse surrounding their civilian use that has centered on privacy (Kaminski 2016). To begin with, flying drones transcend the physical barriers, like walls, gates, fences, and hedges, that we have traditionally relied upon to protect our privacy. Furthermore, drone cameras' capacity to see what the naked eye cannot—such as infrared portions of the electromagnetic spectrum beyond visible red light—shatters longstanding divisions between public and private, interior and exterior, altogether. Drones open up nightmarish visions of constantly being within a Peeping Tom's line of sight. What the effect would be on individual psyches, and more broadly on society as a whole, if there were no places left to retreat from view is an open question, as is how susceptible drones are to individual, industrial, and institutional misuse.

The dystopian nightmares evoked by military and nonmilitary drones alike is a contemporary reincarnation of the utopian and dystopian associations that Paula Amad has argued surround aerial photography, from its inception via cameras suspended from nineteenth-century balloons (or kites, pigeons, and rockets), twentieth-century planes, and drones in the twenty-first. "Given aerial photography's major function in the early twentieth century as a tool of military reconnaissance, not to mention the airplane's primary role in the development of aerial bombardments such as those of Hiroshima and Nagasaki in August 1945 or the airplane's more recent transformation into a literal weapon of mass destruction (with the 11 September 2001 destruction of the World Trade Center Towers)," says Amad, "there is obviously significant material evidence for the association of aerial vision with a negative, violent and even terroristic mode of modern vision" (2012, 69). Fears over a dominating aerial vision targeting the weak by invading their privacy, at best, or wiping them off the face of the Earth, at worst, go hand-in-hand with utopian dreams of a vision whose expansiveness can be put to inventive use.

The "equally extreme utopianism" that Amad shows accompanied early twentieth-century aviation culture is traceable in present-day journalism and research studies breathlessly tracking drones' applications in civilian areas as varied as agriculture, commerce, transport, emergency services and disaster response, environmentalism, moviemaking, journalism, art photography, and many others (Amad 2012, 71). Drones' ability to cover large-scale space is an advantage for pesticide application, monitoring livestock, and surveying farmland (San Diego University 2016). Additionally, by flying at lower altitudes, drones allow farmers to spot insect infestations in their crops more readily than from fixed-wing aircraft (National Geographic 2015). Commercial companies like Amazon are testing package delivery by drone (Scott and Wingfield 2016). Dubai is testing drone taxis that promise to ease traffic gridlock in congested cities around the world (The Economist 2017). The Migrant Offshore Aid Station, a Malta-based organization, uses the thermal and night-imaging capabilities of its two Schiebel drones to locate and rescue migrants risking their lives while attempting to cross the Mediterranean Sea (San Diego University 2016). A drone called "Waste Shark," nicknamed "the WALL-E of water," is diving around the port of Rotterdam collecting up to 1,100 pounds of trash in its open mouth, which could eventually help clean up the great garbage patches clogging the world's oceans (Atherton 2016).

In movie and television production, photojournalism, and art photography, drones are yielding shots that would be impossible to attain in any other way, spawning comparisons to other paradigm-shifting technologies like the lightweight cameras used in 1960s films like *Easy Rider* (1969), and the Steadicam used in 1970s films like *Rocky's* (1976) famous stair-climbing sequence (Verrier 2015). Drone cameras can go where manned aircraft cannot, such as dropping into narrow alleyways and canyons and flying through doors and windows. A drone camera is cheaper than filming from a helicopter, with a camera drone and crew costing $5,000 a day versus a helicopter shoot costing $25,000 a day (Verrier 2015). Drones' relative cheapness has led to their being celebrated as "democratizing the skies," with photojournalists now experimenting with $60 hobby drones to pick up the fine motor skills necessary to fly larger drones and gain an additional tool for their storytelling (Estrin 2017). Instagram accounts like Dronestagram and From Where I Drone have become hubs for drone and photography enthusiasts to share their images, and to trade techniques for finessing their use of the technology (Schwab 2017).

In short, drones' potential civilian applications are countless. It is dizzying difficult to keep up: every day, it seems, brings another news article reporting on yet another innovative experiment with drone technology. From the fray, however, a few key trends emerge. Drones are valuable because, being automated, they can monitor larger spaces more precisely and systematically than a human-piloted plane can. Drones shorten the time required to complete tasks. Drones are economical. They are safer for human pilots, as machines can enter hostile environments without putting their pilots in danger. As a result, drones provide greater access, conveniently reaching places that would be hard for us to get to otherwise. When combined with advanced cameras, drones' greater access also helps us see familiar things in fresh ways, or see unfamiliar things for the first time. These advantages offered by drones are particularly salient within the oil industry, which, being a planet-spanning enterprise, perpetually seeks efficient technical solutions to the problem of monitoring enormous space, while still offering maximum return on investment to shareholders. In the next section, I examine the AeroVironment-BP 3D mapping experiment in greater detail, paying particular attention to its implications for helping us see the large-scale Alaskan oil environment in new ways.

Oil's Spatial Scale

The oil industry is big. It is what Timothy Morton calls a hyperobject: an entity so distended across space and time that it becomes "almost impossible to hold in the mind" (Morton 2013, 58). Circulating oil from areas of production to areas of consumption entails millions of miles of pipelines and shipping routes networked all over the planet. Natural gas distribution pipelines in the United States alone could stretch from Earth to the Moon at least seven times. About 40 percent of all seaborne cargo is oil, and there is more seaborne cargo at any given time, by weight, than there are fish in the sea (Carlyle 2013).

The oil industry's globe-girding distributional network originates in oilfields whose scales themselves defy comprehension. The biggest oilfield in both the United States and North America is the Prudhoe Bay field, on Alaska's North Slope. Discovered in the late 1960s, the oilfield covers 213,543 acres and contains approximately 25 billion barrels of oil. The field is located 650 miles north of Anchorage, and 250 miles north of the outer edge of the Arctic Circle. Exxon and the Atlantic Richfield Company (ARCO) drilled the field's first well, the Prudhoe Bay State #1, on March 12, 1968. British Petroleum (BP) Exploration drilled a confirmation well in 1969, and over the next eight years, Exxon, ARCO, BP, and other companies holding leases in the area scrambled to chart the reservoir, resolve equity participation, and build an initial infrastructure (British Petroleum (BP) 2013).

Research published by the oil industry around this time emphasizes the challenges to development posed by Prudhoe Bay's scale, remoteness, and climate. In a 1971 *Journal of Petroleum Technology* article, F. G. Laraminie of BP Alaska describes how, in order to work successfully in the Arctic, oil companies must either confine operations to the wintertime when the tundra is frozen, or build expensive, five-foot-thick gravel roads and pads in the summer to act as insulators between themselves and the permafrost's thawing upper layer. Helicopters and hovercraft could provide access to isolated field sites in the summer months, but could not operate in the North Slope's frequent fog, blizzards, and "whiteouts," a condition of "diffuse shadowless illumination resulting in loss of depth perception" (Larminie 1971). The challenge of developing the Prudhoe Bay field, in other words, sprang from an earlier challenge: the difficulty of seeing the field clearly in the first place. "Winds up to 50 mph can lift the ice crystal snow into a blinding fog that completely obscures visibility, even in daylight, for several days," a 1978 *Journal of Petroleum Technology* article on logistical problems in Prudhoe Bay co-authored by Exxon and ARCO employees says. "During these times, aircraft are grounded and surface transportation is difficult and hazardous" (Bryan et al. 1978, 852). Visibility is intimately linked to access and possession. Find a way to see the Prudhoe Bay oilfield clearly in all weather conditions, Laraminie and others seem to suggest, and you are well on your way to bringing it under industrial control.

Solving the problem of seeing an oilfield's 3D topographic features clearly amid diffuse lighting conditions that are flattening them into a two-dimensional visual blur is of interest not just to the oil industry, but also to photographers whose work grapples with representing the industry's scale. Edward Burtynsky, Mishka Henner, and Garth Lenz have all used a range of methods, from helicopters to Google Earth, to obtain expansive aerial perspectives on oilfields that come close, perhaps as close as humanly possible, to helping their viewers hold the sprawling oil industry in their minds. In an interview, Lenz describes how he deliberately photographs oilfields from the air either early or late in the day, when the low angle of the sun throws into relief topographic features that would be indistinct otherwise. He uses polarizing filters to get better contrast and richer colors. Lenz believes aerial photography to serve a crucial revealing purpose. "Aerial photography can convey a sense of the scale of activities such as industrial logging, coal mining, shale gas in a way that no other photography can," he says, "It can also reveal activities and impacts that are normally out of sight (and therefore out of mind)" (Pook 2014).

Burtynsky and Henner share Lenz's fascination with documenting the impact of industrial activities on natural landscapes, as well as his fascination with aerial photography's potential to extend human vision by opening up to view what is usually out of sight. Prudhoe Bay, and the oil industry as a whole, is big and difficult to access. By being everywhere all the time, yet sealed off beyond gates, fences, and signs warning casual passersby not to get too close, the oil industry poses a formidable challenge to visibility. Henner overcomes this challenge by knitting together Google Earth's publicly available satellite images of oilfields to assemble eerily beautiful compositions looking almost like abstract paintings. In his words, he sets out "to reveal things that surround us but which we rarely see or don't want to see" (Dunne 2014).

Similarly driven by a mission to reveal aspects of our surroundings that we rarely see, Burtynsky has recently experimented with drones, banking on remotely operated technology to provide visual access to sites that would be off limits to manned aircraft. Over the years, Burtynsky has found the oil industry to be largely hostile to his desire to photograph it, saying that in most cases "they said no when I asked to come in and make photographs, because they couldn't see an upside to letting me in" (Burtynsky 2017). The oil industry jealously guarding itself from prying outside eyes goes hand-in-hand with other logistical challenges to aerial photographers, such as the fact that certain countries have no civil aviation, only industrial or military access to the skies. While working in China, Burtynsky circumvented the absence of civil aviation by using a drone to shoot large-scale hydroelectric dams and agricultural landscapes. Shooting urban development and oil refineries in Nigeria, Burtynsky found that “Unlike a helicopter, a drone could fly at relatively low altitudes,” and unlike standing on a rooftop looking down, “it could take his camera wherever he wanted” (Khatchadourian 2016, 88). Remotely operated drone technology “offers new ways of entering into places that you would never have considered going—or that you couldn’t even go to—before” (Burtynsky 2017).

Writing in 1971, BP Alaska’s Laraminie was already noting the importance of remotely operated technology for providing access to, and thus control over, the Prudhoe Bay oilfield. “Arctic oil installations will be characterized by a high degree of automation,” he says, “involving remote supervision and control of production” (Laraminie 1971, 23). Another BP Alaska employee, T. A. Sharpe, likewise revealed at a 1971 Society of Petroleum Engineers conference that “because of the environment and the difficulties and cost of housing large numbers of personnel on the North Slope, the production facilities have been designed to operate unattended. All data and information will be transmitted to a central control room located in the operations camp, where a computerized supervisory control system will monitor and adjust the production from the field” using minimal human personnel (Sharpe 1971). Effective remote supervision was essential not just because the Arctic’s bitter climate makes it difficult for people to live and work there permanently, but also because the Prudhoe Bay field is too big for people to visually monitor it without technological assistance. Having eyes on giant oil fields at all times is vital for a number of reasons, including deterring criminal activity, mitigating the lost profits and ecological harm engendered by terrestrial pipeline leakages and oil spills at sea, tracking such environmental phenomena as wildlife migrations and ice floes that might collide with and damage facilities, as well as routine infrastructural maintenance.

In Nigeria, for example, vandals avail of the fact that the oil industry cannot supervise every inch of pipeline at all times to tap them, and successfully steal crude. Drones with directional antennas and long-range zoom cameras have been proposed as an efficient solution to the problem of providing real-time monitoring whenever a pressure dip or any significant third-party tampering is detected on a section of pipeline, which would then allow response teams to quickly target the relevant area (Idachaba 2014). In the summer of 2013, the Portuguese navy tested drones’ aptitude for speedily locating marine oil spills. To simulate a spill, the navy dropped 220 pounds of popcorn in the Atlantic Ocean. Flying in a scanning pattern over 62 square miles of open water, their drone pinpointed the popcorn in less than 90 minutes, and the operation from takeoff to landing lasted less than three hours (Jacobs 2013, 42).

Later that year, the FAA selected six test sites around the United States in which to experiment with integrating drones with what it called “the largest, most complex air traffic systems in the world” (Federal Aviation Administration 2013). The six sites were in Virginia, Texas, North Dakota, New York, Nevada, and Alaska, their geographic and climatic diversity intended to provide the FAA with a substantial range of data. At the Alaskan site, BP obtained a public certificate of authorization through the University of Alaska Fairbanks in order to work with AeroVironment on mapping the Prudhoe Bay oilfield. BP was still reeling from the catastrophic 2010 Deepwater Horizon oil spill in the Gulf of Mexico, and testing drones near the North Pole was a relatively risk-free way to explore their feasibility for wider use. Sparsely populated and with little air traffic, Prudhoe Bay presents few logistical or safety hazards (Ungerleider 2014).

Floods, ice breakups, and ice floes perpetually alter Prudhoe Bay’s topography, ensuring that infrastructure built within it needs constant repair to withstand the severe environment (BP 2014). The field’s infrastructure includes approximately 1,000 oil wells and 1,200 miles of pipeline across an area of 400 square miles. Wells and facilities are connected by a network of 200 miles of gravel roads. The gravel roads are crucial to seismic surveys, drilling, maintenance, and other field activities. The roads therefore need to be well-maintained themselves, but manual upkeep is expensive and laborious—simply surveying a one-mile section can cost as much as $70,000 (Smith 2015). Their maintenance can be automated to some degree through GPS guidance, an industrial technique also employed in mining and precision agriculture. However, automated civil engineering requires high-precision 3D maps, and the Prudhoe Bay oilfield’s sheer size is an obstacle to making them.

Remotely Monitoring Oilfields

Possible oilfield mapping methods include traditional land survey, aerial photogrammetry, satellite-based photography, satellite-based synthetic aperture radar, airborne LiDAR, truck-based LiDAR, and drone-based LiDAR (Smith 2015). These methods need to satisfy two requirements: they must supply adequate accuracy, and they must cover the field's full terrain. All the methods, except for the last one, fall short. Aerial photogrammetry, for instance, can cover all of Prudhoe Bay's terrain, but does not provide sufficient accuracy. Truck-based LiDAR, on the other hand, does provide sufficient accuracy, but cannot cover the whole oilfield, as trucks cannot reach areas off the road network, or work around obstructions like well pads and waterways. Only drone-based LiDAR meets both conditions of accuracy and comprehensiveness.

The oil industry and its collaborators have long relied on remotely operated technology registering an array of electromagnetic waves to visually monitor its geographic spread. Throughout the 1970s, the National Aeronautics and Space Administration (NASA) experimented with microwave remote sensing of ice in the Beaufort Sea, north of Prudhoe Bay (Campbell et al. 1980). Microwaves offer the possibility of studying natural phenomena in all kinds of weather, and at any time of the day or night, eliminating observational barriers in an area that is dark and cloud-covered much of the year. The NASA CV-900 Galileo I performed a series of flights ranging in altitude from 500 feet to seven miles, carrying a variety of visual and infrared sensors in addition to imaging radiometers. The microwave imagery gathered allowed scientists to distinguish between old (thick) and new (thin) ice, as well as track ice motion, information useful for oil industry operations in the region.

Between 1974-84, the National Oceanic and Atmospheric Administration developed a high-frequency Coastal Ocean Dynamics Applications Radar, or CODAR, capable of using radio waves to remotely sense ocean surface currents, wave properties, over-water surface winds, and ice movement without expensive and unreliable in-water instrumentation (Barrick et al. 1986). Chevron adapted CODAR to offshore oil industry applications including environmental monitoring and conveying hazard warnings to production platform and drilling vessel operators, improving safety and reducing operational costs. CODAR data gathered from experiments around Prudhoe Bay was visualized in a two-dimensional map using color-coded arrows to chart the radial velocities of ice and ocean surface currents, as well as in a graph that, though two-dimensional, conveys a 3D effect by pinpointing information across three axes: doppler frequency in hertz, range in kilometers, and received power in decibels.

Real-time oilfield monitoring using the electromagnetic spectrum was further developed in the 1990s and 2000s. In 1999, ARCO reported on tests it had conducted over the past three years involving a forward-looking infrared camera mounted on a Twin Otter plane monitoring pipeline corrosion at the Kuparuk oilfield, 40 miles west of Prudhoe Bay (St. Pierre 1999). The infrared camera's aerial perspective enabled it to survey 700 miles of pipeline in less than three flight hours, making it a rapid and efficient inspection tool. The camera was connected to a computer, a GPS receiver, and two video recorders capturing images in standard and high resolution. Infrared imagery was also found to produce better wildlife survey results than usual. The Alaska Fish and Game Department flew over the territory each year to visually count the migrating porcupine caribou herd and estimate the number of new births, but the infrared system detected more caribou calves than did visual observations of the herd's population: the brown Arctic tundra mottled with patches of snow occasionally camouflaged the caribou to the naked eye, but infrared could still see them clearly.

In addition to microwaves, radio waves, and infrared waves, the oil industry has harnessed LiDAR technology—spanning the ultraviolet, visible light, and near infrared parts of the electromagnetic spectrum—to assist in oilfield monitoring. LiDAR equipment uses laser pulses to collect 3D images. Emitting up to 400,000 pulses of light per second, the laser scanner establishes the time delay between transmission and reception in order to calculate elevation values. Since LiDAR can be reflected from any object that the laser pulse strikes, up to five returns are collected per pulse. These multiple returns are recorded and each point is assigned a classification to identify landscape components. The intensity of the reflected energy is captured and analyzed as well, yielding high-resolution topographical mapping and 3D surface modeling (BP 2014). LiDAR technology was invented shortly after the first lasers in 1958, but was initially hamstrung by a series of limitations: it was too costly, heavy, bulky, and required too much power to be practical (Ouellette 2012). Furthermore, the technology only worked if the lasers were fixed to the ground, not if they were placed on moving platforms. Over time, the cheaper, more compact, and less power-hungry solid-state diode pumped laser the more improved the LiDAR's practicality, as did the emergence of GPS, and evolving computer technology newly capable of performing a LiDAR system's complex data analysis. LiDAR now has a range of functions both within and beyond the oil industry. Within the oil industry, LiDAR's multifaceted uses include building geological models, obtaining erosion profiles along pipeline corridors allowing personnel to identify areas where ground cover is no longer within required safety parameters for pipeline burial, and constructing digital terrain simulations that aid in the planning of evacuation routes and helicopter landing zones for emergency situations (Beaubouef et al. 2005).

Beyond the oil industry, self-driving cars use LiDAR for navigation, creating a digital 3D map of their surroundings that allows them to "see" at least up to one football field of distance, in any direction (Vergano 2017). Within the field of archeology, LiDAR's impact is considered revolutionary, comparable to that of radiocarbon dating, or computing itself: just as computers increased the speed of number-crunching, LiDAR compresses information gathering, mapping an environment's agricultural and architectural artifacts in extraordinary detail within a fraction of the time and cost that it would take to do so by hand (Hopkins 2012). Archeologists deploy LiDAR to construct high-definition topographical maps of sites revealing features of the landscape that would be invisible to the naked eye, or even to traditional techniques like aerial photography. For instance, a LiDAR map generated by the New Forest National Park Authority in Britain was able to look past an obscuring layer of oak trees and heather to uncover traces of Bronze-Age mounds and Ancient Roman roads below (New Forest National Park Authority 2015).

Just as drones offer fresh visual perspectives while shooting photographs or films and television shows, LiDAR is likewise reshaping entertainment media like music videos and 3D gaming. The video for the band Radiohead's song "House of Cards" features LiDAR-derived 3D maps of urban spaces in Florida, including streets, buildings, and electric pylons (Radiohead 2008). EA Sports, a sports video game developer, also used a laser scanner to create 3D maps of golf courses, football stadiums, and basketball courts around the country, improving the surface-detail realism and accuracy found in its Tiger Woods PGA Tour, NCAA Football, and NBA Live games' virtual environments. "Accuracy rules in the video-game industry," an Orlando Sentinel article said, "because it helps drive the player's experience" (Pacheco 2012). Accurate measurements also matter in the oil industry's uses of LiDAR. However, as with drones, LiDAR technology allows large-scale spatial scanning in a timely, safe, and cost-effective manner — qualities that are as important as accuracy in day-to-day industrial operations. A promotional video that AeroVironment created for its project with BP in Prudhoe Bay frequently features the words "precise," "rapid," "up-to-date," "fast," "quickly," "real-time," "sooner," and "lower cost," while emphasizing just how dauntingly big the oilfield is, and the risks posed by monitoring it through any means less advanced than drone-based LiDAR (AeroVironment 2017).

The AeroVironment Puma All Environment (AE) drone carried the LiDAR equipment into the air above the Prudhoe Bay oilfield. Puma AEs have a wingspan of about nine feet and are about four feet long, weighing 14 pounds. They are hand-launched, flying 200 to 400 feet above ground level at less than 40 knots, their slow speed enabling them to gather detailed location analytics. They are also especially well-suited to ecologically fragile regions like Prudhoe Bay, as they run on smart batteries, and are quiet (AeroVironment 2014). The Puma AE's point cloud generated a picture of wear and tear on the gravel road surfaces that was compared to a picture of the roads in ideal condition. A data set marking the differences between the two pictures was then converted into a set of instructions for road grader operators. With the aid of a correctional GPS network, the operators followed a map display keeping them along the road's centerline while GPS units mounted on their grader blades moved up and down automatically to "cut and fill" the road surfaces and bring them back to specification (Smith 2015).

Gravel for the roads is mined in pits at Prudhoe Bay that can be up to half a square mile in size, and operate around the clock. The Puma AE's mapmaking ability was also used to create 3D models of the gravel pits showing how much of the raw material was remaining, and identifying areas prone to flooding. As with manual road maintenance, manual gravel extraction estimations are costly, time-consuming, and comparatively inaccurate. Flying over the gravel pits, the Puma AE's LiDAR sensor delivered rapid, precise volumetric analysis, mapping drainage lines and charting sink points and watershed boundaries throughout (AeroVironment 2016). The Puma AE contributed more data on a half-mile-wide gravel pit in 45 minutes than BP had collected in the previous 30 years (Nicas 2014).

Eager to demonstrate the full range of ways drones can enhance operational efficiency within the oil industry, AeroVironment supplemented its road and gravel pit topographies with maps of the BP pipelines criss-crossing Prudhoe Bay. The 1,200 miles of oilfield pipeline are supported on piles driven into the Alaskan permafrost. Freeze and thaw can cause the pilings to shift and potentially result in a pipeline rupture, meaning they, like the roads, mandate continual vigilance—a demanding endeavor given that the field holds over 44,000 pipeline supports. The Puma AE can survey a two-mile-long stretch of pipeline in 30 minutes, a task that would take a human up to seven days (BP 2014). The LiDAR-equipped drone assembled visual and 3D feedback on the pipelines' stability. Successive maps were contrasted for changes over time to diagnose areas needing remediation, and to validate tested remediation methods (Smith 2015).

Extending Human Vision

Unmanned drones can easily access oilfield areas far from the typical aviation infrastructure required of manned aircraft, eliminating the need for human pilots to undertake hazardous journeys, and providing finer-quality data with a high degree of consistency and repeatability for flight profiles (Cunningham et al. 2014). As Amad has shown, human pilots are intensely fallible: "reconnaissance pilots and observers (much like the images they produced) were essentially fragile and imprecise bodies, subject to extreme danger and difficulty" (Amad 2012, 73). Their job "was especially arduous due to their observational imperative to fly over the same terrain repeatedly in a level and straight manner (often relying on nothing other than the pilot's sense of balance) in order to visually scan it in an exhaustive, stable, and uninterrupted fashion" (Amad 2012, 73). Drones remove the fragility and imprecision of the human body from the equation.

Their advantages for systematically monitoring large spaces usually eluding human vision are supplemented by an equally useful ability to catch minutiae that a human eye might miss. To a limited extent within the United States, and to a greater extent abroad, drones are used to closely inspect oil industry facilities like gas flare stacks, which are elevated columns within larger flare systems at refineries that burn off flammable gases to prevent pressure buildup. Traditionally, the integrity of flare systems has been examined through rope access, inbuilt scaffolding, or manned helicopter flybys with a photographer. The disadvantages of trying to carry out visual inspections or take photographs while swinging from ropes or scaling ladders and platforms are obvious: the plant has to be shut down, and inspection personnel are placed in physical danger (Aja-Onu, Akhibi, and Asiodu-Otughwor 2015). Furthermore, manned helicopters cannot fly close to live flares when the system is in operation. Even photographs taken via helicopter during a shutdown cannot capture the detail necessary to assess flare conditions properly. A drone used to gather up-close imagery of a flare boom that, two weeks earlier, a helicopter flyby had declared to be in good condition found a crack in a weld on the flare tip revealing external burning (English 2015). The drone's live video feed, shot from a few feet away, offered operators a sharper view of the weld, translating into repairs essential for the flare system's safety and effectiveness.

Beyond remote corners of gigantic oil fields like Prudhoe Bay's and refinery flare stacks, other parts of oil industry installations that pose access challenges include the legs, underdeck, and overside areas of offshore drilling platforms (Conolly 2014). Attempting to decommission an offshore platform in the North Sea, the oil corporation Shell tried erecting scaffolding beneath it to check the soundness of the underdeck. Frequent storms over a period of two months repeatedly sent half-finished scaffold structures to the seafloor. Cyberhawk, a British drone inspection and surveying company, performed an underdeck appraisal in five days, allowing Shell to determine that it was solid enough for the platform to be lifted off it in one go. Cyberhawk drones transmit live, high-definition video and infrared video to their operators, enabling them to identify metallic components betraying signs of thermal fatigue and to locate sources of gas leaks at refineries and production platforms. In the future, Cyberhawk anticipates that tiny microdrones will be developed capable of flying autonomously inside bulk storage tanks to generate 3D images that would uncover critical defects if present. Chemical fumes emanating from the storage tanks make this task hazardous for humans at the moment (Jacobs 2013, 40-41).

Drones thus extend human vision in two main ways. Firstly, their LiDAR, thermal, or infrared competencies all mean that vision is no longer confined to the spectral capacity of the human eye. It expands to encompass regions of the electromagnetic spectrum before violet or past red light. Conventional photography relies on the narrow band of the spectrum to which our eyes are sensitive, but infrared and thermal imagery ventures into heat's longer wavelengths, and LiDAR to ultraviolet's shorter ones. The visible, in other words, "becomes a small part of a larger field of sensory exploration of the environment" (Manovich 1993). As a result, recording objects' positions in space is no longer constrained by whether our eyes are capable of registering them or not.

The second way in which drones extend human vision is by removing the conditions of accessibility once constraining the recording of objects' positions in space. Areas that would be difficult or dangerous for people to try to reach can easily be penetrated by mechanical drones. Dziga Vertov predicted breaking the accessibility barrier a century ago. Lamenting the "imperfections and shortsightedness of the human eye," he dreamed that the next stage of cinematic progress following a "kinok-pilot" guiding a camera's movements would be a "kinok-engineer, with remote control of cameras"—an innovation sounding remarkably similar to a drone operator (1984, 14; 19). Vertov believed that "the position of our bodies while observing or our perception of a certain number of features of a visual phenomenon in a given instant are by no means obligatory limitations for the camera" (1984, 15). Inhabiting the perspective of a perfectly mobile seeing machine, he says "I draw near, then away from objects, I crawl under, I climb onto them. I move apace with the muzzle of a galloping horse, I plunge full speed into a crowd, I outstrip running soldiers, I fall on my back, I ascend with an airplane, I plunge and soar together with plunging and soaring bodies" (Vertov 1984, 17). Drones, as we have seen, draw near to and make visible minuscule cracks on flare stacks. They are likewise adequate to drawing away from and aerially inscribing objects as huge as the Prudhoe Bay oilfield. Drones crawl under offshore drilling rigs and climb onto them, plunging and soaring together. In short, drones perceive more and better than we can, opening up new vistas to visualization unavailable to normal eyes.

Revealing technologies that extend human vision, including LiDAR-equipped drones and the digital 3D maps they generate, are attractive options for removing oilfield employees from the mercy of the elements. Oilfield employees using digital 3D maps in Prudhoe Bay transport themselves, through the computer screens in their offices, into a virtual simulacrum of the harsh Arctic environment outside. This simulation frees their bodies from real exposure to what the industry calls the four D's: dull, dirty, difficult, and dangerous work. Working in an oilfield means running the risk of injury or death in a catastrophic accident at the best of times, and in Alaska this bodily risk is compounded by severe weather conditions all year round. Winter temperatures in northern Alaska frequently drop to -30ºF with extreme winds, and even in the warmest summer months the average daily temperature is only 45ºF (BP 2017).

The fact that the oil industry is in the Arctic at all speaks to a wider global energy trend heralding the end of "easy oil." "Haunted by the specter of depletion, states and corporations embark on a desperate scramble for oil," in Michael Watts's words, "which is leading inexorably to a tooth and nail struggle for both conventional and unconventional hydrocarbons," including tar sands, shale gas, and deepwater oil and gas (Watts 2012, 438). Just as virtual-reality technology allows energy-hungry humans to mine unobtanium on the planet Pandora despite its toxic atmosphere in Avatar (2009), the challenging operating environments of unconventional hydrocarbons seem to point toward even more advanced technological enhancement of the human body's modest capabilities in the years to come (at least in the U.S., which has so far been slow to adapt to renewable energy). In a paper delivered at the 2015 Arctic Technology Conference, two employees from the firm GRI Simulations presented what they called the Virtual Arctic Simulation Environment, a software system designed to train oilfield workers in how to navigate real-life remotely operated vehicles, or ROVs, within Arctic subsea trenches. The presentation sold the technology much as EA Sports might market its athletic video games, emphasizing the "high fidelity" of its interactive 3D graphics (Dodd and Hamilton 2015). GRI Simulations' VR experience allows infrastructure to be designed and operations to be practiced in advance, freeing oilfield employees from prolonged exposure to a real-life environment hard on the human body.

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