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October 2022 | The Biggest and Smallest Stories

ROBOTICS 101
SENSORS THAT ALLOW ROBOTS TO SEE, HEAR, TOUCH, AND MOVE

Imaging-Based DNA Sequencing
PAST, PRESENT & FUTURE

Advances in AI
FOR INDUSTRIAL INSPECTION

3D Laser Triangulation
BRINGING DEPTH TO MACHINE VISION

Lithium-Ion Batteries
HOT GROWTH, PRESSURE, AND LOOKING TOWARD THE FUTURE

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Our imaging technology begins with the visible spectrum, and extends far beyond it, from deep infrared through extreme UV and all the way to X-Ray frequencies. Our products define the top end of performance in the world's most demanding digital imaging applications.

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With a global network of experienced and technical sales professionals, unmatched technology and unrivaled components, Teledyne's vision solutions team are ready to help define your advanced vision solution.

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POSSIBILITIES
The biggest and smallest stories

ARCHEOLOGY, ASTRONOMY, EARTH OBSERVATION, SPACE EXPLORATION, HEALTH CARE, LIFE SCIENCES, SMART CITIES, ARTIFICIAL INTELLIGENCE, AND AUTOMATED DRIVING ARE JUST A START.

With technical advancements revolutionizing established industries and helping create entirely new ones, keeping up with the edges of innovation requires looking everywhere. Founded in 2014, The Possibility hub is dedicated to sharing these stories: the technology, science, and people that shape digital imaging and its countless applications. That covers a massive scope of industries that you wouldn't, at first blush, consider related. The demand for smartphone cameras has driven innovation that other industries use daily. Quality control issues can be solved with an imaging system instead of manufacturing specification. Something that works in space can work equally well underwater. We've seen repeatedly that innovations in one industry can help others. We want to facilitate this cross-pollination of ideas and insights.

Publishing it is only possible through a collaborative effort by the Teledyne group of companies, our partners, and our customers. Collectively, we bring unrivalled expertise across the spectrum of imaging solutions, and decades of experience. Sharing these stories makes us excited about the possibilities of the industries we serve, and we hope they might inspire you, too.

— GERALYN MILLER, Editor-in-Chief

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OCTOBER 2022

IMAGINE THE POSSIBILITIES

Robotics 101: Sensors that Allow Robots to See, Hear, Touch, and Move

VISION, AUDIO, MOVEMENT, AND TOUCH SENSORS ALLOW MODERN ROBOTS TO PERFORM INCREASINGLY SOPHISTICATED TASKS.

BY Possibility Editorial

Have you ever seen a humanoid robot doing parkour?

Two arms, two legs, a square head and a thick rectangular torso hopping hibbity dibbity over boxes and wooden pallets. It even did a backflip.

Yeah, most robots can't do that.

Most robots don't *need* to do that.

The cool parkour robot—Atlas from Boston Dynamics—is an experimental research platform that the company uses to test and evolve robot bodily dexterity. It learns its moves primarily through simulation and mimicry. And while Atlas is interesting and makes for a good viral video, humanoid robots are the exception in the world of robotics. For practical applications, they are not at all useful.

Robots are typically used to perform tasks that are considered "dull, dirty, or dangerous." The most common type of robot is an industrial robot, like the articulated arm manufacturing companies use on assembly lines. Robotic arms have a stable, immovable base, between two and five moving joints, and an appendage at the end—called a manipulator—that functions like a hand. Other common robots are professional service robots, like the logistics robots that look like large hockey pucks that Amazon uses to move goods through a warehouse, or domestic robots that vacuum your house. None of these robots are doing parkour.

Robots are often defined as physical machines that can "sense, think, and act." Sensors measure external conditions and deliver that data to a computer processor or controller within the robot that makes sense of that data then decides how to act. For example, a vacuum cleaning robot will use a vision sensor to image a room, identify a bit of dirt, then move to vacuum it up.

Robots, can perform just about any task that a human can dream up. As such, robots need a wide array of sensors to sense the world and move through it.

VISIONS SENSORS

Robots usually need to see what they're doing. But robots don't typically see like a human does. The human eye is one of the most sophisticated sensors ever created. Robots do not need nearly as much clarity and focus, but rather can get by with simple vision sensors that, when coupled with machine learning software, can allow the robot to do just about anything we want.

For instance, iRobot's Roomba vacuum robots do not use high-tech sensors, but rather inexpensive cameras found in smartphones more than 10 years ago. For the most part, robots are not trying to make out images with high definition (which takes more internal computing power to process and can stress battery life), but rather are looking for general shapes, outlines, or colors that the computer vision algorithm can identify.

Common types of vision sensors in robotics include 2D and 3D cameras, lidar, radar, infrared, and phototransistors. If the vision system is working in the visible range, then lighting becomes necessary, where other vision sensors allow robots to work in the dark. Common visible light tasks include pick & place or assembly tasks, object detection, navigation, and some types of inspection.

Robotic automotive assembly line.

One interesting example is called a "delta" style robot that you might find on the conveyor belt of a consumer packaged goods factory. The robot hangs over a conveyor belt and uses simple vision sensors like a camera and/or a barcode scanner to identify items coming down the line. It will then use its manipulators, like little suction cups, to pick up items and pack them into boxes to be shipped.

Some common use cases that a robot will need to use vision sensors include:

- **Quality assurance:** using sensors to quickly assess if a product has a defect.
- **Object detection:** see an object and determine what it is.
- **Material handling:** identify material and move it from place to place.
- **Navigation:** avoid obstacles while moving through a room to get from one specific point to another.
- **Mapping:** see an area and create a computer-generated model of it.

AUDIO SENSORS

Why does a robot need to hear? The realm of robots is rapidly changing. For many years, most robots were the articulated arms found on factory floors, or other types of professional services in factories or warehouses. Robots in these environments have little need to hear.

As robots interact more with humans, audio sensors have become more important. Audio sensors—microphones, mostly—are often used for speech recognition so that a person can talk to a robot, and it will be able to "understand" and then act. Audio sensors can also be used for navigation (sonar or echolocation, for example), or detect pressure differences within an environment.

Common types of audio sensors and varieties of microphone include: acoustic pressure sensors, pressure microphones, high amplitude pressure microphones, and probe microphones.

ARE SMART SPEAKERS WITH VIRTUAL ASSISTANTS ROBOTS?

Siri, Alexa, Cortana, and the Google Assistant do what a robot does according to our earlier definition.

They sense with microphones, compute the speech, then respond (sense, think, and act). And yet, most people would not classify them as robots.

MOVEMENT SENSORS

Movement sensors often work in conjunction with a robot's moving bits (actuators) to assist in the robot's mobility. One of the most common types of a movement sensor is called an incremental encoder which is often found within an industrial robotic arm. It measures the rotation of the joints on the arm so that it moves at the right angle and speed.

Other movement sensors include accelerometers, gyroscopes, inertial sensors, and GPS sensors.

TOUCH SENSORS

You wouldn't think that a robot needs to "feel" like a human would. But touch sensors allow robots to have more nuanced capabilities than the typical "see an object, move an object" that they are often used for.

Robots use touch sensors for a variety of tasks. For example, bump sensors are used for navigation to tell the robot that it bumped into an object and thus must change course. Force sensors allow the robot to know when pressure or mechanical stress is being applied. Temperature sensors tell the robot if something is hot or cold (and thus must be avoided).

SENSOR FUSION: COMBINING SENSORS TO MAKE MORE COMPLETE ROBOTS

The dramatic increase in computer processing power (along with cloud computing) over the decades has made robots much more useful than before. While every individual sensor within a robot will have its own feedback loop within the robot's controller, the combination of disparate sensor systems ("sensor fusion") is giving us sophisticated robots that are better at performing a variety of tasks.

The most prominent example of sensor fusion right now is probably in the realm of autonomous vehicles. While the notion of a car driving itself without human input is not currently practical, we're moving in that direction by combining powerful computers with sensor systems like lidar, radar, 2D and 3D cameras, accelerometers, gyroscopes and more. Whereas simpler robots may have one or two of those sensors to perform singular tasks, sensor fusion allows the vehicle to take all those data inputs and make split second decisions.

Barring some dramatic breakthroughs in artificial intelligence, we will likely never be welcoming our new robot overlords. In fact, robotic systems often work better when paired with human capabilities. We have all the tools to build more powerful and capable robots that will help us as we tackle the problems of the present, and well into the future.

SCAN FOR MORE INFORMATION

Kibele-PIMS Shows How Imaging Ensures Food is Reliably Sorted and Packaged

FULLY AUTOMATED PACKAGING SYSTEMS USE RELIABLE, DURABLE CAMERAS TO ENSURE SUFFICIENT RESOLUTION AND SPEED FOR FLAWLESS SORTING AND PACKAGING.

BY Patrick Menge, Teledyne DALSA, Business Development Manager Europe

In their facilities in Istanbul, Kibele-PIMS has developed and commissioned two state-of-the-art, fully automated systems for the Unilever companies Knorr and Lipton, where food is identified, sorted and then stacked on pallets by robots. The larger of the two systems was built for Knorr. Its task is to classify the types of soup, sauces and other company products, packaged in small batches, that are delivered from production via a 27-meter-long feeding conveyor, and then to transfer the identified product types to the respective packing station. The cartons are sorted according to type across 17 stations, where three Kuka robots installed on linear axes place them on pallets and wrap them with adhesive film as soon as a pallet is fully loaded. Finished pallets are then made available on conveyor belts for collection by trucks.

SORTING BY IMAGE PROCESSING SYSTEMS

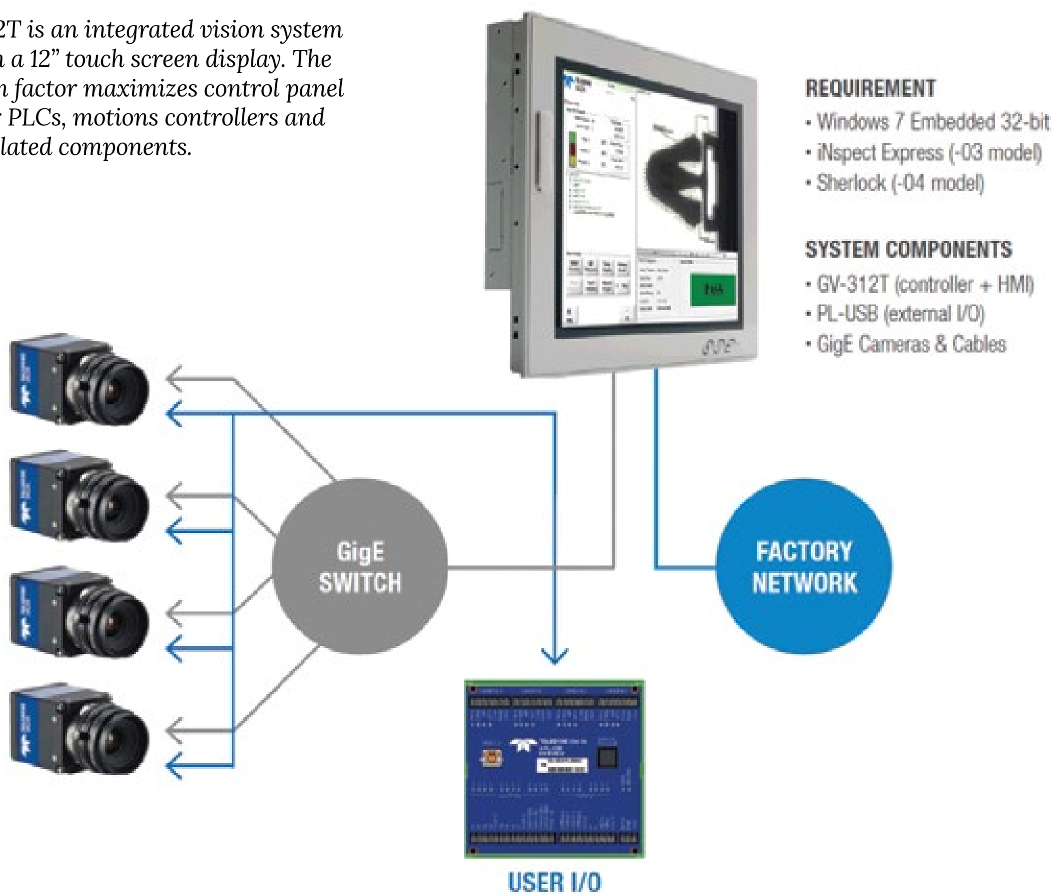
“Image processing systems play a decisive role in this application. Without them a reliable solution would not have been possible,” emphasizes Erdal Başaraner, who played a key role in the development of the two systems at Kibele-PIMS. “In the version for Knorr, a total of 19 cameras are in use. At the beginning of each packaging station, a camera reads barcodes on the boxes, which are used to classify the product type and assign it to the correct conveyor belt. At the same time, the incoming boxes are checked for possible damage to the packaging. Defective cardboard boxes just stay on the feeding conveyor belt until the end where they are collected and manually assessed and repacked, if possible.”

After the robots have loaded undamaged boxes onto the pallets, the completed pallets are transported past two additional cameras, which are used to record the number of pallets, the expiry dates and again the type of product. This information is then sent to a labeling machine that prints the associated trans-port labels, attaches them to the pallets and thus releases them for shipment.

When choosing the right cameras for this application, Başaraner and his colleagues decided to use Teledyne DALSA’s Genie Nano M1920 area cameras. This model met all of the resolution and speed requirements that Kibele-PIMS had previously specified. “In addition to that, we knew from our previous experiences with the Genie Nano series that these products have the reliability and durability to perform well even under harsh industrial conditions,” says Başaraner.

With four GEVA 312T industrial image processing PCs, equipped with the image processing software Inspect, all images are evaluated with the help of products from the Canadian manufacturer. Three of these GEVA PCs evaluate the images from the 17 cameras in the feeding conveyor area, the fourth one calculates the data from the two cameras at the end of the Knorr line. “A big advantage of the GEVA 312T workstations is their integrated touchscreen,” Başaraner explains his choice. “We can therefore also use them as the graphical user interface. In addition, we save the complete data of the products and the pallets on the GEVA PCs and have the opportunity to generate a wide variety of reports at this point and, if necessary, to pass them on to our customers’ servers.”

The GEVA-312T is an integrated vision system complete with a 12” touch screen display. The slim-line form factor maximizes control panel real estate for PLCs, motions controllers and non-vision related components.



LONG-TERM PARTNERSHIP

According to Başaraner, the trust that Kibele-PIMS has in Teledyne DALSA as a permanent partner for the entire image processing equipment is based on a long history: "In the past, we had different requirements for the vision systems that we wanted to integrate in order to implement various systems. Depending on the type of inspection process, we have implemented area and line scan cameras or even X-ray cameras to optimally solve the respective tasks. This is where one of Teledyne DALSA's major strengths has been evident for years: They can supply practically any vision technology we need to accomplish our applications with the required reliability. In addition to the cameras, our partner also carries high-quality image processing boards, specially optimized industrial PCs such as the GEVA series, or powerful software packages such as Inspect and Sherlock, which are successfully used by our customers and in numerous applications worldwide. Teledyne DALSA transfers their many years of experience from this large number of applications into the development of new products, and this is something where we and our customers benefit a lot."

RELIABLE SOLUTIONS

About a year before the Knorr system, Kibele-PIMS had already developed and commissioned another system where ten different types of tea from the manufacturer Lipton are pre-sorted and packaged. This variation is very similar to the Knorr system, even if it is a little smaller, incorporating ten lines, five robots from Universal Robots, 12 Genie Nano cameras, and three GEVA 312T workstations. Başaraner is very satisfied with the results of both sorting lines: "Before switching to the fully automated solutions, the food packages were manually sorted, which was a very exhausting task. In the new setup, the boxes arrive every 1.5 seconds on average on the Knorr line and every 2 seconds on the Lipton line. Compared to manual sorting, this means a significant increase in profitability and considerably fewer errors in the correct pack- aging of the food. Teledyne DALSA's imaging components used in these fully automated sorting and packaging lines have been an essential guarantee for the achieved success."

The current systems are designed for large dealers who usually order complete pallets of a single type of food. Kibele-PIMS is currently working on systems that allow different types of food to be packaged on one pallet. This concept is more effective for smaller retailers, as the order quantities can be smaller that way. "For this next generation of systems, we will surely trust in image processing from Teledyne DALSA again," says Erdal Başaraner with certainty based on the positive experience with Kibele-PIMS' Canadian partner.

The Knorr food boxes are checked for damaged packaging and classified using a barcode by one camera at each of the 17 lines.

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Teledyne DALSA
Industrial Vision Solutions

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NEW 67 MP, AND 37 MP CMOS VERSIONS

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SCAN FOR DETAILS

The output from an automated ABI 373 DNA sequencer that the Human Genome Project used to determine the complete human DNA sequence.

DNA Sequencing is Getting Faster, More Accurate and Mobile

THE RAPID MATURATION OF DNA SEQUENCING TECHNOLOGY HAS GIVEN RISE TO AN EXPLOSION OF GENOMIC DATA THAT COULD HELP FUNDAMENTALLY CHANGE HEALTHCARE AND SCIENCE.

BY Possibility Editorial

The human genome has 19,000 to 22,000 genes, all combining to tell the story of our bodies. DNA and RNA and full pairs of chromosomes hold a lot of data, to the point that it used to take supercomputers to do the heavy lifting of DNA sequencing. And locating a specific gene could take days or weeks, if it could be found at all.

The march of technology has made DNA sequencing faster, more reliable, and accurate. DNA sequencing can now be done with a handheld device paired with a smartphone. And researchers are now able to isolate and analyze specific genes without having to perform the cumbersome process of sequencing an entire strand of DNA.

The first full DNA genome ever sequenced was the humble PhiX174, the single-strand virus that infects E.coli. Developed by British biochemist Fred Sanger and colleagues in 1977, the "dideoxy chain-termination method" for sequencing DNA molecules—called the "Sanger method"—dominated the field of gene sequencing for the next 30 years and was eventually used to sequence the entire human genome.

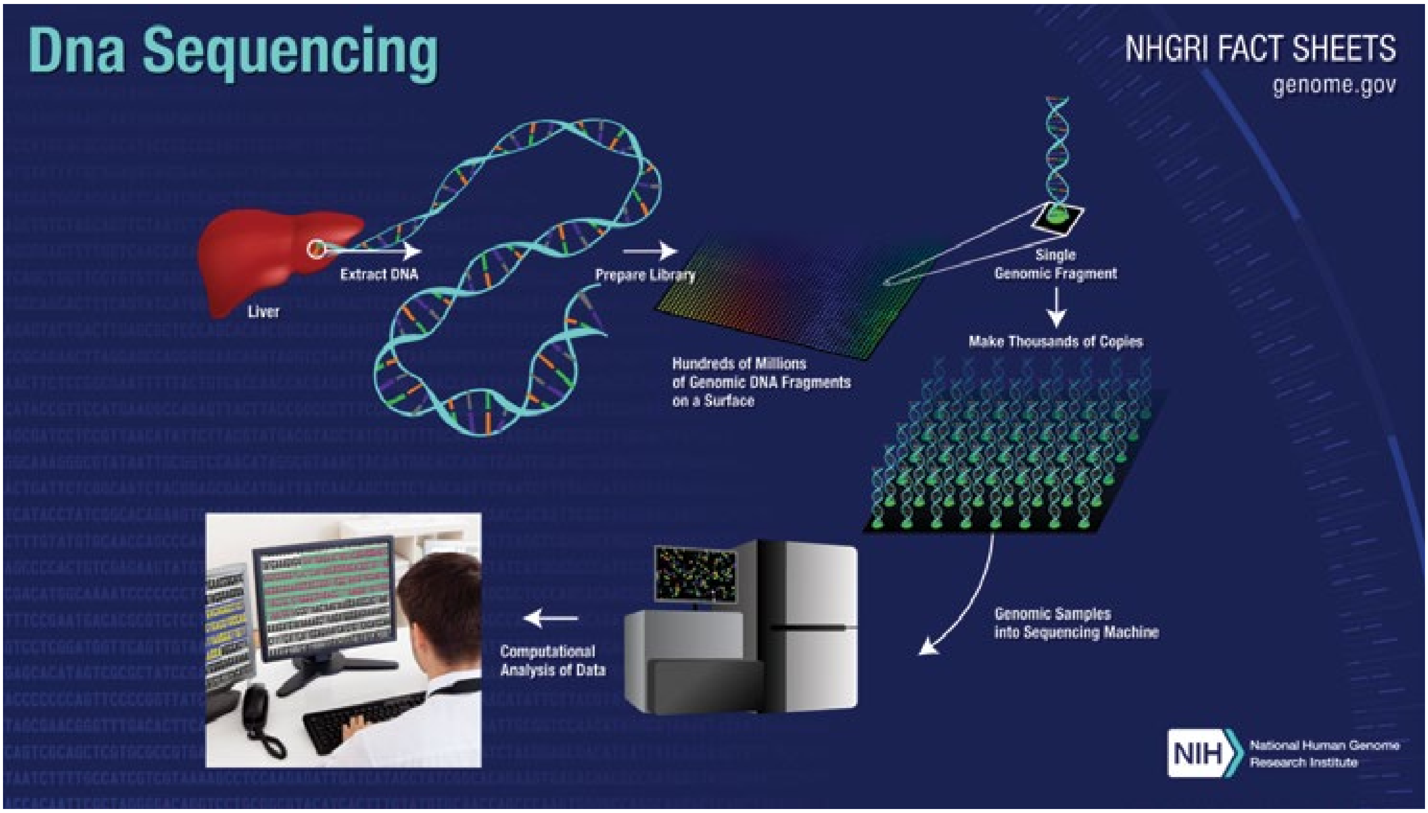
Completed in 2003, the Human Genome Project took 13 years to complete and cost about $3 billion. With today's technology, the project could be completed in about a day at a cost closer to $1,000. And with an app like iGenomics, it could eventually be done with a smartphone.

Even with the advance in technology, the human genome has three billion data points. Finding a specific gene—such as a mutated gene that causes cancer—has historically been very difficult, if it could be accomplished at all. But researchers developed a method in 2020 that can help isolate regions of genes for rapid analysis, promising quicker and more precise diagnosis in the future.

FROM THE SANGER METHOD TO ISOLATING SPECIFIC GENES

While the Sanger method dominated the field for three decades, it was very slow and imprecise. After the Human Genome Project concluded, scientists began releasing new kinds of DNA sequencing methods that are collectively known as Next Generation Sequencing (NGS).

Next Generation Sequencing techniques have led to an explosion of data in genomics. Researchers have been building databases of rare and infectious diseases, cancers, and psychiatric disorders. The 100,000 Genomes Project was an initiative from the United Kingdom that began in 2012 to sequence the genomes of 100,000 people with rare diseases or cancers to build the most comprehensive genomics database of its kind ever created. The PyscheENCODE project compiled data from 2,000 human brains to "form the most complete



The basic method of DNA sequencing, from extraction to analysis. Image via the National Human Genome Research Institute

picture of how regions that regulate DNA expression can influence the brain and its function." These kinds of databases couldn't have been completed with the Sanger method.

One NGS method (or third generation, depending on whom you ask) that has gained traction within the last decade is called "nanopore sequencing." A nanopore is what it sounds like, a pore of nano size. According to Oxford Nanopore Technologies, the method "enables direct, real-time analysis of long DNA or RNA fragments. It works by monitoring changes to an electrical current as nucleic acids are passed through a protein nanopore. The resulting signal is decoded to provide the specific DNA or RNA sequence." Nanopore sequencing has promised to offer low-cost genotyping, rapid processing of samples with results in real time, and high mobility. The method has been used for the identification of viral pathogens, human or plant genome sequencing, and monitoring of antibiotic resistance, among other uses.

In November 2020, scientists led by a team from the University of Washington announced a breakthrough using a nanopore technique called Targeted Long Read Sequencing (T-LRS) that allowed them to rapidly isolate specific regions of gene. In a trial of 33 people with known genetic disorders, the method—called Read Until—proved to be more accurate than either PCR or Cas-9 techniques (terms you might recognize from the news of testing methods for COVID-19).

The researchers describe how the method works:

"We applied the adaptive sequencing mode known as Read Until using the ReadFish software package, which allowed us to dynamically select target regions for sequencing. In this mode, software analyzes the signal after a DNA molecule enters a pore to determine whether that molecule lies within a specified genomic region of interest. If it does, the pore continues to sequence the molecule; if not, the DNA molecule is ejected from the pore."

The study was completed using a nanopore sequencing device called GridION from Oxford Nanopore that is about the size of a desktop printer.

IMAGING AT THE MOLECULAR LEVEL

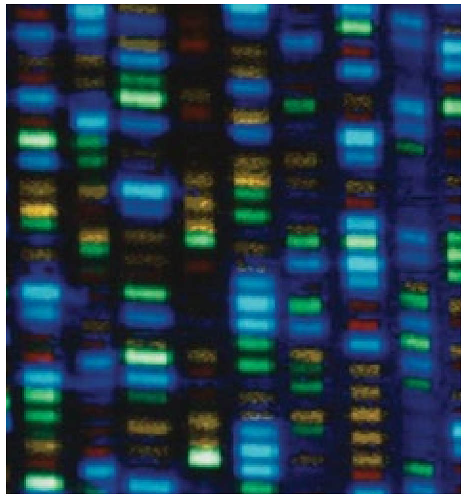
Scientists have continually gotten better at reading and sequencing DNA at its most minute scales.

Researchers out of the University of Tokyo published a paper in December 2020 that described a unique method for spatial decoding of DNA barcodes at the resolution of a single molecule. DNA barcodes are specific short sections of DNA from a gene that is often used to identify species, like how a barcode is used to identify a product at a supermarket.

The researchers repurposed a method used from a Heliscope machine, from the now-defunct Helicose Biosciences company. Called "single molecule fluorescent sequencing," the method works by imaging a single fluorophore molecule (a fluorophore is chemical compound that can re-emit light after being excited) without having to replicate the DNA through amplification methods, which could lead to bias in the results.

Essentially, the team used fluorescence microscopy to create a novel method of DNA sequencing at the molecular level by repurposing and improving on a method that had gone out of favor among researchers. The method improves upon existing practices because it does not require a large sample of DNA, does not require replication of the sample through amplification, and can analyze samples at the single molecule level.

Below: The MinION sequencer by Oxford Nanopore Technologies



The output of a DNA sequencer.
Image via the National Human Genome Research Institute

SEQUENCING AND ANALYSIS, ANYWHERE

The history of DNA sequencing has been set in laboratory environments. The instruments were large and cumbersome, sitting on benches and desks alongside equally large computers. Moore's Law, like it has with everything else computing, has changed that. The smartphones in our pockets are more powerful than the advanced laptops from 10 years ago. It was thus inevitable for DNA sequencing to make its way out of the lab and into the field.

Oxford Nanopore Technologies has been on the forefront of the miniaturization of DNA sequencing. Its MinION sequencer is the size of a thick harmonica and weighs 450 grams. And yet, analysis of the sequence would often still need to be done on a laptop or desktop computer, limiting its benefits when used in field testing.

A project called iGenomics hopes to change that. iGenomics is an iPhone app that was designed to complement the DNA sequencer devices made by Oxford Nanopore. By removing the need for a large laptop or cloud computer to analyze the data generation by devices like the MinION, iGenomics hopes to free DNA sequencing to go . . . anywhere.

DNA sequencing aboard the International Space Station is a distinct possibility. Or testing for virus variants such as Zika or COVID-19 in remote locations of the world.

"The true novelty of this application is not in the algorithms used but rather how they have been implemented in a mobile environment," the creators of iGenomics wrote in a research paper published in December 2020. "An important use case of iGenomics could be a researcher with limited computational resources sequencing complementary DNA (cDNA) of a coronavirus sample, loading and aligning the cDNA reads with iGenomics, and getting a first analysis of the coronavirus mutations within a few seconds."

FASTER, MORE ACCURATE, AND MOBILE

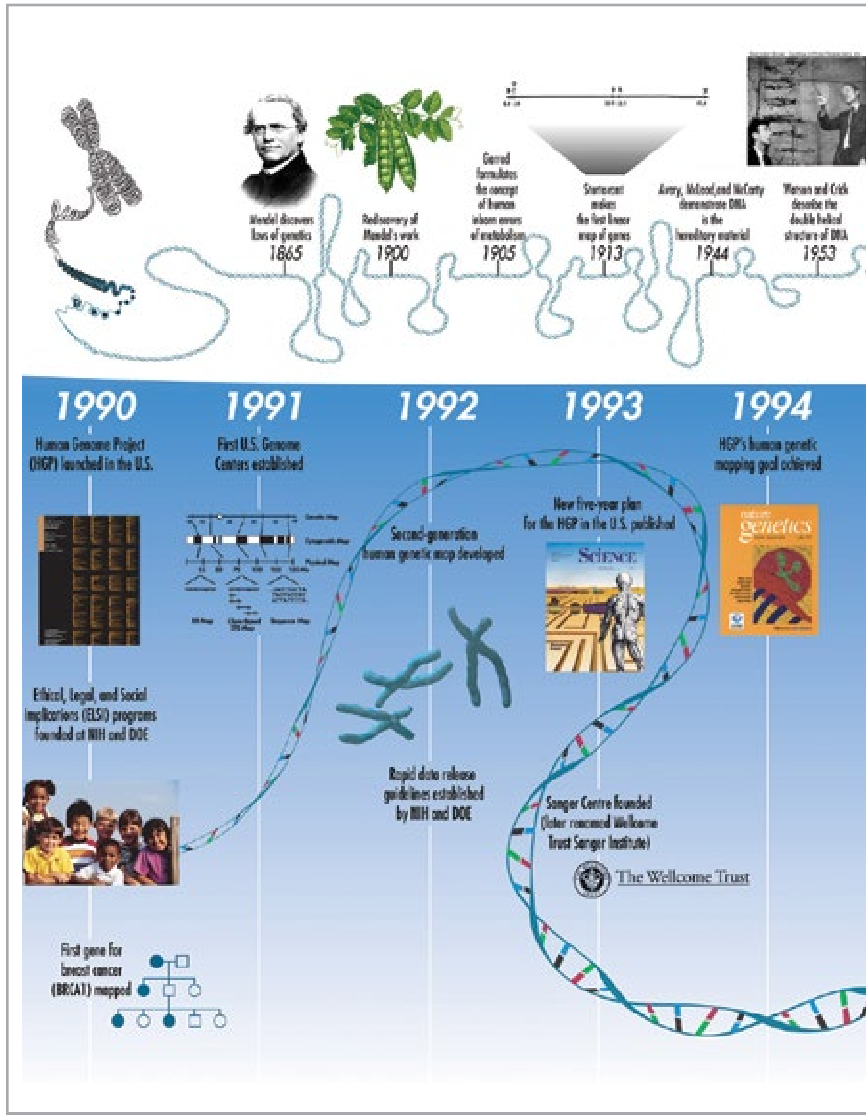
The rapid evolution of DNA sequencing methods combined with the power of big data and mobility promises a future of genomic breakthroughs that few could have imagined a few decades ago. Soon we will likely be able to quickly diagnose a form of cancer, sequence its genetics, then use artificial intelligence to build medicines to treat it, unique to the individual patient. Genetic variants of contagious diseases can be identified quicker, wherever they are found. The unique DNA barcodes of plant and animal species can be studied in the field, fundamentally changing the nature of bioscience.

SCAN FOR MORE INFORMATION

Imaging-Based DNA Sequencing: Past, Present & Future [Part One]

HOW IMAGE ANALYSIS AND COMPUTATIONAL TOOLS HAVE TAKEN GENOME SEQUENCING FROM YEARS TO MINUTES; FROM POPULATION TO PERSONAL.

BY Possibility Editorial



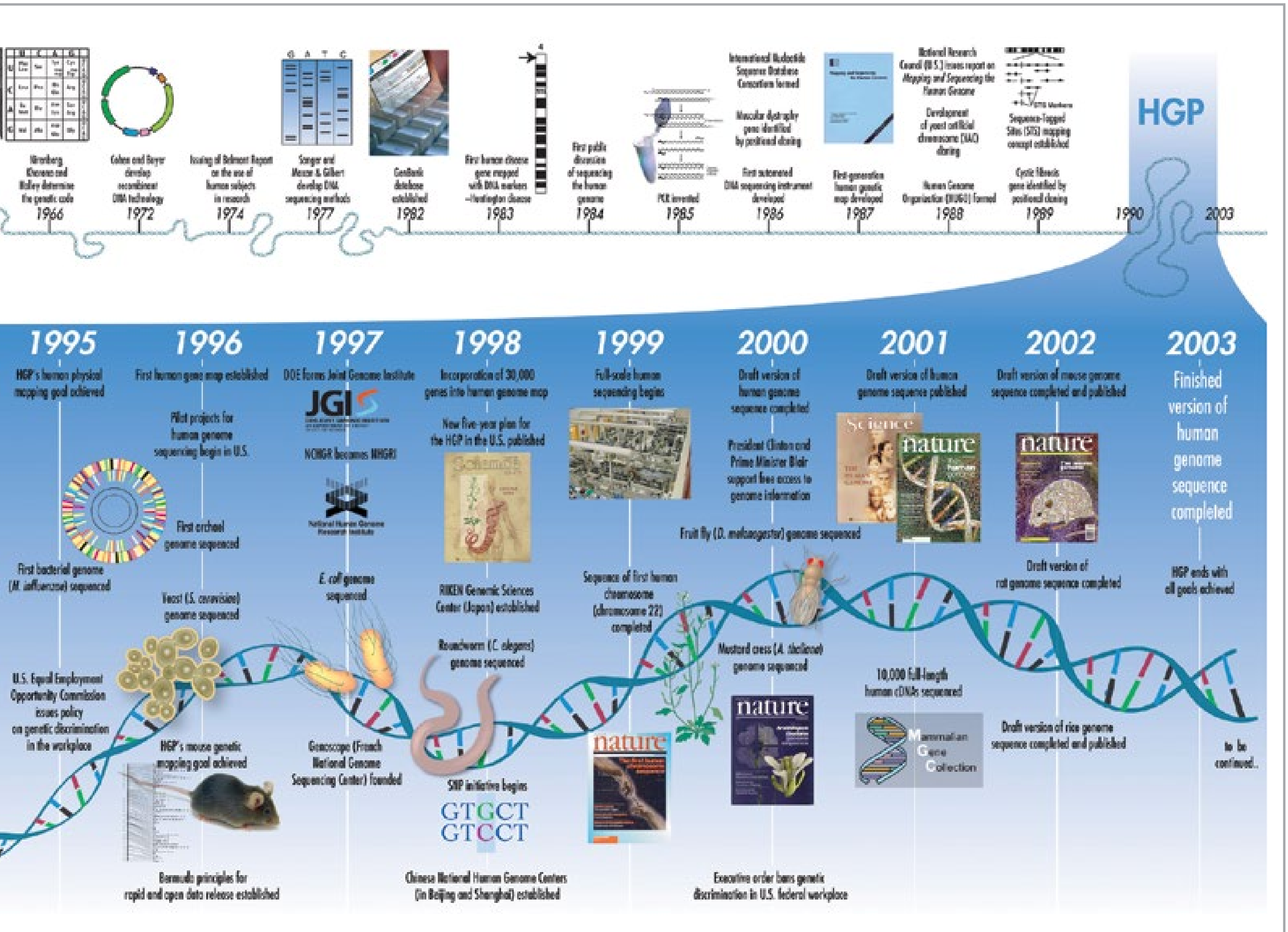
DNA sequencing has improved exponentially in recent years. The Human Genome Project took 13 years and nearly $3 billion USD to sequence the entire human genome, finishing in 2003. And even this was a rough draft and prone to errors. Now there are sequencing techniques that can be completed in real time, where entire genomes are sequenced in minutes or hours and the cost is as low as $1000 USD per genome. Today the market is growing rapidly thanks to the declining cost of sequencing procedures, new government funding, the rise of consumer solutions, and the increasing prevalence of chronic diseases. Between 2020 and 2025, the market is set to double to 50 billion dollars.

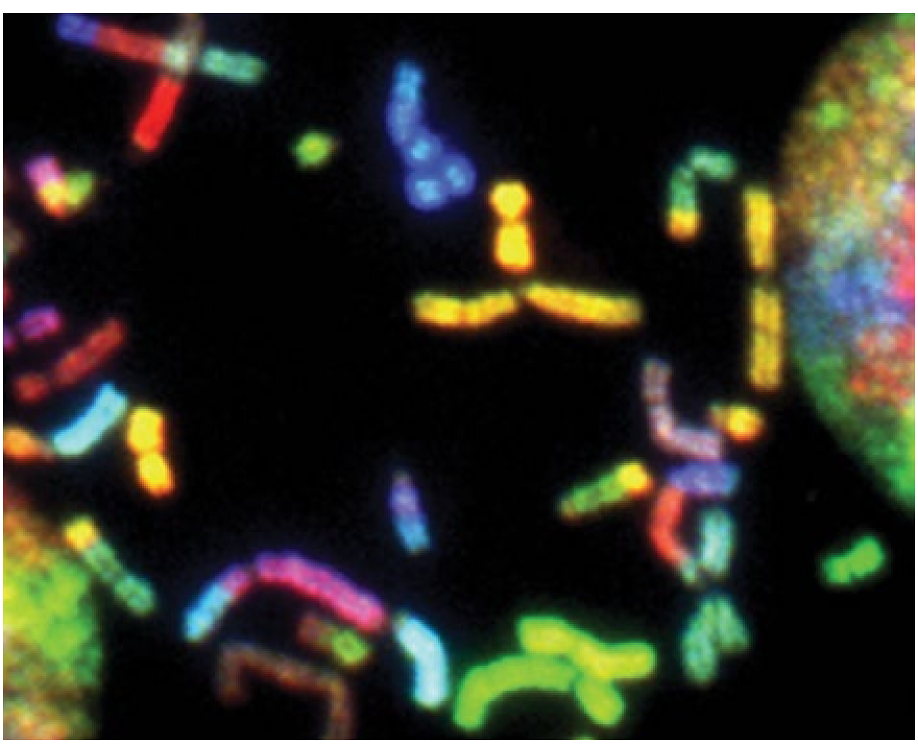
As with all scientific advancements, there are a multitude of drivers behind it. Dramatic changes in image analysis and computational tools have been essential in making these leaps. For example, data storage alone has made a significant contribution. Just 15 years ago a typical USB thumb drive was less than a gigabyte, and cloud storage wasn't widely available. The data from a single genome could take up 200 gigabytes. For a lab that utilizes imaging data, each researcher generates terabytes of images every year, so fast and cheap storage is a must.

EARLY GENOMICS: CREATING A NEW SCIENCE

Compared to modern methods, the original Sanger Sequencing process is arduous and material-heavy. It relies on dideoxynucleoside chain-terminating reactions, where each of the four DNA nucleotide building blocks are labeled with a radioisotope marker. These four reactions are then run on a polyacrylamide gel in four separate lanes, where the various fragment lengths are separated out by the electrical field. X-ray imaging is used to detect the radiolabelled nucleotides, thus identifying the base pairs and their location, which is used to build the sequence.

The Sanger method is a slow and manual process, in it's original form it could take several days to sequence just 50 base pairs [Sanger & Coulson 1975]. In addition to being slow and labor-intensive, the original Sanger method is prone to error, but it does have the advantage of utilizing fairly minimal data storage and basic imaging techniques. Even from these early days it was clear that computer-aided methods would be required to automate the processing of data.
As researchers sequenced more and more genomes and built larger reference libraries, they increasingly needed tools that could compare the new data with existing sequences to find overlap.
It was around this time that the NIH





Above: The Human Genome Project timeline, with major milestones in genomics from 1865 to 2003.
Image via Darryl Leja / Human Genome Project

Left: Chromosomes prepared from a malignant glioblastoma visualized by spectral karyotyping (SKY) reveal an enormous degree of chromosomal instability — a hallmark of cancer.
Image via Thomas Ried / National Cancer Institute.

founded GenBank to store sequence information. GenBank allows researchers to access an annotated collection of publicly-available sequence data for over 300,000 organisms. This incredible, collaborative tool allows labs to easily compare new sequences with previously decoded ones and find overlap, evolutionary conservation, or even pick a target sequence for mutation. GenBank started with 680,000 base pairs and 606 sequences in 1982; by 1992 this increased nearly 200x, and nearly 42,000x by 2002! This exponential growth continues, thanks to faster, more accurate methods coming online.

The initial use of the Sanger method was incredible and exciting, but many labs were creating faster ways to implement it. One such creation was facilitated by the discovery and manipulation of the Green Fluorescent Protein (GFP). Smith & Hood produced fluorescently labeled DNA primers in 1985, which they used in conjunction with Fluorescence Energy Resonance Transfer (FRET) to sequence in a semi-automated fashion. In 1987, Prober *et al.* demonstrated that four different fluorophores tagged to chain terminating dideoxynucleotides could be used to map a sequence using a single vial for sample preparation and a single lane for gel electrophoresis, instead of the four vials and lanes in the original Sanger method.

Directly imaging the gels to determine the fluorophore for each fragment size meant a faster, more precise building of the DNA sequence. However, the gel run still took 6 hours in this new method, with additional time needed to analyze the data produced. This updated method allowed researchers to sequence up to 600 bases an hour, which was a huge advancement over the original Sanger method. But the human genome is roughly 3 billion bp, so at that rate it would have taken over 500 years to sequence it.

In 1986, Applied Biosystems brought the ABI 370A automated sequencer to market, which could process up to 32 samples per run, more than doubling the methods by Prober and team. This system relied on early computer algorithms to correctly identify the base pairs and order, which would become more and more critical for improving output.

When the Human Genome Project was proposed in 1990, they estimated it would take 15 years. This estimate was very optimistic if they were only using the technology available when they started. But rapid improvements were on the horizon.

One area for improvement was imaging, specifically through improvements in fluorescent labels. To understand the critical improvements made by developing better fluorescent tags and dyes, it is important to understand the dominant imaging technique for sequencing, FRET. FRET is what allows all four fluorescent tags to be excited by a single wavelength– but emit different signals that the detector /camera can distinguish. Typically in fluorescence imaging, you will use one fluorophore for a given experiment, then excite that fluorophore (the light from a laser [photon] energizes the electrons of the fluorophore) and you can capture the corresponding emission (the release of a photon from the fluorophore – energy is lost in the transition, so the photon released is lower energy and emits a longer wavelength of light) to create an image. You might even use multiple fluorophores, but each would need to be excited by a different wavelength supplied by a separate laser to be able to distinguish them from one another (e.g. a 488nm laser will excite GFP, a 591nm laser will excite Red Fluorescent Protein, or RFP). FRET allows scientists to image multiple fluorophores, which emit at very different wavelengths (sufficient spectral overlap to allow them to be distinguished from one another) using a single excitation laser. This works by a donor fluorophore absorbing energy in the form of a photon, then transmitting that energy to an acceptor fluorophore (not in the form of a photon), and the acceptor then releasing that energy as a photon.

The same donor fluorophore can be used for all four nucleotides, so one excitation laser can be used – but emission of four different wavelengths based on the base pair can be achieved by using four different acceptor fluorophores. This, combined with computational methods, allows for real-time imaging and base-pair calling, substantially increasing the speed of sequencing, as demonstrated by Applied Biosystems in the late 80s. Further improvements to this technique were made through the advancement of fluorescent labels. New dyes developed specifically for energy transfer were able to improve signal-to-noise ratios by 4-5 fold, making base calling more accurate.

In addition to improving fluorophores and image analysis, researchers were also focused on creating longer sequence read lengths. The Sanger method created read lengths of ~800bp, but the full sequence for even simple organisms are thousands to millions of base pairs, and the human genome registers in at billions of base pairs. So, researchers needed a way to sequence longer segments. They began using “shotgun” sequencing, where they fragment the DNA, clone it to high copy numbers using the newly invented Polymerase Chain Reaction (PCR), and then sequence the fragments. Computational models are used to align the fragments into a contiguous sequence based on overlapping sequences. This allowed for faster assembly of longer sequence segments. This technique combined with capillary electrophoresis, which provided faster run times and better separation of the fragments, and in line FRET imaging is what is known as semi-automated Sanger Sequencing. Nearly 1000bp read lengths at 99.999% accuracy were achieved this way.

Applied Biosystems remained the market leader throughout the ’90s, improving and released new technology each year including machines that used capillary electrophoresis and fluorescence imaging to create massively parallel experiments. By 1998, 1000 bp could be sequenced in less than an hour – but there were new techniques and technologies still on their way.

NEXT GENERATION/SECOND GENERATION SEQUENCING – BETTER ACCURACY AND SPEED

The early 2000s were marked by a significant shift in the market as many new players entered. Next Generation Sequencing (NGS) technology was a key new method, which used many cycles of amplification to create huge amounts of DNA for sequencing. The combination of much larger amounts of DNA and the miniaturization of the sequencing process using microfluidic devices means that hundreds of millions of sequences can be produced in parallel. This produced much faster, more accurate sequencing results – though often with significantly shorter read lengths (35-500 bp, vs the 800 bp by Sanger sequencing). Computational tools were developed to overcome the short read lengths and sequencing costs plummeted. 454, Solexa, Illumina, Ion Torrent and others joined Applied Biosystems in the development of NGS technology. In particular, the high throughput technique for pyrosequencing was introduced, which utilized the light generated through pyrophosphate synthesis instead of fluorophores. This technology was commercialized by 454 Life Sciences in 2003 with the GS20. This machine could sequence up to 25 million base pairs in a single 4-hour run, enabled by CCD sensors beneath nearly 1 million micro-wells where the sequencing reactions took place. This was a disruptive technology, using an entirely different method, and could sequence DNA lengths of ~500 bp with 99% accuracy.

Soon after, Solexa was founded, using sequencing by synthesis techniques that relied on fluorescent labels; essentially the Sanger method but at a much larger scale. This change in scale was facilitated by miniaturization, the use of microfluidics and improvements in process automation. Acquisition of colony sequencing (bridge amplification) technology from Manteia allowed for stronger fluorescent signals, and therefore improved base calling. They also developed an engineered DNA polymerase and reversible terminators – which led to a platform that could read individual base pairs as they were added to the sequence. This platform produced up to 1M bp per run, but sequence lengths were relatively short, at only ~35bp. In 2007 Illumina acquired Solexa and set out to become a market leader in NGS.

Technician prepares for a viral whole-genome sequencing experiment at the Cancer Genomics Research Laboratory, part of the National Cancer Institute’s Division of Cancer Epidemiology and Genetics (DCEG).

In part two, we will explore the current state of image-based genomic sequencing and what we can expect in the future.

SCAN FOR MORE INFORMATION

Imaging-Based DNA Sequencing:
Past, Present & Future [Part Two]

HOW IMAGE ANALYSIS AND COMPUTATIONAL TOOLS HAVE TAKEN GENOME SEQUENCING FROM YEARS TO MINUTES; FROM POPULATION TO PERSONAL.

BY Possibility Editorial

This is Part Two of Imaging-Based DNA Sequencing: Past, Present & Future. If you haven't read it, *see page 16.*

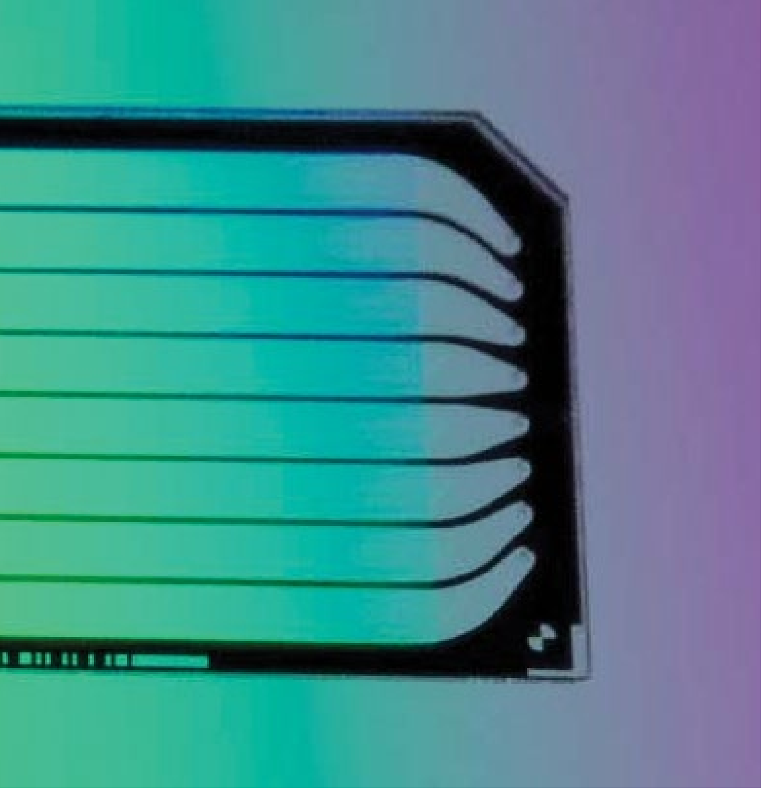
THIRD-GENERATION SEQUENCING: METHODS PROLIFERATE

Today, Illumina is the clear market leader of NGS, and as Third-Generation Sequencing (TGS) arrive, there is another wave of new technologies on their way with hopes to improve on the short read lengths of Second Generation technologies. NGS technologies all require large genome DNA to be fragmented and amplified due to the limitations in read lengths. This fragmentation and amplification has significant consequences, including amplification bias of repetitive DNA units by PCR and the need for computational models to align the DNA fragments. There is not always sufficient fragment overlap to accurately align segments of DNA, which makes *de novo*, or discovery sequencing, challenging with NGS techniques. TGS is most easily defined as sequencing without amplification, and typically is characterized by much longer read-lengths than for NGS. There have been several approaches to accomplishing long read lengths in sequencing.

PacBio led the charge with their zero-mode waveguide technology. The technology used nano holes to tether a single DNA polymerase, which allowed real-time observation of each addition of a fluorescently labelled nucleotide to the chain. This process was named Single Molecule Real Time (SMRT) sequencing. And additional companies came on board with PacBio, including the Oxford Nanopore device, which doesn't use image analysis at all but rather monitors electrical activity.

SMRT sequencing can produce read lengths of 10-20 thousand base pairs. Although the error rate was higher than Illumina's machines, there was reduced sequencing bias, and the sequencing data was high quality, despite the limitations. Updates to this methodology led PacBio to release a High Fidelity (HiFi) machine in 2019 with long reads at the same accuracy of the short reads produced by Illumina. That same year, PacBio released a new machine Sequel II with new chemicals and a novel ZMW nanowell smartcell that can produce up to 4M HiFi reads with 99.999% accuracy, and dramatically reduces the sequencing cost.

TGS platforms produce relatively noisy data which has led to significant reliance on computational tools to get reliable results. PacBio's FALCON uses Hierarchical Genome Assembly Process (HGAP) technology. This software takes the longest read produced and uses it to align shorter reads; a consensus read is created from all of the reads based on computational algorithms developed in the mid-nineties (de Bruijn Graphs). Canu is another alternative software developed for this purpose; it creates sequences through the overlap layout-consensus of long reads. One challenge for TGS is that the time for assembly based on computational methods is becoming longer than the time for sequencing and the same can be said about the computational costs.



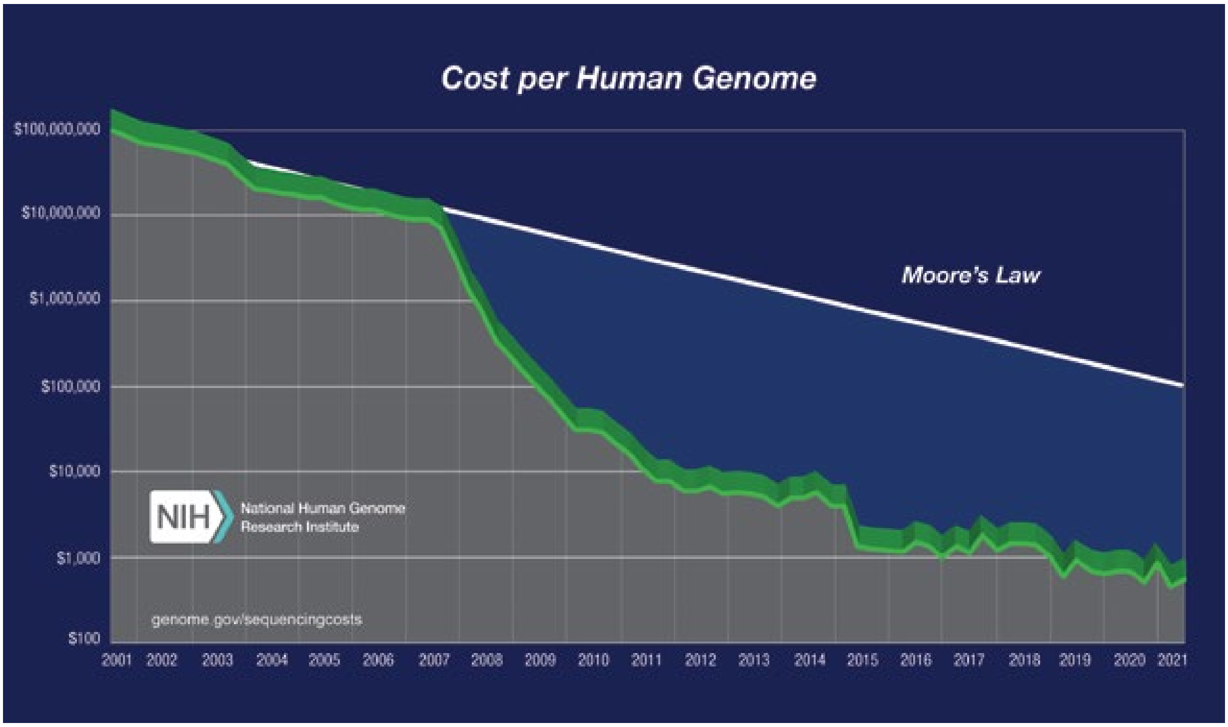
Left: A technician holds a DNA sequencing flow cell at the Cancer Genomics Research Laboratory, part of the National Cancer Institute's Division of Cancer Epidemiology and Genetics.

In the Third-Generation landscape, Illumina continues to fight for market shares with its NovaSeq platform that can generate up to 20B bp per run. However, this platform is limited to short reads less than 250bp and requires use of a suite of computational tools for sequence alignment. Illumina itself has its own suite of software tools for use with their sequencers. Everything from lab automation tools to AI-based analytical tools and a platform called DRAGEN that claims to process the entire human genome in 25 minutes! That's certainly dramatically faster than 13 years. The future of sequencing is likely a combination of NGS and TGS techniques, taking advantage of the strengths of each system to create complete, accurate genome sequences – at the individual level.

LOOKING FORWARD: MORE DATA, MORE IMAGING, MORE PERSONAL

The era of personalized medicine is here and is expected to become more accessible to the individual. However, with that access a familiar challenge arises, how do we save all of this data in a retrievable and safe way? This is such a challenge for researchers that tools have been developed to help labs estimate how much storage they need and what types of storage (e.g. cloud, server) and the associated costs. Raw imaging data can occupy a huge amount of storage space, which can be expensive to manage. In response, many technologies are no longer storing the raw image files acquired during sequencing, and instead compress a whole genome data into a relatively more manageable 100GB. That's still a lot of data, but it also seems remarkably small to describe the recipe for an entire human being.

The arrival of personalized medicine is powerful, it allows early cancer detection, genetic screening, improved diagnostics and personalized therapeutics. While this level of personalization has the potential to lead to better medical outcomes, it comes with a host of challenges. 100GB for a genome seems rather reasonable, until you imagine millions of individuals mapping their genes, the storage requirements start to become staggeringly large. In addition, data protection should be on everyone's mind as we begin generating individual sequencing. The advent of genealogy companies like 23andme have highlighted an interesting question of what ownership we have of our heredity and what resources we have to protect our genetic data.



Cost per Human Genome Sequenced: note: the logarithmic scale on the Y axis; and the sudden and profound out-pacing of Moore's Law beginning in January 2008. The latter represents the time when the sequencing centers transitioned from Sanger-based sequencing to next-generation DNA sequencing technologies. Image via Human Genome Project

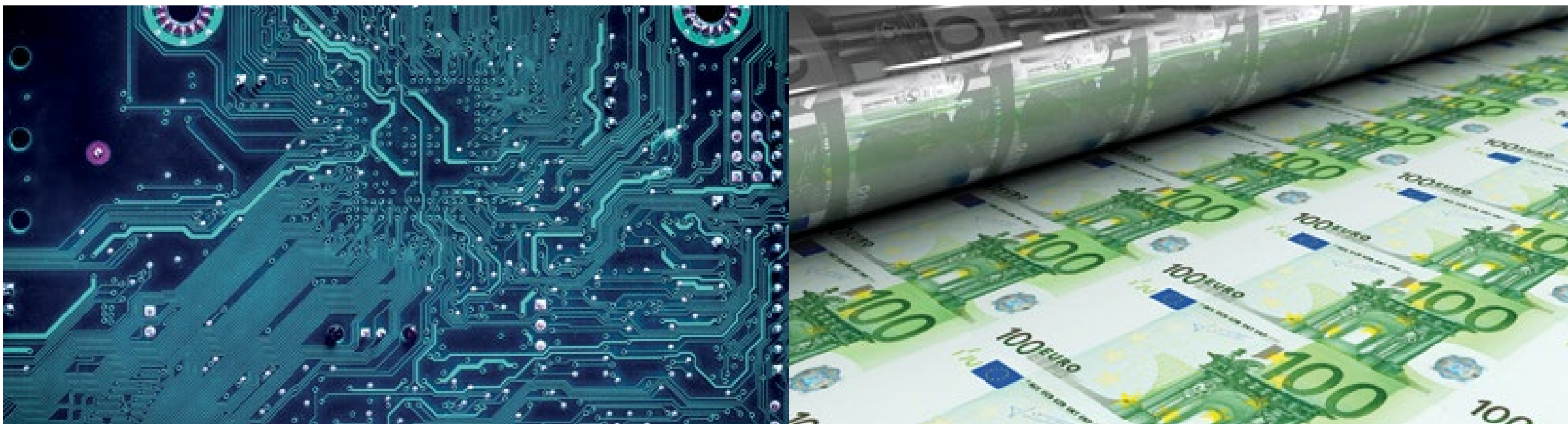
Some scientists predict that moving from population-based genomics to single-cell genomics will be a critical step in the precision medicine journey. Single-cell genomics can allow three-dimensional imaging of a cell, aided by super-resolution microscopy – to visualize cell fate in living tissue. This, combined with the ability to manipulate the genome using CRISPR can lead to discovery of gene mutation pathways and prediction of cell behavior, which in turn could lead to more targeted therapies and cures. The 2030 Bold Predictions for human genomics put forth by the National Human Genome Research Institute (NHGRI) predicts that genome sequencing will become a routine part of medicine, like getting blood drawn. Imaging and image analysis tools will continue to be critical in the development of personalized medicine. The current approach to genome sequencing deals with the genome in a static state – but an individual genome is not static, our bodies are full of dividing cells and mutations occur over time. To this end, a multitude of techniques are being developed to study genome dynamics in real time. Use of rapidly evolving light sheet microscopy, and other super-resolution techniques like stochastic optical reconstruction microscopy (STORM), photo-activated localized microscopy (PALM) and stimulation emission depletion (STED) microcopy will allow better understanding of the relationship between structure and function at the cellular level.

NGS, TGS, novel imaging techniques, and advancements in data analysis tools will be combined to create genomic information at our fingertips, or as the NHGRI 2030 predictions state, our personal genome will be "available on our smart phones in a user-friendly form."

SCAN FOR MORE INFORMATION

Teledyne DALSA
Industrial Vision Solutions

IMPROVE DEFECT DETECTABILITY WITH A SINGLE SCAN



NEW LINEA ML 8k MULTISPECTRAL CLHS CAMERA

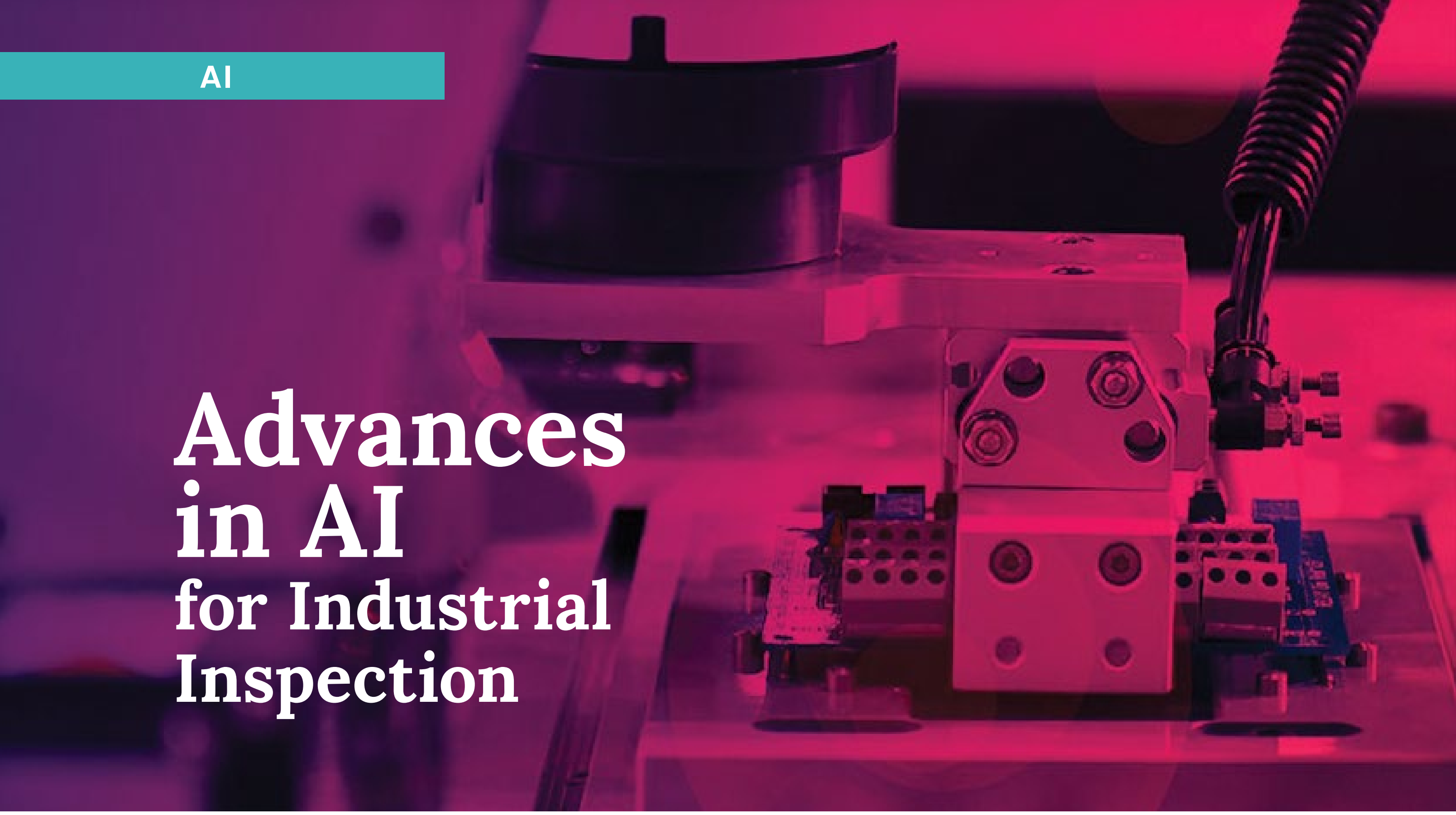
Teledyne's Linea™ ML 8K multispectral camera provides spectrally independent RGB and NIR outputs making it uniquely capable of detecting defects both on and under the surface of a wide variety of materials, components, and products.

Combined with the Teledyne DALSA Xtium™2 CLHS series of high-performance frame grabbers, the Linea ML 8k multispectral camera represents a breakthrough in data throughput in the industry.

GET MORE INFORMATION:
www.teledynedalsa.com/linea-ml

TELEDYNE

SCAN FOR DETAILS



Advances in AI for Industrial Inspection

THE MANUFACTURING INDUSTRY IS BEING TURNED ON ITS HEAD AS AI AND DEEP LEARNING TURN QUALITY INSPECTION INSIDE-OUT.

BY Bruno Ménard, Smart Products Division at Teledyne DALSA

The manufacturing industry is being turned on its head as AI, and deep learning transforms the way we create goods and how quality inspection is employed. The combination of software, new deep learning techniques, power of parallel processing, and ease-of-use tools is at the core of this transformation.

While traditional image-processing software relies on task-specific algorithms, deep learning software uses a multilayer network implementing pre-trained or user-trained algorithms to recognize good and bad images or regions. Traditionally, hundreds, or even thousands, of high-quality, manually classified images were required to train the system and create a model that classifies objects with a high degree of predictability. Just gathering this type of dataset has proven to be an obstacle, hindering deep learning adoption into mainstream manufacturing environments.

New technology advancements are making it easier for manufacturers to embrace deep learning as part of the inspection process. Today, we train deep learning systems with fewer bad images or even none. While deep learning software for machine vision has been around for more than a decade, it is now becoming more user-friendly and practical. As a result, manufacturers are moving from experimenting with deep learning software to implementing it.

DEEP LEARNING VS. TRADITIONAL METHODS

Deep learning is ideal for tasks that are difficult to achieve with traditional image processing methods. Typical environments that are suitable for deep learning are those where there is a lot of variables, such as lighting, noise, shape, color, and texture. For example, in food inspection, no two loaves of bread are exactly alike. Each loaf has the same ingredients, and each weighs the same amount, but the shape, color, and texture may be slightly different but still within the range of normality.

Another example may be the ripeness of an apple. Ripeness could mean color, softness, or texture; however, there is a range of possibilities where an apple is considered ripe. It is in these types of environments where deep learning shines. Other examples are inspecting the surface finish quality, confirming the presence of multiple items in a kit, detecting foreign objects, and more, to ensure quality throughout the assembly process.

A practical example showing the strength of deep learning is scratch inspection on textured surfaces like metal. Some of those scratches are less bright, and their contrast is in the same order of magnitude than that of the textured background itself.

Traditional techniques usually fail to locate these types of defects reliably, especially when the shape, brightness, and contrast vary from sample to sample. Figure 1 illustrate scratches inspection on metal sheets. Defects are clearly shown via a heatmap which is a pseudo-color image highlighting the pixels at the location of the defect. Another example of defect inspection is the ability to classify a complex part as being good or bad as. For instance metal screws are objects presenting a high degree of variation on their surface make it extremely difficult for traditional algorithms to isolate defects. Deep learning algorithms are very good at inspecting those type of objects are shown in Figure 2.

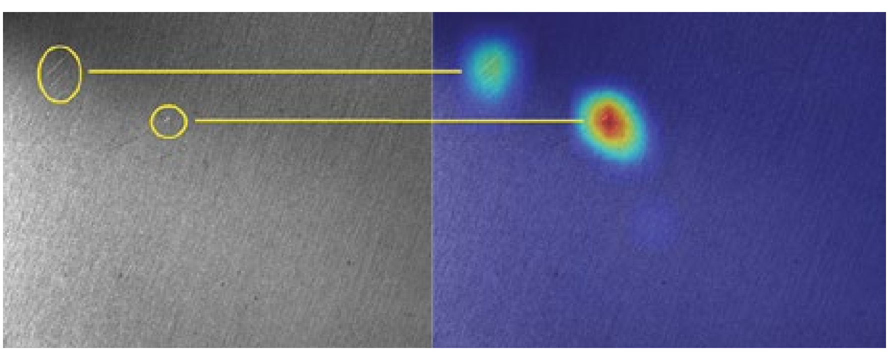
Defect Detection Using Simple Classification

Despite the advantage of deep learning over traditional image processing techniques, challenges do exist. First, many users lack the understanding of what is required to achieve success with deep learning. Second, until recently, deep learning required a huge data set to train a system. Many applications have not been able to take advantage of deep learning due to the lack of high quality, manually classified images. In the case where a large data set is available, the next challenge is to label each image. This labeling can be a daunting task because it has to be done by an expert and needs to be error-free. The cases where there is a large number of classes (different groups with a unique label for each) become prone to errors.

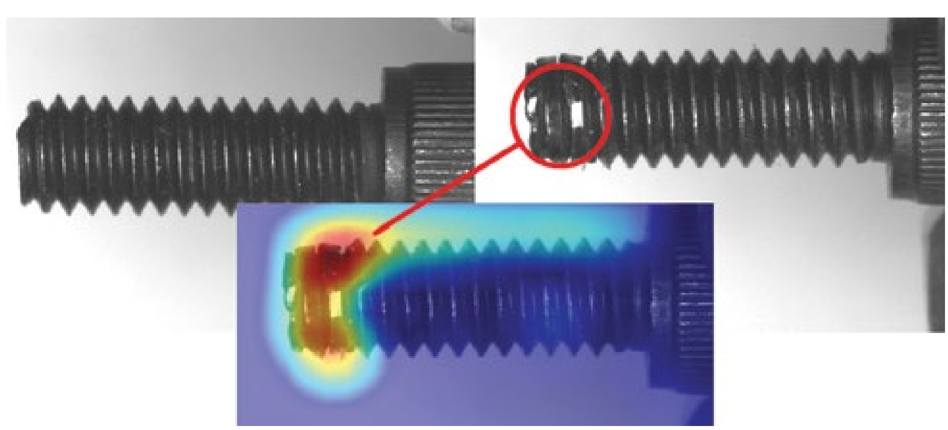
Subtle labeling errors are one reason for failure to reach satisfactory performance from AI tools. It is painful to realize the amount of wasted time involved before realizing that the failure is due to bad labeling in the original data set. The fact is that a proper data set is the most important item in a particular system and is usually treated as proprietary IP by the user.

Typical deep learning applications require hundreds or even thousands of image samples. In more challenging or custom applications, the training model may require up to a million or more image samples. Even if you can get enough images, you have to ensure you have the right mix of "good" and "bad" images to meet the parameters of the training model. To achieve the expected results from the training model, you need a balanced data set. This type of training that uses both good and bad examples is called defect detection and is considered a simple classifier.

To verify if the training model is accurate, you need to test the model with a new set of images. If the model achieves close to the training set model, it is said that the model generalized well. In the case where the model does poorly on the test set, this tends to reflect that the model remembers all training cases and has not learned what makes an image good or bad and is known as overtraining or overfitting. If the test set does better, then the



Surface Inspection on Brushed Metal
Left: a plate of brushed metal with scratches
Right: the heatmap output of a classification algorithm showing the defects



Inspection of Damaged Screws
Top left: a perfect screw
Top right: a bad screw with damaged section encircled.
Bottom middle: the heatmap output of a classification algorithm showing the defect

training set is suspicious (perhaps due to a poor distribution), or the test set is too small. This method is called supervised learning.

A NEW DEEP LEARNING TECHNIQUE: ANOMALY DETECTION

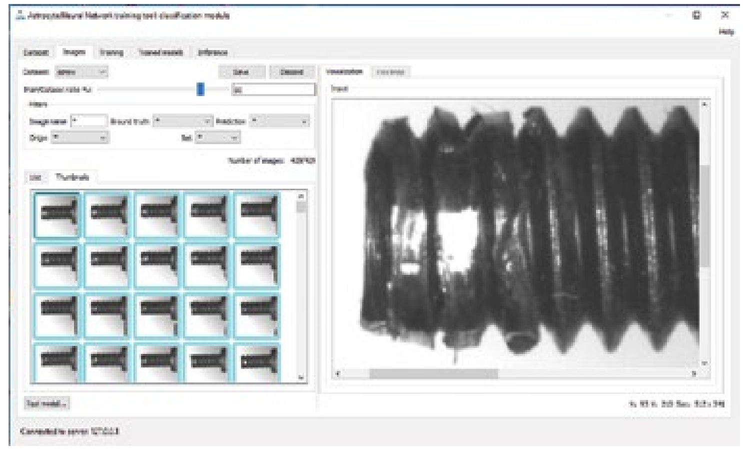
Some applications may only have good examples. In many production environments, we see what is acceptable but can never be sure of all possible cases which could cause rejects. There are cases where there is a continuous event of unique new rejects that can occur at very low rates but are still not acceptable. These types of applications could not deploy deep learning effectively due to the lack of bad examples. That is no longer true. New tools have enabled manufacturers to expand the applications that benefit from deep learning.

There is a new technique for classification called anomaly detection, where only good examples train a network. In this case, the network recognizes what is considered normal and identifies anything outside that data set as abnormal. If you were to put the "good example" data set on a graph, it would look like a blob. Anything that falls within the blob classifies as normal, and anything that falls outside the blob classifies as abnormal – an anomaly. The previous examples shown in Figure 1 and Figure 2 are both solvable with anomaly detection in situations where just a few or even no bad samples are available for training.

Available today, anomaly detection tools enable the expansion of deep learning into new applications that could not take advantage of its benefits previously. The inclusion of anomaly detection helps to reduce engineering efforts needed to train a system. If they have the data, non-experts in image processing can train systems while reducing costs significantly. Teledyne DALSA's Astrocyte software is a training tool based on Deep Learning algorithms that includes classification, anomaly detection, object detection, segmentation and noise reduction.

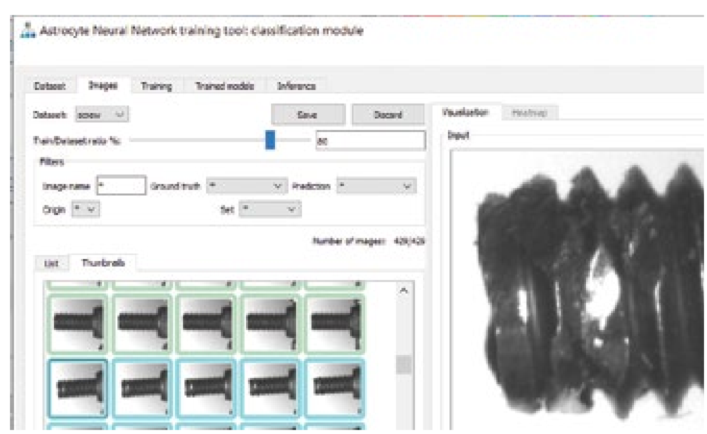
Implementing Deep Learning for Defect Detection

Whether using a simple classifier or anomaly detection algorithm for implementing detect detection in manufacturing environments, one must train the neural network with a minimal set of samples. As mentioned previously, anomaly detection allows an unbalanced dataset, typically including many more good samples than bad samples. But regardless of how balanced, these samples need to be labeled as good or bad and fed into the neural network trainer. GUI-based training tools such as Astrocyte are an easy way to feed your dataset to the neural network while allowing you to label your images graphically.



Astrocyte Software from Teledyne DALSA

Figure 4 below illustrates classification training in Astrocyte where all samples are listed as thumbnails. For each sample, the rectangle around the thumbnail specifies the label (i.e., good or bad) and this information is editor by the user at training time. One easy way to automate this process is to put the samples in two different folders (good and bad) and use the folder names as labels. Another important aspect to consider when training a dataset is to reserve a portion of these samples for testing. One good rule in practice is to allocate 80% of the dataset for training while leaving the remaining 20% for testing, as seen in Figure 4 as the Train/Dataset Ratio %. When the training samples pass through the neural network, the weights of the neural network adjust for a certain number of iterations called epochs. Unlike training samples, testing samples are passed through the neural network for testing purposes without affecting the weights of the network. Training and testing groups of samples are important to develop a proper training model that will perform well in production.



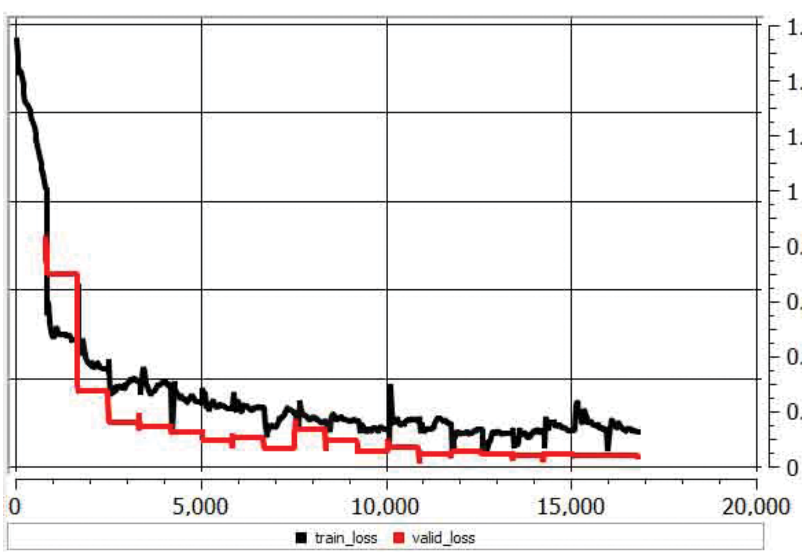
Training and Labeling

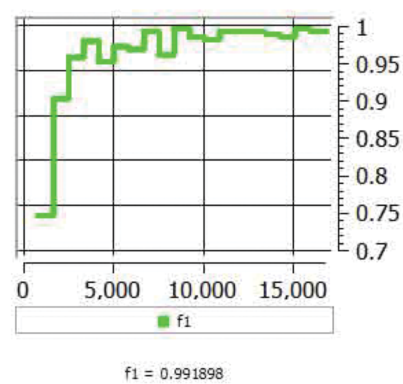
Once the training set is created and labeled, the training process can begin. Training parameters are called *Hyperparameters* (as opposed to "parameters," which are the actual weights of the neural network). Most common hyperparameters include the ***learning rate*** which tells the algorithm how fast to converge to a solution, the ***number of epochs*** which determines the number of iterations during the training process, the ***batch size*** which selects how many samples are processed at a time, and the model architecture that is selected to solve the problem. A common example of model architecture for a simple classification is ResNet, which is a Convolutional Neural Network, a frequently used model architecture in classification problems such as defect detection.

Once hyperparameters are configured (good training tools provide default values which work well in practice), the training process is ready to be launched. Training time ranges from a few minutes to a few hours and is dependent on the number of samples in your dataset, the hyperparameters, and the power/memory of your GPU card. During training, you can monitor two basic metrics: *loss functions and accuracy*. The loss functions show the difference between current model prediction (output of neural network) and expectation (the ground truth). These loss functions should go toward 0 while training. If they diverge, you may have to cancel the training session and restart it with different hyperparameters. The accuracy tells you how good your model is to properly classify samples. This metric should go toward 100% during training. In practice, you will rarely achieve 100% but often between 95% and 99%. Figure 5 depicts a graph of loss functions and accuracy while training in Astrocyte.

After training is complete with acceptable accuracy, your model is ready to use in production. Applying a model to real samples is called *inference*. Inference can be implemented on the PC using GPU cards or on an embedded device using a parallel processing engine. Depending on the size, weight, and power (SWAP) required by your application, various technologies are available for implementing deep learning on embedded devices such as GPUs, FPGAs and specialized neural processors.

Deep learning is more user-friendly and practical than ever before, enabling more applications to derive the benefits. Deep learning software has improved to the point that it can classify images better than any traditional algorithm—and may soon be able to outperform human inspectors.





Loss Functions and Accuracy
Above Left: loss functions (train and validation)
Above Right: accuracy measure (called f1)

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A Better Vision
for Transformational Transportation

IMAGING-POWERED INTELLIGENT TRAFFIC SYSTEMS ARE MAKING THE LIFEBLOOD OF OUR ECONOMY CLEANER AND MORE EFFICIENT.

BY Possibility Editorial

You're stuck in your car, with traffic at a standstill. And you're not the only one. Hundreds of other frustrated commuters are packed onto the same highway, their cars idling, emitting high levels of the greenhouse gases that contribute to global warming.

In the U.S. alone, personal vehicle idling wastes about three billion gallons of fuel every year, contributing a jaw-dropping 30 million tons of CO_2 annually to the atmosphere. While the choices we make can have an impact—Natural Resources Canada estimates that if Canadian motorists spent three minutes less idling every day of the year, they could reduce CO_2 emissions by 1.4 tons annually—we can't solve this problem through behavior modification alone. If we're serious about reducing greenhouse gas emissions from motor vehicles, we need to make changes to infrastructure.

Offering a new systems-level approach to traffic-flow management, Intelligent Transportation Systems (ITS) is implemented at the smart-city level. Leveraging existing technologies, such as high-performance cameras, Gigabit Ethernet, and artificial intelligence (AI) software, ITS can help reduce traffic congestion by keeping motorists informed in near real-time of what's ahead, far more efficiently than crowdsourcing applications such as Waze or Google Maps, which gather data from smartphone users.

ITS, in contrast, integrates compact, ruggedized and lightweight high-resolution, high-speed cameras that support wide dynamic range, image compression and easy networking over long distances. As with most embedded-systems innovations, ITS also features trainable AI software that enables "continuous learning," where systems already in the field learn automatically at runtime. A traffic-surveillance drone, for example, must fly at multiple altitudes. An engineer working in the home office can train the initial AI model with images collected at one altitude, e.g., 10m. Once deployed in a real-world environment, the continuous-learning algorithm activates, adapting the model when the drone is flying at other altitudes. This AI model, which also responds to variations in size and can adjust the viewing angle of image capture, frees the development team from performing a mandatory full model re-training in the lab, saving countless human hours.

With high speed, high resolution, and the ability to multi-cast its data to multiple PCs for simultaneous data analysis, a next-generation camera like the Genie can serve traffic flow control and license plate recognition simultaneously.

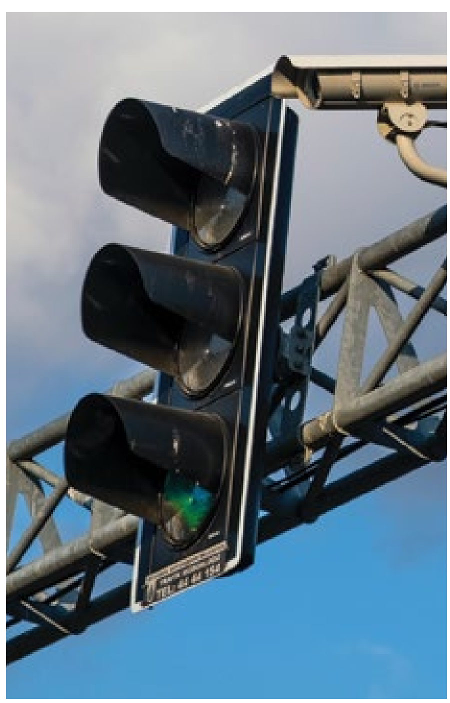
There's much more to ITS than keeping us informed of congestion due to traffic accidents or a heavy rush-hour. Because systems in the field are always on and always connected, they're automating toll management to keep traffic flowing smoothly. Miles-long backups before toll plazas—which frustrate motorists and contribute to air pollution—are becoming an inconvenience of the past.

"A new generation of AI-enabled high-resolution, high-speed networked cameras that capture images accurately in all lighting and weather conditions make open-road tolling systems both viable and practical from a technology standpoint," says Doug Sanderson, Vice President of Engineering, at Teledyne Lumenera. "Whether installed on roadside poles or secured to the gantry above the road, these ITS platforms trigger an enhanced image capture that sends information on a vehicle's license plate to a central office to ensure correct billing."

"Such systems are attractive to smart city planners, who appreciate their greater efficiency and affordability, especially when compared to building and maintaining old-fashioned toll booths and covering the salaries of the personnel who staff them."

SMARTER AND SAFER

The intelligence in ITS platforms can help keep us safer in other ways as well. Smart cities are deploying ITS for speed- and red-light enforcement. Most municipalities can't allocate enough police offers for traffic enforcement. For someone who regularly travels five or ten miles per hour over the speed limit, perhaps that sounds like good news. But when the safety of drivers, passengers and pedestrians is a concern, it could be a very serious issue.



According to the National Highway Traffic Safety Administration (NHTSA) of the US Department of Transportation's most recent data, speeding was a factor in more than 25% of all traffic fatalities in 2018. And a 2019 American Automobile Association (AAA) report found that more than 28% of crash deaths at traffic lights resulted from a driver running a red light.

"Unlike human traffic-enforcement officers, AI-based ITS can be deployed throughout a smart city at relatively low cost," says Sanderson. "ITS also has the benefit of hindsight. A camera-based system with a loop buffer can see 'back in time,' rolling back 20-30 seconds. That kind of system can help provide evidence to aid investigators in determining the cause of a traffic collision. Did someone run a red light, was someone distracted or intoxicated, or is there be another reason? Today's advanced ITS can process this data at the edge of the network, with a person in a central office analyzing the information."

Fleet management

ITS is becoming increasingly important for fleet management. Support for cargo surveillance, for example, helps to ensure asset protection. An embedded vision system with AI capabilities could alert the fleet manager that there's excessive movement in a row of new cars in transport by truck from Alabama to New York. The fleet manager could inform the driver of the problem, preserving the integrity of the cargo—and offsetting a potentially dangerous situation for the truck driver and other vehicles on the road.

IMPROVING MASS TRANSIT

From the first steam-powered cable car (San Francisco, 1873) and the first subway system in the United States (Boston, 1897) to the zero-emissions electric bus fleets of today, we've made leaps in innovation in mass transportation. As a result, hundreds of millions of people, a share of whom don't own cars, can afford to travel between work, school and home.

There's an environmental benefit beyond the economic one because mass transit is typically much more fuel-efficient than traveling by car.

While not every American with access to mass transit takes it regularly, in 2019 alone, the 55% of Americans who have access to mass transit took 9.9 billion trips. While the pandemic shifted many Americans away from public transit, at least some percentage of us will return to mass transit when we feel comfortable doing so.

We're at a crossroads of opportunity in improving public transportation, and not just through safeguards such as mask-wearing. We can employ ITS to monitor the progress of subways, trolleys and light rail systems—keeping travelers informed of when the next train, bus or trolley will arrive. Removing the guesswork that most of us find frustrating with public transit is important. Enhancing its safe operations is another.

Intelligent inspection

From roads and bridges to tunnels and railways, key segments of our public transportation infrastructure are at risk throughout many parts of the world. Sending out crews for in-person inspection is extremely costly and time-consuming, making it impractical at the scale required to ensure our safety.

ITS, on the other hand, is ideally suited to the task of surface inspection. While machine inspection is fairly easy to accomplish with uniform surfaces, if you're inspecting textured materials, such as brushed metal or wood, irregularities in the material might look the same as the image itself.

"That's why you need AI in an ITS to train on many samples before you deploy in the field," says Bruno Ménard, Software Director, Teledyne DALSA "Knowing the difference between a defect and the typical structural information of the material is critical to accuracy."

Installing ITS platforms across thousands of miles of high-speed railways could allow public and private owners to monitor the condition of their tracks on an ongoing basis. Keeping tracks in good condition would keep the lines fully operational, satisfying travelers and benefiting owners financially. It could also reduce the chance of a train derailing because of damaged tracks, a potentially catastrophic event.

While we are still in the early days of rolling out ITS around the world, we're seeing interest from very large cities, many of which are plagued by traffic congestion and crumbling infrastructure. Which makes sense because the benefits of ITS are many. More efficient traffic-surveillance and toll platforms for cleaner air. Less time in traffic for improved quality of life. More efficient traffic-rules enforcement to keep people safer. Ongoing surface inspection of our roads, bridges, tunnels and railways to keep transit fully operational.

We're at the beginning of what we can achieve through ITS—and the road ahead is full of promise.

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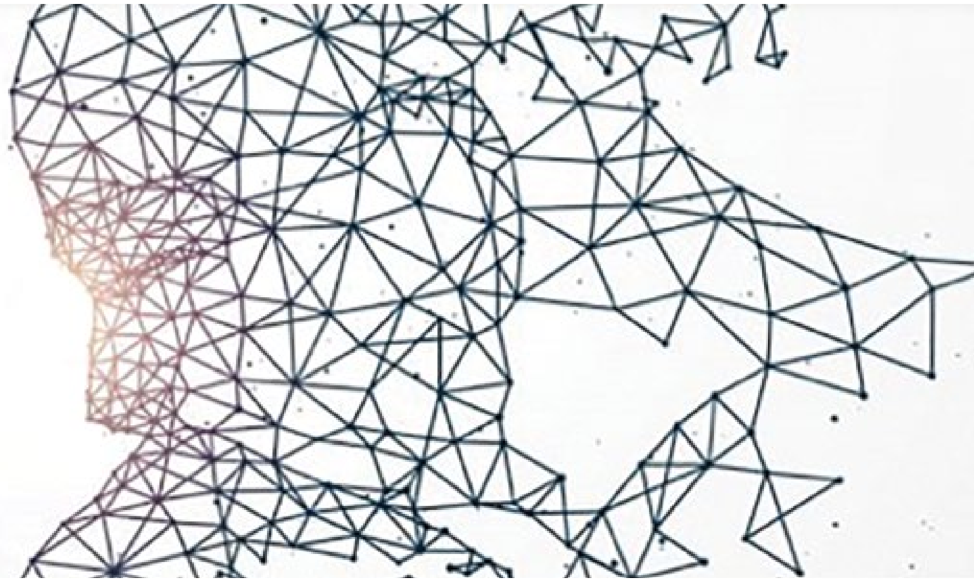
How Artificial Intelligence Keeps Getting Smarter



GIANT DATA SETS AND MULTI-TASKING ALGORITHMS. WILL WE EVER SEE A CONSCIOUS COMPUTER?

BY Dany Longval

Over the last few years, many of the improvements in digital imaging have been in processing. Cameras are getting smarter and doing more on their own. Embedded vision system are using smarter machine learning algorithms. Artificial intelligence is being used to diagnose and track COVID-19.

But how smart can computers get? How independent can they be? Artificial General Intelligence (AGI) is the hypothetical ability that, one day, a computer will be able to perform any task as well, or better, than a human. It's either the epitome of hope for computer evolution, or the beginning of the end of the human race, depending on whom you ask.

What most people can agree on is that AGI is not going to happen any time soon.

Robots are the quintessential combination of artificial systems and mechanistic structures. The ultimate derivative of AGI would likely be a robot that can outperform a human at any task while conversing fluently and contextually in a dozen languages. But, as yet, robots are objectively dumb machines, at least when compared to a human. Robots can often perform one task extremely well, but fail when asked to do a different, unrelated task.

For instance, robots have a really hard time folding clothes. Walking up stairs. Turning doorknobs. Moving across a crowded room without bumping into everything. If you understand the state of modern robotics, you are likely very confident that an AGI in not in our immediate, or even medium-term, future.

In this edition of Future Tech Review, we'll look at some of latest developments in how artificial intelligence models are learning and discuss the possibilities of how we might someday create a sentient computer.

GPT-3 AND THE BLESSINGS OF SCALE

GPT-3 is the largest machine learning model in the world. Developed by AI researchers at OpenAI in San Francisco, GPT-3 is a natural language model that uses deep learning to produce human-like text. GPT-3 is massive, on the order of 175 billion machine learning parameters (the previous largest model when GPT-3 was released was Microsoft's Turing NLG at 17 billion parameters).

GPT-3 produces human-like speech to an uncanny degree. In March 2021, OpenAI reported that 300 different applications are using GPT-3 to perform various duties to recognize and produce speech.

AI can power a new genre of interactive stories and using GPT-3 to help power their story-driven "Virtual Beings." Lucy, the hero of Neil Gaiman and Dave McKean's Wolves in the Walls, which was adapted by Fable into the Emmy Award-winning VR experience, can have natural conversations with people thanks to dialogue generated by GPT-3.

For instance, a company called Viable is using GPT-3 for sentiment analysis by pulling information from live chat logs, user reviews, surveys and help desk tickets. Fable Studio uses GPT-3 to power the speech of its "Virtual Beings," virtual reality characters that people can interact with.

The thing with GPT-3 is that its method is not particularly new nor sophisticated (as far as cutting-edge AI research goes). It is based on a natural language processing (NLP) architecture known as the Transformer and consists of a generative model that pre-trains unstructured data (GPT stands for generative pre-training). Many AI researchers figured that a model the size of GPT-3 would hit a point of diminishing returns, meaning that, at some point, the size of the model does nothing to improve its performance. And yet, to the surprise of many, GPT-3 performs precisely because of its scale. It has shown the capability for meta-learning (learning to learn) to a degree unseen by other machine learning models. The fact that GPT-3 can improve its performance and perform sophisticated meta-learning has led researchers to drudge up old theories about the potential for AGI.

American writer and researcher Gwern Branwen explains:

The blessings of scale in turn support a radical theory: an old AI paradigm held by a few pioneers in connectionism (early artificial neural network research) and by more recent deep learning researchers, the scaling hypothesis. The scaling hypothesis regards the blessings of scale as the secret of AGI: intelligence is 'just' simple neural units & learning algorithms applied to diverse experiences at a (currently) unreachable scale. As increasing computational resources permit running such algorithms at the necessary scale, the neural networks will get ever more intelligent.

The extrapolation and implications of GPT-3's performance may be that scale has been the answer to building the first steps for AGI all along.

EIGHT THEORIES ON CONSCIOUS COMPUTERS

Artificial General Intelligence is but one step in the science fiction of the evolution of computers. The next step is, of course, sentient and conscious machines that have thoughts and feelings and are basically a race of beings unto themselves. Even if AGI is achieved, that doesn't necessarily mean those computers will have, you know, emotions and stuff. They will just be really smart machines.

The problem? Humanity knows almost nothing about how consciousness forms. We are pretty sure that we are conscious beings but are not so certain when it comes to other lifeforms. Is a frog a conscious being? A dog?

In his book The Fourth Age, author and futurist Byron Reese collected the eight theories of how consciousness forms with an eye towards one day creating a living machine.

1 **Weak emergence:** Renowned futurist Ray Kurzweil believes that consciousness may be, "an emergent property of a complex physical system." Human brains are so complex that the theory is that consciousness formed as a property of the system. Weak emergence is thus when an unexpected outcome occurs, but in retrospect is completely explainable.

2 **Strong emergence:** Unlike weak emergence, strong emergence is when an outcome occurs (like the development of consciousness) and is completely inexplicable, a trick of physics or perhaps some kind of magic. Reese gives the example of a human body. A body contains about 60 different elements, but no law of physics can explain how those 60 elements, arranged just so, can lead to the emergence of consciousness.

3 **Physical property of matter:** Instead of an emergent phenomenon, consciousness may be a completely understandable byproduct of normal physics. The problem is that we just don't understand the inherent nature of matter and physics. In this theory, if we fully understood the physics, then consciousness would be a completely explainable process.

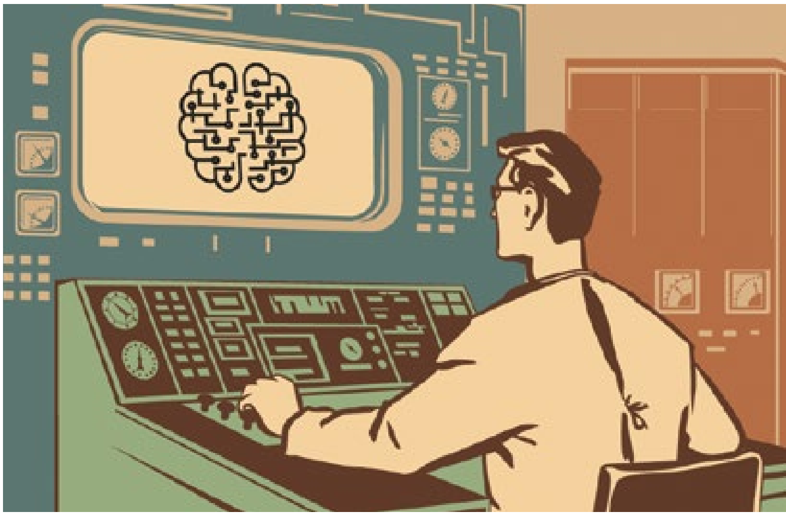
4 **Quantum phenomenon:** A variant of the physical property of matter theory, but specifically that consciousness is created at the quantum level. Famous mathematician Roger Penrose believes that, since human and computers brains are so different, computers will never be able to gain consciousness. Thus, consciousness is the outcome of quantum processes within neurons in the brain.

5 **Consciousness is fundamental:** The universe has four fundamental forces: gravity and electromagnetic interactions at the macro scale; and the strong and weak interactions at the subatomic scale. Most complex systems can be described through simpler systems (for instance physics explains chemistry which explains biology which explains life). The fundamental forces are ground truth, they cannot be explained by simpler systems. Could consciousness be another fundamental force?

6 **Consciousness is universal:** This theory states that everything has a degree of consciousness. The rocks, the trees, the components of your iPhone. When people attribute consciousness to the entire planet under the guise of "Mother Earth" (derivative of the "Gaia Principle"), they are espousing a view that consciousness is universal. It's an old principle, though often goes modern name of "integrated information theory."

7 **Trick of the brain:** Perhaps all the other theories of consciousness are overthinking the problem. Instead of some kind of magic emergence or physical system, consciousness is just how the brain works. "It [consciousness] is astonishingly wonderful but it is not a miracle and it isn't magic. It's a bunch of tricks," said researcher Daniel C. Dennett.

8 **Spiritual:** Some kind of deity was like, "okay, now we give them consciousness" and it was so. Now, if we apply these theories to the "blessings of scale" notion of GPT-3 above, we can see the ideas of weak emergence or the physical properties of matter. Since GPT-3 is so big, perhaps the very scale is leading to some kind of emergence, seen first through its meta-learning properties. Or perhaps that scale has created a sufficiently complex system where natural physics is beginning to create something new. Or, in all likelihood, it's just a really smart algorithm on top of a giant dataset.



ONE ALGORITHM TO RULE THE ROBOT

As established above, most robots are only good at doing one kind of thing at a time. This is a function of the algorithms that govern a robot's behavior. It's not so much that the robot can only do one thing well, but that an algorithm tends to only be able to perform a single task. A robot can be a complex set of algorithms working together, but that kind of complexity can often lead to failure modes.

DeepMind, an artificial intelligence research company owned by Alphabet, is trying to change that. The company published research in August 2020 on how it uses one algorithm—called Scheduled Auxiliary Control—to perform a variety of different kinds of movement. Essentially, DeepMind is teaching an algorithm to multi-task by learning little snippets of one action, then another action, as opposed to learning an entire action at once and going on to the next.

Jack Clark, an AI researcher and author of the popular "Import AI" newsletter, explains:

DeepMind shows that it's more efficient to try and learn multiple skills for a robot at once, rather than learning skills in sequence. In other words, if you're trying to learn to walk forwards and backwards, it's more efficient to learn a little bit of walking forwards and then a little bit of walking backwards and alternate till you've got it down to a science, rather than just trying to learn to walk forward, perfecting that, and then learning to move backward.

DeepMind uses Reinforcement Learning to teach the algorithm to move the robots. The technique cut the learning time in half.

"DeepMind was able to learn a range of movements on one robot which took about 1590 episodes, netting out to around five hours of work," wrote Clark in Import AI. "If they'd tried to learn the same skills in a single task setting, they estimate it'd take about 3050 episodes, adding another five hours. That's an encouraging sign with regard to both the robustness of SAC and the utility of multi-task learning."

AN AI'S VIEW OF THE FUTURE OF DIGITAL IMAGING

Advances in one type of application typically find their way into others. This changing understanding of how AIs are understood, built, and learn will have many consequences for future applications. For example, AIs that can teach themselves may not require the huge data sets typically required for professional applications (which has hindered their use in many industries). And the fact that AIs can be taught multiple tasks at once, a single implementation could learn to both automate and optimize a workflow. So it may not be as difficult to implement AI in new applications, but the possible results could be significantly better.

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NEW AI-BASED GRAPHICAL APPLICATION

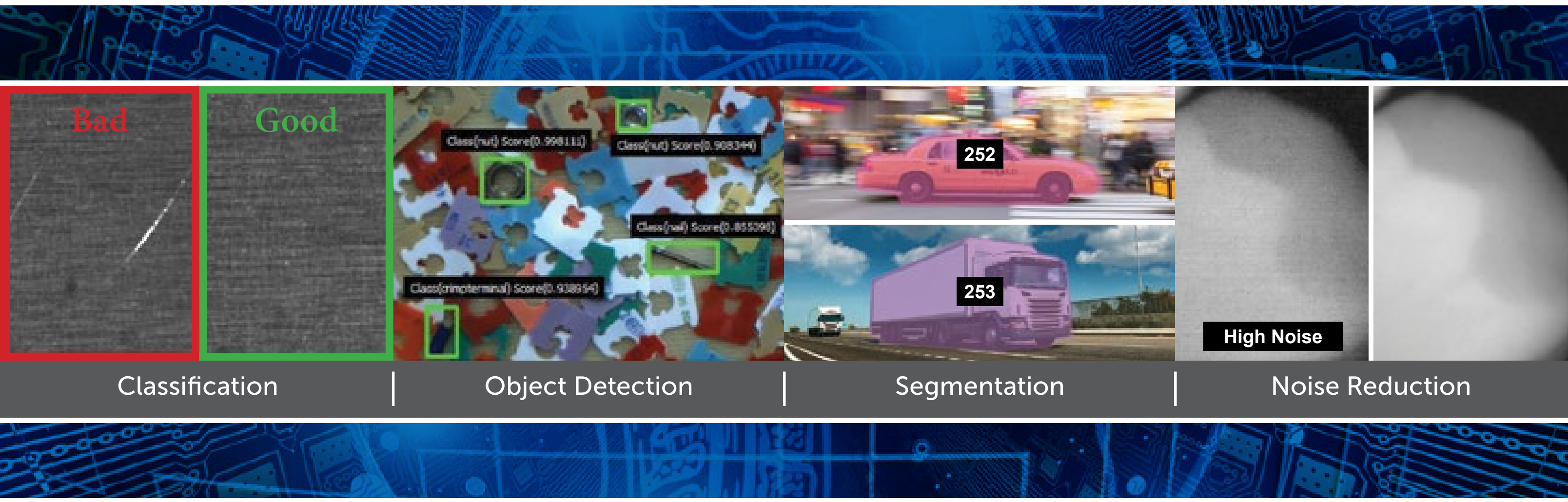

IMAGE PROCESSING AND ARTIFICIAL INTELLIGENCE SOFTWARE

Sapera Vision Software Suite
- Sapera LT
- Sapera Processing
- Astrocyte™

Teledyne DALSA's latest **Sapera Vision Software suite** includes Sapera Processing and the new Astrocyte™ graphical application for artificial intelligence (AI). Through its highly flexible graphical user interface, users can train neural networks to perform classification, object detection, segmentation and noise reduction on existing images. The new version of Sapera Vision Software is ideal for applications such as surface inspection on metal plates, location and identification of hardware parts, detection and segmentation of vehicles and noise reduction on x-ray medical images.

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The Rapid Deployment of 3D Imaging Applications

3D MACHINE VISION IS DRIVING EXCITING NEW POSSIBILITIES FOR FASTER, CHEAPER, AND MORE ACCURATE INSPECTION.

BY Bruno Menard, Software Director for Teledyne DALSA Vision Solutions

3D machine vision, or the precise three-dimensional measurement of complex free formed surfaces, is truly a disruptive technology. As 3D imaging gains ground, how can companies get up and running quickly with 3D applications? This article will examine what it takes to make 3D work in your imaging applications with specific recommendations and use case examples.

For many applications, multiple 3D sensors are required. Software for multiple 3D sensors need to support specific functions. We will review these details, after a brief overview of 3D machine vision technology.

3D MACHINE VISION TECHNOLOGIES

Compared to more conventional 2D imaging, three-dimensional imaging is hard. Commonly used 3D machine vision technologies include stereo vision, Time-of-Flight (ToF) scanning and 3D triangulation.

With stereo vision, images from two cameras are processed to measure the difference in the images caused by the displacement between the two cameras, enabling the system to accurately judge distances. This takes more processing time than 2D systems, but today's multi-core processors can easily handle real-time 3D machine vision.

Time-of-Flight (ToF) scanning determines the depth, length, and width of an object by measuring the time it takes light from a laser to travel between the camera and the object. Typical TOF 3D scanning systems can measure the distances from 10,000 to 100,000 points on an object every second.

3D triangulation systems use lasers that shine thousands of dots on an object and a camera that precisely locates each dot. The dots, the camera, and the laser form triangles, allowing the system to use trigonometry to calculate the object's depth even for non-standard sized objects such as multiple parts for an engine component.

FASTER AND CHEAPER PROCESSING ENABLES MORE 3D APPLICATIONS

Human eyes and brains often have a hard time processing the extra information available with 3D imaging – just think of watching a 3D movie. However, computers today can do that quite well.

That hasn't always been the case. In the 1980s, dimensional imaging was merely a research curiosity, only making its way out of the laboratories and into application demonstration in the 1990s. As computers became more powerful in the 2000s, they were able to handle more sophisticated algorithms and process data more quickly. Finally, there were applications where 3D imaging could produce more reliable and accurate results than 2D.

Initially, 3D laser scanners found their way into the oil industry. Geological features could be measured, and oil refineries and other large industrial plants could keep track of geographical shifts or other threats to pipelines and equipment. The potential of a new discovery or the huge expenses of a failure meant that the companies were willing to put up with high costs and complexity. Later, manufacturing industries—particularly automotive—found ways to use 3D imaging for quality control. The construction industry uses 3D scanners to survey and model buildings and city sites.

As processing became easier, and prices came down, 3D imaging found its way into more markets. The medical field began exploring dental applications. Real estate and construction companies could create three-dimensional models of houses and other structures to build, repair, and even sell.

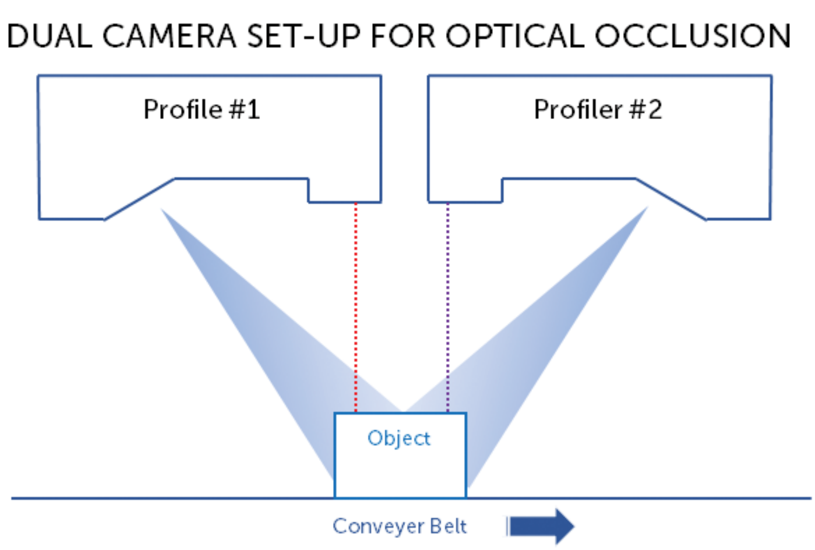
3D IMAGING LEVERAGING MULTIPLE SENSORS

In certain 3D applications the use of multiple sensors is required. Here are two examples:

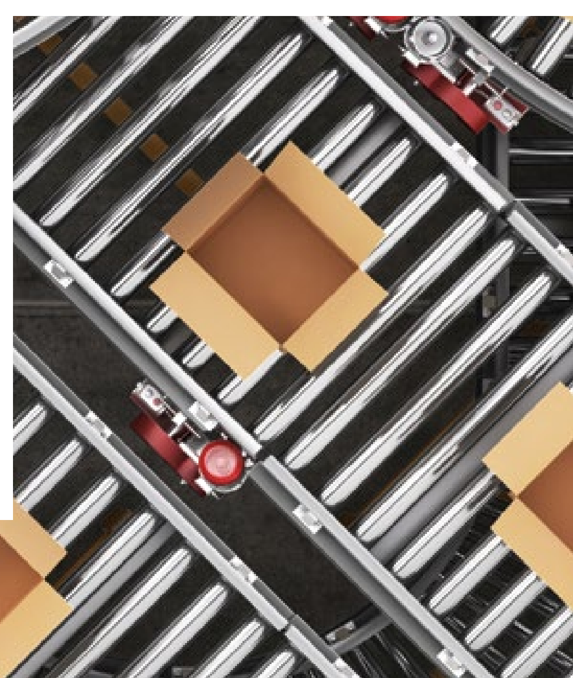
Covering a large field of view (FOV) with high resolution. Scanning large objects requires a 3D sensor with a large FOV. This is possible, but in practice it could result in an insufficient resolution for the application and may therefore reduce the precision of the measurements. In this case, setting up multiple 3D sensors next to each other can solve the problem. One example would be the inspection of car indoor roof foam panels. This involves a very large FOV for a rather small depth.

3D is required for any precision depth measurement. For example, solder inspection can only be achieved with precision via 3D. Another example is the inspection of seals on food packaging.

Scanning complex, integral objects is not possible with a single 3D sensor as the laser cannot reach all parts of the object. An integral object is a 3D model of a real object with data points on all surfaces of the object. For example, this could be a machined metal part on which we want to make measurements of various subparts (width, height, angles). Or, these parts may include cavities not seen by single laser. In order to successfully scan these complex parts, we need multiple profilers to be able to reconstruct the total surface. Several configurations of 3D sensors – such as side-by-side, back-to-back, opposite configurations — are possible to allow scanning of all parts and combining them together provides an integral object output.



Scanning integral objects and eliminating shadows.



To do this, we scan a calibration object (e.g., a prism), and compute transformation via a specialized algorithm. We end up with one affine transformation for each profiler to be applied at runtime in order to produce data in a unified coordinate system. It takes all scans and outputs a 3D image of the object:

SOFTWARE REQUIREMENTS

When multiple 3D sensors are used, the software needs to support the following requirements:

1 Timing Synchronization

When multiple sensors are involved, timing synchronization is required to avoid interference between sensors (i.e. prevent one sensor from seeing the laser of its adjacent sensors). To do this, the sensors are configured to strobe lasers and start exposing alternately in time (one after the other). Ideally, this synchronization is organized in such a way that the primary sensor is electrically trigged while sending a software command to all other sensors via Ethernet link. To ensure precise and non-drifting synchronization, the PTP standard (Precision Time Protocol) is used.

2 Unified Coordinated System

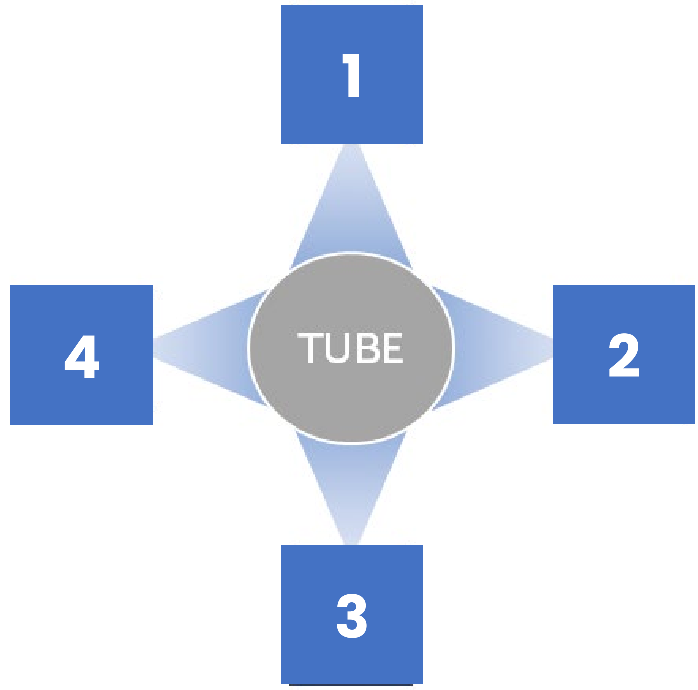
In a multiple-sensor configuration, each individual sensor has its own coordinate system which needs to be calibrated and transformed into a unified coordinated system for the application. Calibration is performed using a known calibration object on which an algorithm extracts features of interest before computing a transformation (typically rigid transformation based on six degrees of freedom). Once transformations are applied to all sensors and redundant 3D points are eliminated, a unified view of the scanned object is produced and ready for measurements. Calibration object may be of different shapes, sizes and layout. Calibration objects need to be easy to manufacture and easy to mount (often customers produce their own calibration object) while being suitable for extracting features such as corners, lines, vertex, etc.

3 Graphical Software

Software provides ability to manipulate the parameters of the system such as timing, layout scenarios, calibration objects, transformations, etc… all in a graphical way in order to ensure an optimal balance between ease-of-use and flexibility.

4 Measurements

Measurements are performed on the resulting data in the unified coordinate system. Measurements are defined on primitives such as points, lines and circles. There primitives are fitted to the real data points for maximum precision.



A RAPIDLY GROWING GLOBAL MARKET

3D machine vision was developed to enable automated quality control. But it is now being applied much more widely, in concert with automation and machine learning. Quality control has evolved into production optimization—systems that detect potential problems at a very early stage, identifying the causes and automatically fixing them on the fly.

Analysts are predicting double-digit growth across the industry: 3D modelling, scanning, layout and animation, 3D rendering, and image reconstruction. The 3D camera industry is forecast to reach US$17.6 billion in 2025 and the 3D scanning segment is expected to reach US$14.3 billion by 2025. Growing use of 3D imaging in smartphones, cameras, and televisions continues to drive demand, and the use of 3D imaging software in the automation industry continues to propel further adoption as implementation becomes less burdensome, and easier to deploy.

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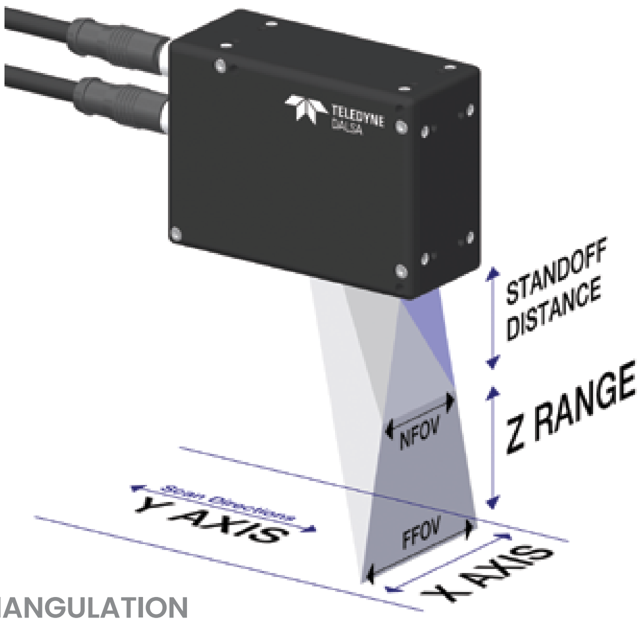
3D Laser Triangulation:
Bringing Depth to Machine Vision

BY Inder Kohli, Senior Product Manager, 3D Sensor Technology

3D vision is going mainstream – and that's a good thing. Advances in technology and reduced costs now make 3D vision a technology that can be applied to all sorts of applications and industries, including semiconductor and electronics, EV battery manufacturing, automotive manufacturing, food production, and pharmaceutical packaging. You'll find 3D sensors and profilers on production floors, in automation, robotic guidance, and quality control.

In the past, 3D systems were too slow to keep up with production, too expensive, too hard to configure, and too difficult to maintain. Instead, system designers have relied on line (1D) and area (2D) scan imaging to perform inspections in a complicated arrangement of cameras and lighting, and extrapolated depth information with software.

Parallel advancements in sensor quality and speed, embedded vision, FPGAs, lasers, optics, and smart systems have made 3D imaging a much more viable option today. 3D imaging technologies now, are low-cost, reliable, repeatable, easy to implement, and proven in a wide variety of demanding applications. And while 1D and 2D are still in wide use, 3D now presents a solid alternative in nearly every instance.



3D LASER TRIANGULATION

One of the 3D imaging technologies making this possible is 3D laser triangulation. The technique has been around for quite some time, but until recent advances, its use for inline applications was curtailed due to the complexity of calibration, limited scan rate, required computing power, and in-field maintenance costs.

In a typical laser line profiler, a laser stripe is projected on an object and is imaged using a 2D (area/matrix) image sensor. After determining the position of the laser stripe on the image sensor, the profiler gives the information for the lateral (X-axis) and depth (Z-axis) created by the optical triangulation of the laser stripe. The resulting set of XZ pairs along the laser line is called a profile. The distance between two consecutive profiles in the direction of motion constitutes the 3rd axis (Y). By scanning the object in such a way, we obtain a surface scan (X, Y, Z) of the object.

ACHIEVING PERFORMANCE

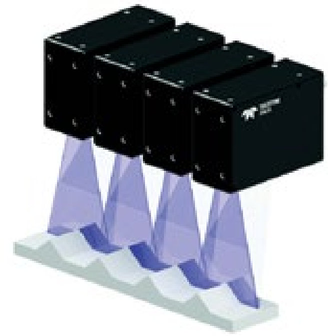
With the advancements of high-speed CMOS image sensors and the power of modern FPGAs, fast and reliable embedded systems allow 3D profile sensors to deliver a larger field-of-view (for a given measurement range) and high-dynamic range imaging (HDR) at unprecedented speeds. By incorporating functionalities such as the ability to support diffused and specular configurations, and a high-speed data transmission interface like 5-GigE, 3D profile sensors are better equipped to meet the challenges presented by today's inline 3D machine vision applications. Offered in a wide range of optical arrangements, these sensors use scalable processing architectures and deliver height and width resolutions down to a few micrometers.

BETTER USABILITY AND INTEGRATION

Integrated laser triangulation profilers are easier to use and set up, and require no special lighting arrangements. By carefully balancing various building blocks of the profiler design (image sensor, laser capabilities, optical path, mechanical and electronics) accurate measurements are obtained at a relatively lower cost.

As the profilers become more reliable and the technology matures, users are likely to be more accepting and willing to choose it as a preferred technology. For example, laser triangulation can be very tolerant of vibrations. By scanning, small vibrations can help to reduce the overall noise created by the speckle of the laser.

Clever architecture design allows you to further increase the power of the system by adding processing blocks, such as artificial intelligence, pixel processing, and smart sensors among others.



Examples of multi-sensor installations

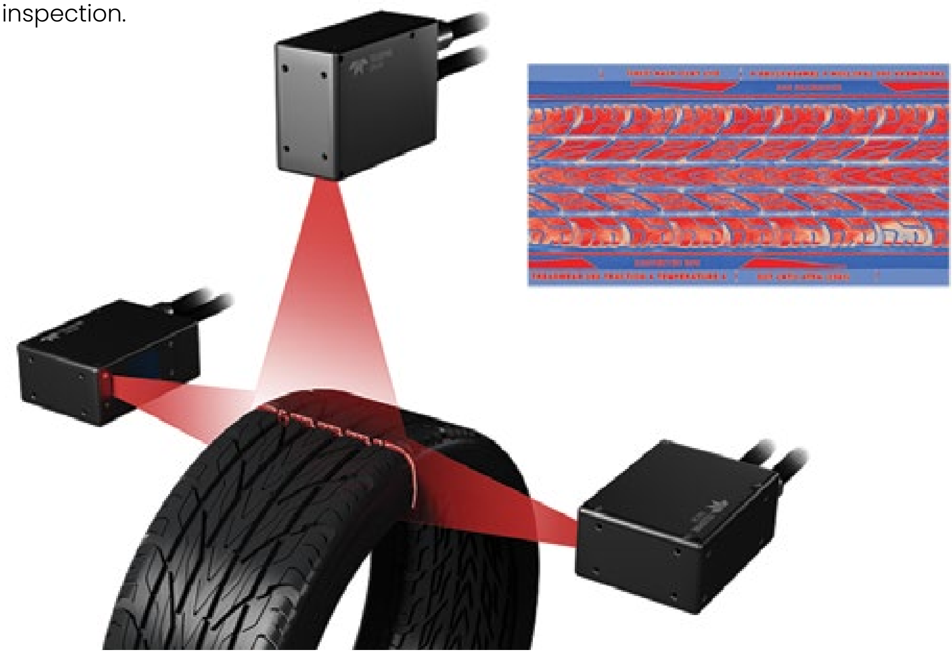
SYSTEM DESIGN FOR A WIDER FIELD OF APPLICATIONS

Today's laser profilers combine HDR capabilities and reflection elimination algorithms to measure object features despite varying degrees of surface reflectivity. In addition to the eye-safe red lasers, models are also available in blue laser configurations, suitable for scanning objects with surfaces that are either very reflective or not visible to red lasers.

Developments in modern electronics and artificial intelligence (AI) have enabled systems to become even more powerful, and at a reasonable cost. For applications where the field of view of a single 3D profile sensor is insufficient, users can combine several 3D profilers for a synchronized inspection or in cases where objects require 360º inspection.

Examples of such applications include inspection of large panels of wood, metal, drywall, plastic, and extrusions of various types. Extruded parts with asymmetrical features on each side require the use of multiple sensors around the object. This requires that all sensors are configured in such a way that the resulting 3D image is a true representation of the object. This requires that all sensors be precisely synchronized to generate a combined image to ease measurements.

3D inspection of car tires is a typical application for the use of the 3D profile sensor.

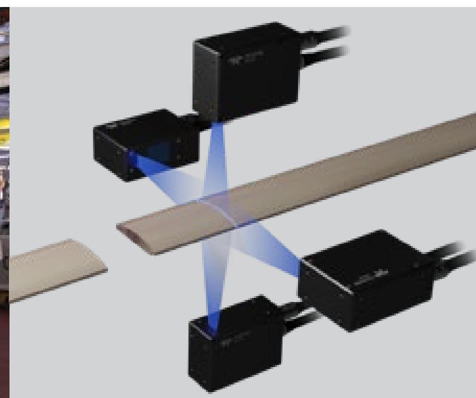


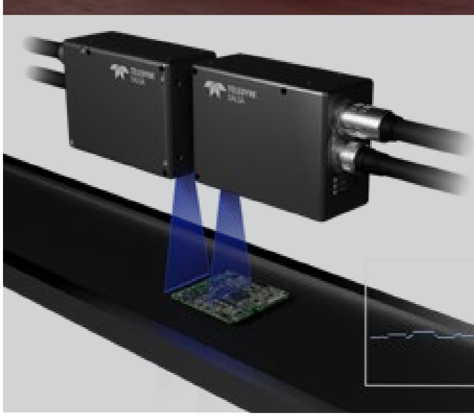
LIMITATIONS AND FURTHER CONSIDERATIONS

Despite the advancements of 3D laser triangulation in terms of performance, cost, and usability, there are still issues that need to be considered in successful system integration. Because laser triangulation needs to look at angles, occlusions are often a problem. Occlusions are shadows created by the positioning angle of the profiler caused by the geometric triangulation. One solution is to use one or two lasers and multiple cameras. The sensor may also limit the overall speed and performance of the system. Laser speckle is also a challenge, which is the inherent noise generated by the laser itself, reducing the resolution of systems.

KEY MARKETS & APPLICATIONS

Still, 3D laser triangulation-based systems are suitable for a surprisingly wide variety of applications, including inline height measurement in numerous market segments including electronics and semiconductor production, robotics, automotive manufacturing and factory automation in general.



INDUSTRIAL

- Inline metrology
- Volumetric measurements
- Robot guidance
- Gap and flush measurements
- Surface inspection

ELECTRONICS

- Chip lead inspection
- BGA and micro BGA inspection
- Solder paste inspection
- Bare and Populated PCB inspection
- Machine Vision

PARTS INSPECTION

- Part identification
- Embossed OCR
- Embossed barcode
- Bead inspection
- Pick and place
- Wood and lumber inspection
- Angular measurements

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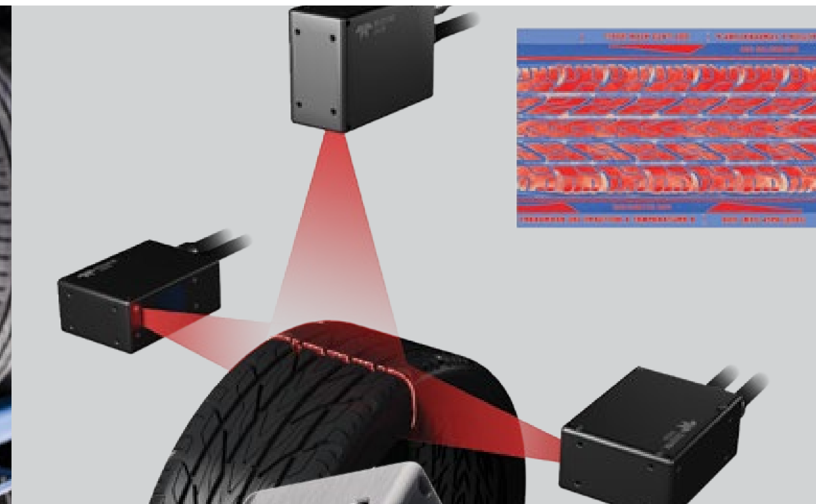
Z-TRAK2 3D PROFILE SENSORS
FOR IN-LINE TIRE MEASUREMENT AND INSPECTION



SCAN SPEEDS UP TO 45 kHz

The Z-Trak2™ family ushers in a new era of 3D profile sensors for in-line real-time tire measurement and inspection. These models deliver scan speeds of up to 45 kHz combined with a suite of powerful features:

- Ready to deploy, no in-field calibration
- Combine multiple sensors for 360° inspection views
- Measure diameter, length and identify defects
- Outputs 3D and intensity images at the same time
- 3rd party software ready
- Measure thickness, read embossed OCR, and detect defects

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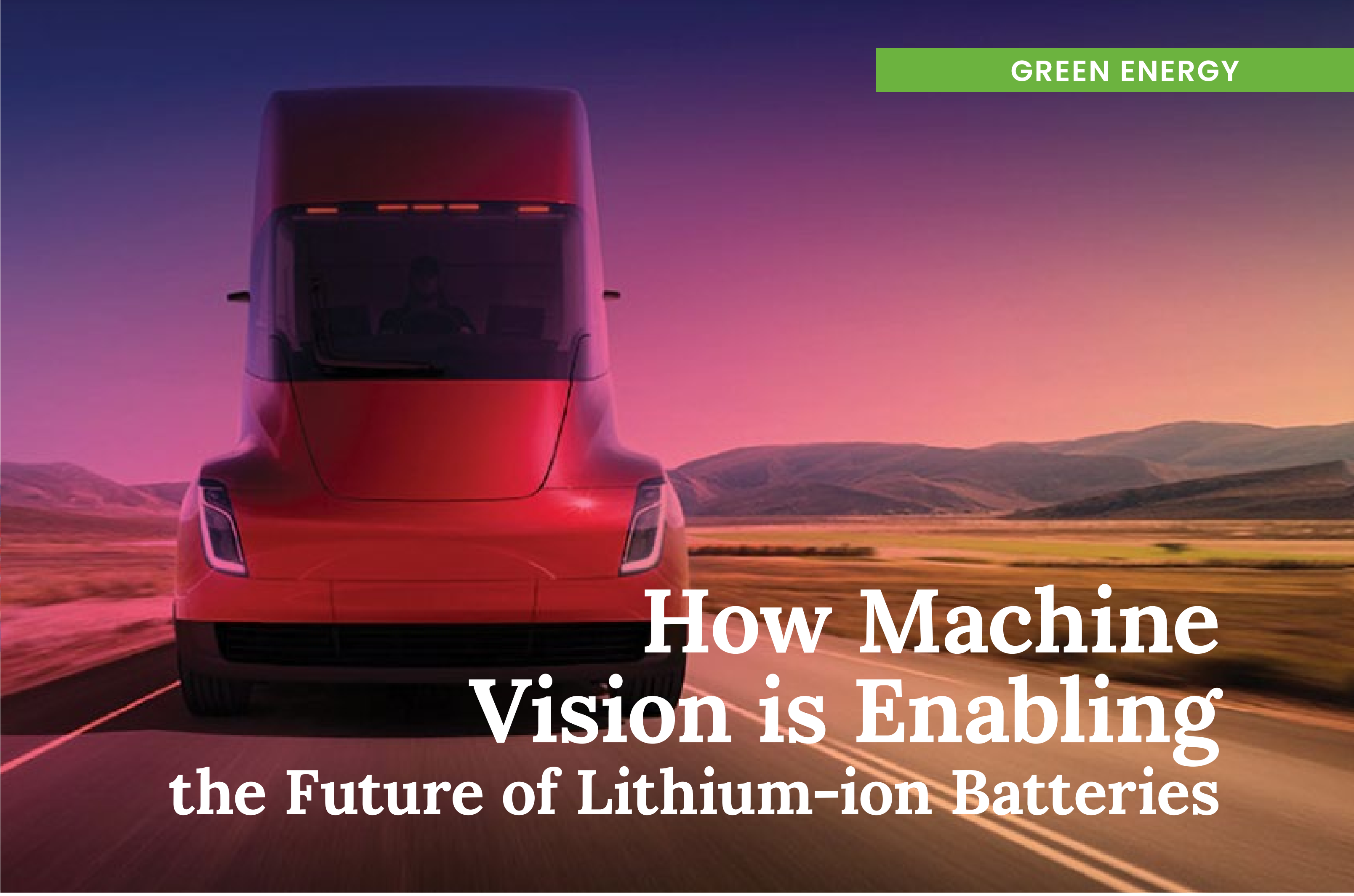


How Machine Vision is Enabling the Future of Lithium-ion Batteries

LITHIUM-ION BATTERIES IN ELECTRIC VEHICLES AND SOLAR POWER SYSTEMS WILL BE BEHIND THE GROWTH OF THE GREEN REVOLUTION.

BY Christian Loeb *Photo: Image Courtesy of Tesla, Inc.*

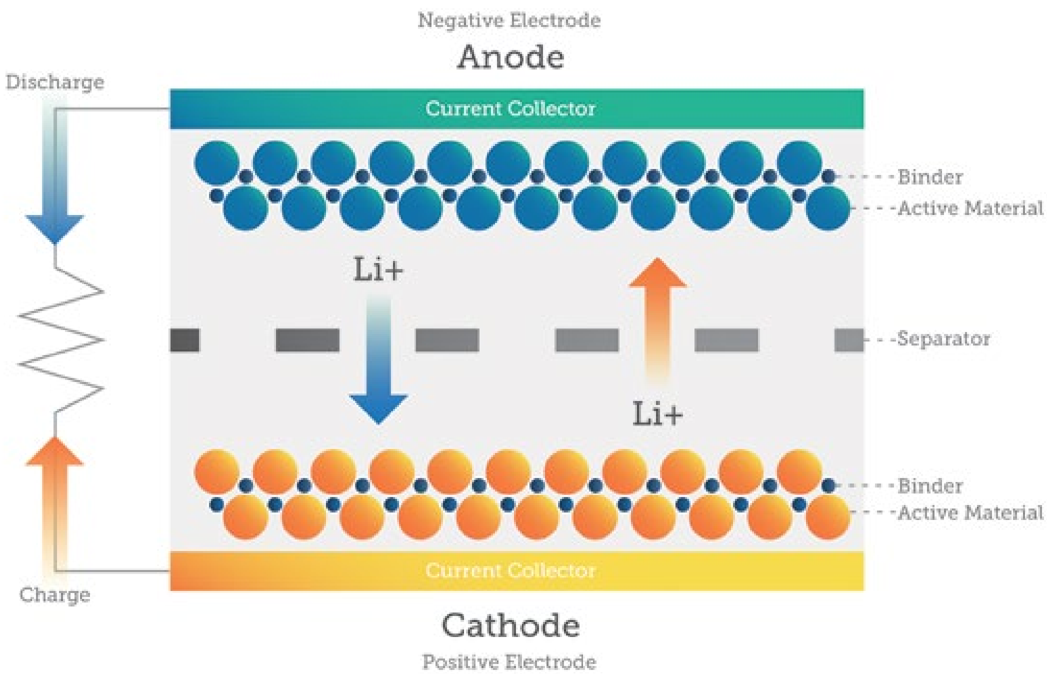
The quintessential electric vehicle, the Tesla Model S, uses more than 7,600 lithium-ion battery cells. In the near future, we may look at that kind of battery usage not as quintessential, but quaint.

The transition to green energy in the coming decades will require a commensurate increase in battery production and innovation. Lithium-ion batteries will be the workhorse of a green energy revolution in the near to medium future, storing power for nearly everything, from electric vehicles and eventually airplanes, to homes and commercial buildings.

Lithium-ion batteries come in three shapes: cylindrical, pouch and prismatic (also called a battery can). Your smartphone probably has a pouch battery while most household appliances will have cylindrical batteries.

Battery production is ramping up across the world. Tesla finished building its infamous first “gigafactory” for battery cell production in aptly-named Sparks, Nevada in 2015. Another Tesla gigafactory, working mostly on solar power storage opened in 2017 in Buffalo, New York. The company has plans to open two more factories in coming years, in Berlin, and Austin, Texas. European battery company Northvolt will begin large-scale construction on a gigafactory in Skellefteå, Sweden in 2021.

The transition to green energy provides a long runway for a new sector of the global economy. Manufacturing will benefit as the demand for solar cells and batteries ramps up, and with any new technological development, an industry ecosystem will develop to support its growth and production. The lithium-ion battery is at the forefront of an ecological and economic revolution.



The structure of a lithium-ion battery. Compared to metallic alternatives, lithium-ion is more stable during operation and charging. They're typically twice as energy-dense as nickel-cadmium batteries, but can tend to be heavier than other options.

HOW LITHIUM-ION BATTERIES ARE BUILT

For all their importance, lithium-ion batteries are conceptually simple devices. Alternating cathode (positive charge) and anode (negative charge) electrode sheets are stacked on top of each other, with a separator sheet between each layer. A liquid or solid electrolyte is mixed in to facilitate energy transfer between the cathode and anode sheets.

Cathodes sheets are typically made from aluminum foil, while anode sheets are made from copper foil. From there, each sheet is coated with specific materials to promote conductivity, efficiency, and binding.

Active materials: determine the capacity, voltage and characteristics of a specific lithium-ion battery. For cathodes, active materials often include lithium cobalt oxide, lithium manganate oxide or lithium iron phosphate. Anodes are typically coated with some kind of carbon material, such as black lead or lithium titanite.

Binders: are used to adhere the mixed materials to the foil sheet.

Solvents: promote the mixing of materials in the slurry until they are ready to coat the appropriate sheets.

In addition, a cathode will include a conductive element to reduce internal resistance and increase conductivity within the cell.

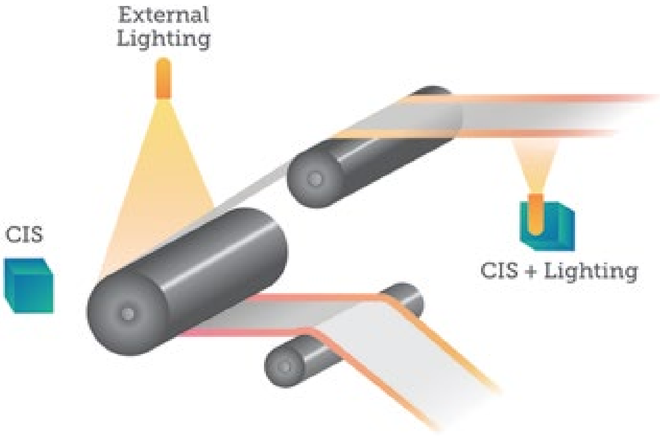
The separator sheets that go between the electrodes are manufactured from porous polyolefin film material that are applied with an aramid coating fluid and then cut to size. Once the layered electrode sheets are ready, they are placed in the battery casing in one of the three major formats, cylindrical, pouch or prismatic. Depending on the form and specifics of the battery, the casing will include external positive and negative terminals (to connect to the device being powered), an insulation layer between the case and the electrode stacks, a gasket, a degassing hole and other elements.

One of the first mass-produced lithium battery types, cylindrical cell are made up of sheets of anodes, separators, and cathodes that are sandwiched and rolled up. These cells are well-suited for automated manufacturing, and the shape allows the cell to tolerate a higher level of internal pressure without deformation. Cylindrical cells are commonly found in medical instruments, laptops, e-bikes, power tools, and combined in the massive packs in Tesla vehicles.

USING CAMERAS FOR LITHIUM-ION BATTERY QUALITY ASSURANCE

While lithium-ion battery production may be conceptually simple with coated electrode stacked sheets and an electrolyte solvent, the actual process is fairly complicated and sensitive. The thickness of the coatings on the electrodes can have a significant effect on a battery's performance or even its stability.

Line scan cameras powered with machine learning algorithms can help automate and streamline the quality assurance stage of lithium-ion battery manufacturing. A line scan camera—such as the Linea family of cameras from Teledyne DALSA—is a camera that can be mounted on a factory production line to monitor the production of materials as they are moved through the manufacturing process. Line scan cameras are well-suited to inspection of electrode sheets, since the sheets are run at high speeds from big spools through the coating and stacking process.



Line scan cameras, contact image sensors, and 3D laser profiles can all be used for inspecting electrode sheets.

Laser profiling from inspection cameras can cover the whole manufacturing process of lithium-ion batteries. The cameras can measure the thickness of the electrode sheets and coating, look for surface defects on the sheets such as dents, scratches or bent edges, measure the dimensions of the battery casing for cylindrical or pouch batteries, and monitor the quality of the weld of the external terminal on the batteries.

SCAN FOR MORE INFORMATION

Workers on a copper foil production line for electronic lithium batteries.

THE GROWTH POTENTIAL FOR LITHIUM-ION BATTERIES

The demarcation line for the growth rate of lithium-ion batteries is often projected in terms of how many electric vehicles are being sold compared to internal combustion engine vehicles. Electric vehicles are expected to hit 10 percent of vehicle sales by 2025 and then accelerate to 28% by 2030 and 58% by 2040. For instance, California—the most populous state in the U.S. and one of the biggest economies in the world on its own—aims for all new cars and passenger trucks sold in the state to be zero-emission vehicles by 2035.

As battery storage is often paired with renewable energy, the growth of one directly informs the adoption of the other. According to the U.S. Energy Information Administration, 70 percent of new energy production capability to come online in country in 2021 will be from renewable sources (39 percent solar, 31 percent wind). As such, the capacity for battery storage will also rise this year, quadrupling growth from previous years. The world's largest solar-powered battery will come online in Florida by late 2021.

Manufacturers need to prepare to be able to meet the coming demand for lithium-ion batteries. The use of line scan cameras, laser profiling and machine learning will help manufacturers streamline quality assurance and efficiency.

GREEN ENERGY

Lithium-Ion Batteries:

Hot growth, pressure, and looking toward the future.

A TECHNOLOGY ONLY A FEW DECADES OLD IS DRIVING THE FUTURE OF TRANSPORTATION FOR THE NEXT CENTURY. INSPECTION IS HELPING US KEEP UP.

BY Gerard White Sr. Business Development Manager Teledyne DALSA

Today's rechargeable batteries, led by lithium-ion chemistry, are in many ways proven, and yet so challenging at the same time.

Developed in the 80s and 90s, lithium-ion batteries (LIB) made their first big impact on mobile devices: smartphones, tablets, cameras, and power tools. This is only possible because LIB are good. Their high energy densities and voltage, stability, low weight, long life cycle, and diversity of chemistries make them ground-breaking, so far ahead of previous rechargeable battery technologies. Their use has been expanding ever since, with demand continuing to grow rapidly worldwide.

Today, consumer electronics represent only 20% of the demand for LIB, and that number is expected to keep falling. Instead, the future will be in driving the global transport and energy systems to electric power and enabling a more decarbonized future for humanity. According to the World Economic Forum, passenger cars will account for 60% of global battery demand by 2030. Along with commercial transportation and the energy sector, the global market for lithium-ion batteries is forecast to grow at a CAGR of around 20% from 2022-2027, reaching a market size of US $200 billion in 2027. Electric vehicles (EVs) are transforming the automotive and transportation industry and are expected to account for most of lithium-ion battery demand. Frost & Sullivan expects between 12 million and 15 million EV sales in 2025, a tenfold increase in global lithium-ion battery capacity from 2018. According to Frost and Sullivan, Asian battery manufacturers had the first-mover advantage, due in part to the high demand for EVs in China and have already accounted for about 70% of global lithium-ion cell production.

Rechargeable battery technology isn't static, either. As multiple companies look to make improvements in performance, efficiency, and quality, their solutions continue to morph and change.

And if the world is going to have a chance of reaching zero carbon emissions, rechargeable batteries will be a critical part of the solution.

SPEEDBUMPS ON THE ROAD TO GLOBAL UBIQUITY

Still, there are risks. LIB are complicated to make, especially for EV applications where safety, durability and modularity compete with competitive pressures on performance, efficiency and price. Individual cells must be produced and then assembled into battery modules containing hundreds of cells. Like in any manufacturing process, perfection is the goal, not a destination. There are always limits to yield. This is complicated by the fact that a single cell failure can necessitate the disassembly of an entire module and removal of the failed cell or cells. Undiscovered failed cells are even worse: they can greatly degrade the output power and performance of the whole module, or even present hazards.

In 2018, the U.S. National Transportation Safety Board investigated a series of fires in Tesla vehicles, looking at whether the high-voltage LIB posed safety risks to first responders after crashes.

In 2021, Australia, perhaps the country most committed to bringing lithium batteries into its electrical grid, also

faced challenges with battery systems. In 2021, it saw a fire at its big battery system in Victoria during testing. Now, investigations are underway regarding power grid failures where the battery-based backup systems didn't meet expectations. The causes are still unclear.

In April 2022, U.S. safety regulators have opened a new investigation into electric and hybrid vehicle batteries after five automakers issued recalls due to possible defects that could cause fires or stalling. The National Highway Traffic Safety Administration said the new probe covers more than 138,000 vehicles with batteries made by LG Energy Solution of South Korea and affects cars made by General Motors, Mercedes-Benz, Hyundai, Stellantis and Volkswagen.

While these cases are concerning, they are not surprising. The current safety and quality standards of manufacturing for fossil fuel and internal combustion engines has benefited from more than 100 years of refinement. Although EV have also a long history, their accelerated mass production development did not take place until the 1990's where NiMH (Nickel Metal Hydride) batteries were used for EV and LIB developed into a viable alternative.

SAFER BATTERIES THROUGH INSPECTION

More demanding applications for LIB require us to develop a better understanding of the performance, degradation, and hazards of both materials and devices. The failure of a battery system in almost any electric system poses multiple hazards. Lacking a long

AUDI e-tron Production at the CO2-neutral plant at Brussels: Final acceptance of battery cell module controller and cabling.
Copyright Audi AG

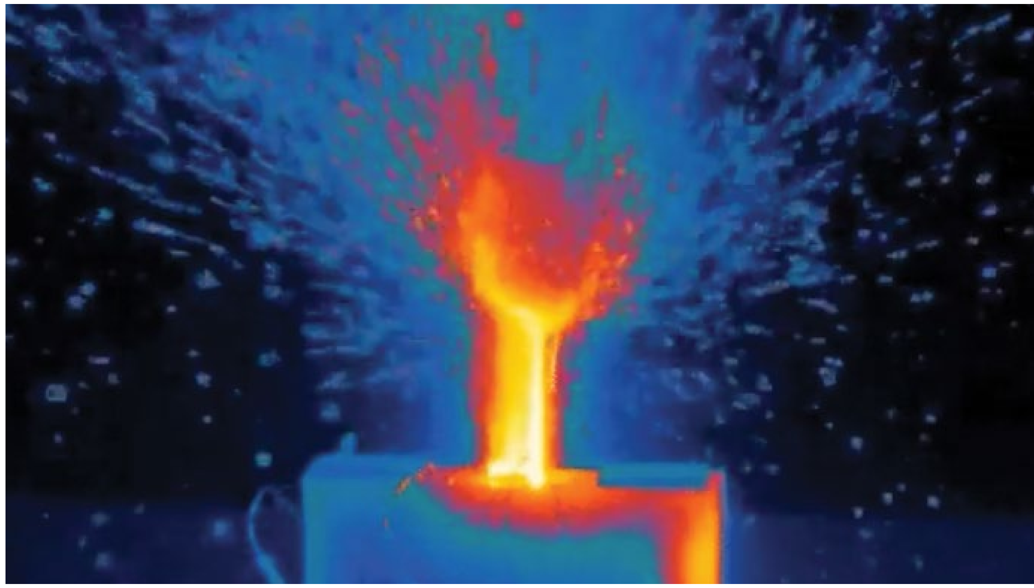
track record on standardized equipment to understand the risks, there's a strong case for increasing quality control testing on all individual cells before and after they are assembled into modules. While each cell and module likely have their current tested at different stages, this only provides a partial understanding.

The best quality strategy is to start inspection as early in the production process as possible, so as not to waste time and resources on scrapping or recycling nearly finished product. Early defect detection allows manufacturers to finetune the feedback loop, adjusting process machinery to optimize results.

As we saw in an earlier Possibility article, the first visual inspection happens in the manufacture of foils, which are used to make the electrodes (cathodes and anodes). The quality and consistency of the foils and their coatings are critical to the function and safety of the cells: foreign particles, bumps and non-uniformities which can over time press or rub through the separator foil, thus causing a short circuit resulting in catastrophic battery failure. Typically, this inspection is done after the slicing or punching processes which can cause particles to be deposited on the surface prior to the rolling, folding, or stacking of the electrodes.

Often, it's a matter of a few dark grey defects on a dark grey background that can determine the performance and lifetime of a battery cell. Manufacturers are finding it important to look for these defects from the 50-micron level all the way down to 10 microns. Contact imaging is often used for a 'rough' initial pass, but for detailed inspection further down the line, companies turn to line scan cameras, and high-sensitivity TDI (Time Delay & Integration) cameras to provide the necessary resolution and sensitivity.

More innovative solutions have included Multi-Field TDI cameras that provide the additional benefit of simultaneously capturing light from three different spectra and angles, providing more image data for defect detection and analysis without incurring further costs or slowing the system.



High-speed thermal imaging captures spreading heat in a battery during a nail penetration test. Image courtesy of Teledyne FLIR

Other types of imaging are used at different stages of assembly. High-speed 3D laser profilers are used to measure the form of more 3-dimensional objects such as the contact tab welding uniformity, tab deformity and orientation. A poorly welded contact tab can break or cause an intermittent loss of contact. Area scan cameras are used primarily in the packaging of individual cells into larger batteries, where the orientation of hundreds of cells in the housing must be precisely controlled.

Once assembled, the 'black box' nature of battery modules, especially in transportation applications with higher levels of sealing and protection presents problems: how do you inspect if you can't see inside? That requires imaging beyond the visual range.

For example, the Battery Innovation Center (BIC) focuses on the rapid development, testing, validation, and commercialization of safe, reliable, and lightweight batteries for both commercial and defense applications. Their process includes extensive abusive (or destructive) testing, exposing batteries to some worst-case scenario to understand any resulting safety issues. To gather the most data possible from these tests, BIC uses a Teledyne FLIR high-speed thermal camera to reveal heat details other technology can't capture.

With thermal imaging, engineers can easily see what's going on outside the battery when damaged, and what's happening inside and how the heat is progressing.

Researchers have also looked at different types of X-ray diffraction for in situ analysis, including X-ray and even ultrasound imaging. This allows the analysis of the physical structure and materials of the battery, providing clues to physio-chemical reactions associated with battery operation and degradation. Although CT analysis cannot reveal the electrochemistry within the cell, it can reveal the mechanical inner workings. A thermal runaway fire can have mechanical causes, but electrochemical processes can leave mechanical evidence. As with any application, there is a balance between image quality and time.

Some of this can be done with fast 2D X-ray systems, but visible information is limited. With 3D X-ray imaging, it's possible to get a full picture for critical aspects of a battery cell and module, while time-lapse (4D) tomography is helping reveal the processes and transformations in an operational battery as it ages.

Commodity or cryptocurrency? The changing price of nickel traded on the London Metal Exchange has made it very hard for manufacturers to plan. Accessed April 27, 2022.
Data via Markets Insider.

Industrial computed tomography (CT) is finding more uses in detecting defects and internal changes throughout a battery's lifecycle. Still, it can be difficult to make out the interesting structures: with the materials being very similar in density and often quite thin, the result is often a low-contrast grayscale image. CT-data analysis and visualization software are adding functions that allow a more informed look with the help of artificial intelligence.

Dynamic Neutron Radiography has proven to be another promising option for non-destructive testing, giving researchers real-time data on the inner workings of a system. In comparison to X-rays, neutron interactions offer some useful advantages to X-ray imaging, as they interact differently with elements. Firstly, lithium and the liquid electrolyte inside batteries are extremely sensitive, and neutron methods have a lower chance of adverse reactions. Second, the high visibility of neutrons for lighter weight elements like hydrogen and lithium enables the direct observation of key battery processes, such as lithium diffusion, electrolyte consumption, and gas formation. Researchers are still working to help neutron imaging catch up with the spatial and temporal resolutions of today's CT scans, where this kind of diffraction imaging can help us better tackle the challenges of current and next-generation battery chemistries.

For deeper analysis of the non-structural conditions within the battery, some researchers have turned to electron microscopy, which can reveal the electrochemical reactions within a battery. Like neutron imaging, resolution can still be a challenge, but the field is advancing very quickly. There is a strong potential that this kind of imaging will improve our fundamental knowledge of the nanoscale electrochemistry events inside all kinds of rechargeable ion batteries.

THE UNPREDICTABLE FUTURE OF BATTERY CELL MANUFACTURING

Today it seems that from an R&D perspective, the LIB technology is mature and it's more about optimizing product and production. Optimization is driving promising moves toward new chemistries to make batteries more cost-effective and environmentally friendly.

For example, cobalt is one of the primary metals in lithium-ion batteries, because the metal increases battery life and energy density. But cobalt is one of the most expensive materials in a battery. While battery prices have fallen 89% between 2010 and 2021, they still make up about 30% of the total cost of an electric vehicle. With EV sales worldwide growing rapidly, demand for raw battery materials like cobalt is expected to outstrip supply. Solutions that obviate the use of cobalt (and even lithium, both of which have sparked serious environmental and human rights concerns) are becoming more attractive.

Some of those solutions rely more heavily on nickel, which brings its own challenges. In the beginning of 2020, Indonesia, which controls a quarter of the world's supply of nickel, put a halt to its nickel exports two years early. But the vagaries of the pandemic and global finance led to the price of nickel falling, hurting investment in companies that otherwise would have invested in increasing their nickel output, only to skyrocket in early 2022.

New technologies will be introduced to overcome one of the fundamental drawbacks of current LIBs: The liquid, fluorine-containing, and highly flammable electrolyte. This ingredient poses severe challenges for handling, storage, and potential recycling) of the battery cells. Emerging energy storage technologies based on more abundant materials like magnesium show promise. Batteries made from magnesium metal could have higher energy density, greater stability, and lower cost than today's lithium-ion cells. Another promising direction lies in a move to solid-state designs that are much more stable but aren't (yet) competitive in performance.

Today, and for the foreseeable future, the hurdle for LIB and its analogues will continue to be manufacturing reliable, high-quality cells in the face of constant optimization and the fluctuations of a global supply chain. This may influence the designs that manufacturers pursue, and the tools they use to perfect and inspect them.

SCAN FOR MORE INFORMATION

GREEN ENERGY

Bright Light, Big Future:
Solar Power on the Rise

LOOKING AT THE SOLAR INDUSTRY IN THE 2020s

BY Possibility Editorial

The sun is shining on solar in the 2020s. Despite the supply chain disruptions in the underlying components caused by the Covid-19 pandemic, it represents the second-largest absolute generation growth of all renewable technologies, slightly behind wind and ahead of hydropower. According to BP, the global growth rate of solar production in 2019 was 24.3%, with the rate rising to 33.2% in non-OECD countries. Many studies indicate that this growth rate will continue, thanks to government policies, falling costs, and rising demand have all driven considerable growth rates around the world.

Rising energy demand coupled with the growing population and raising the non-conventional price of energy is expected to drive the market in the upcoming years. Government initiatives for the use of renewable energy, low maintenance and operating cost of the solar power project, and rapid industrialization in the developing countries are bolstering the global market for solar energy.

While government programs – both incentives and communication – have been main factors for the growth of the solar energy market are government incentives provision & tax rebates for the installation of solar panels and awareness of environmental pollution. Increased rooftop installations for residential use are expected to a boom in the market during the forthcoming years. Furthermore, the rising demand for solar power towers in electricity generation is projected to generate more demand for concentrated solar power systems.

Rising energy demand coupled with the growing population and raising the non-conventional price of energy is expected to drive the market in the upcoming years. However, climatic conditions especially in the geographical region, such as snowfall, rainfall, and high initial installation cost may restrain the growth of the solar energy market. Conversely, government initiatives for the use of renewable energy, low maintenance and operating cost of the solar power project, and rapid industrialization in the developing countries are bolstering the global market for solar energy.

United States government previously stated plans to cut the cost of electricity generation by 50% by 2030. The current administration announced that 100% of energy production in the US will be carbon-free by 2035. Many states in the country such as California, New Jersey, and others have their solar energy targets for 2030, which are expected to create several opportunities for the United States solar energy market in the future.

While policies and climate events have increased interest in solar power, it's the dramatic fall in price that has enabled this dramatic growth.

According to International Energy Agency's World Energy Outlook 2020, no other power-generation technology matched solar's pace this past decade, resulting in the "cheapest…electricity in history" with the technology cheaper than coal and gas in most major countries.

With governments, private industry, and consumers all seeking energy sources that are greener but still affordable, solar cell manufacturers are under pressure to increase the quality of their products and reduce costs. Improvements to solar panel manufacturing over the last decade have been a key driver of this downward cost trend. Scaling up production while integrating new technologies demands more automation and quality control, as yield is critical.

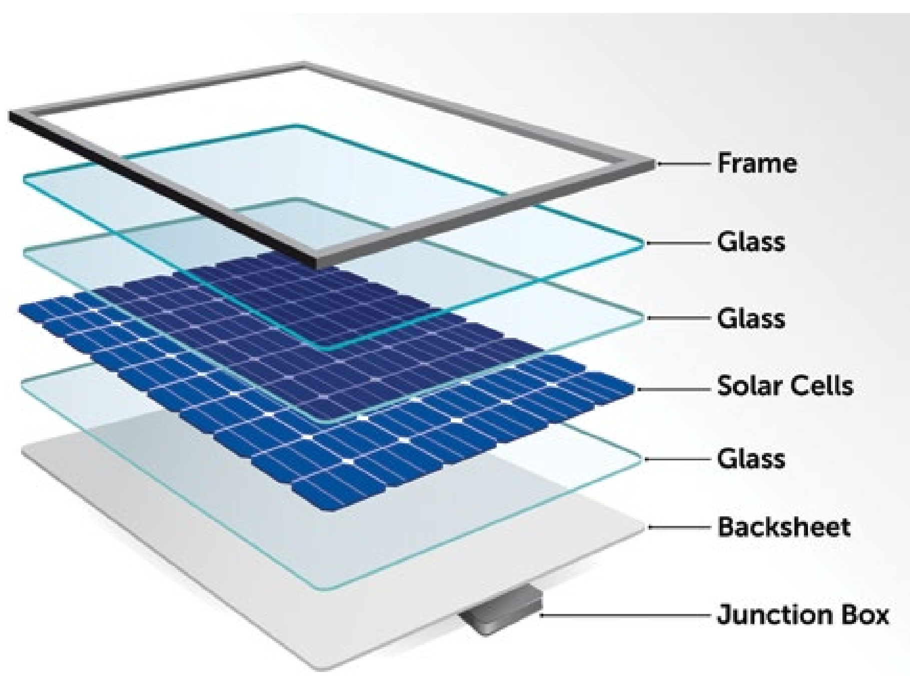
COMPLEX ASSEMBLY

This success can cause difficulties, Simultaneously, as technologies are more established, and demand is climbing quickly, expected volumes are up, and margins are down. As we've seen in other industries, this makes the efficacy of the production line absolutely important. Exacerbated by workforce limitations under COVID-19, many manufacturers are investing in more automation technologies: robotics for assembly and advanced imaging for inspection.

Automation and inspection are both critical to high-quality, consistent, and high-throughput solar panel manufacturing. There are delicate components and multiple layers, all requiring precise placement and alignment. Material handling, cell cutting, and component bonding are all very automated in modern factories, but an error in any one of them risks lower initial performance, and shorter operational life for each solar panel.

This makes inspection crucial. End-of-line testing of electrical parameters like current voltage and peak power rating ensure that panels perform at expected standards. Imaging allows us to look for quality issues, such as cracks and misalignments that indicate initial quality, but also longevity of the panel itself in the field.

Like many areas of electronics manufacturing, leading manufacturers have already moved to 100% inspection and the rest of the industry is working to catch up. Optical inspection becomes required at after every major processing step.



Assembly Layers of a Solar Panel. Manufacturing each panel requires precise layering of glass, semiconductors, metals, and coatings, subjecting them to many etching, bonding and electrochemical steps.

A SINGLE CRACK CAN TELL THE FUTURE

Chasing efficiency, modern silicon solar cells are getting thinner, in some cases approaching 100 microns. Thinner and cheaper also means more fragile. Each stage of production creates an opportunity for tiny cracks to appear. For example, after soldering the copper in connecting wires will contract, pulling away from the silicon boards they're connecting, causing small cracks. Cracks can also occur at the crystal growth stage, or during cutting.

Any imperfection in solar cells, such as cracks, poorly soldered joints, and mismatches, lead to higher resistance and become hot spots in the long run. The long term effects of hot spots include burnt marks that degrade solar cells and back sheets and may eventually lead to fires if left unchecked.

Imperfections in the glass layer can makes cells more susceptible to breakage. Whole production lines get stopped by contamination from shards from broken wafers or glass. Once installed, the front glass panel of a solar panel provides the first line of defense against the elements: storms, dirt, and even a stray baseball. If the glass is broken, the panel will absorb and convert less light, and such as water and dust can get into the panel to cause more problems undermining the integrity of the entire panel.

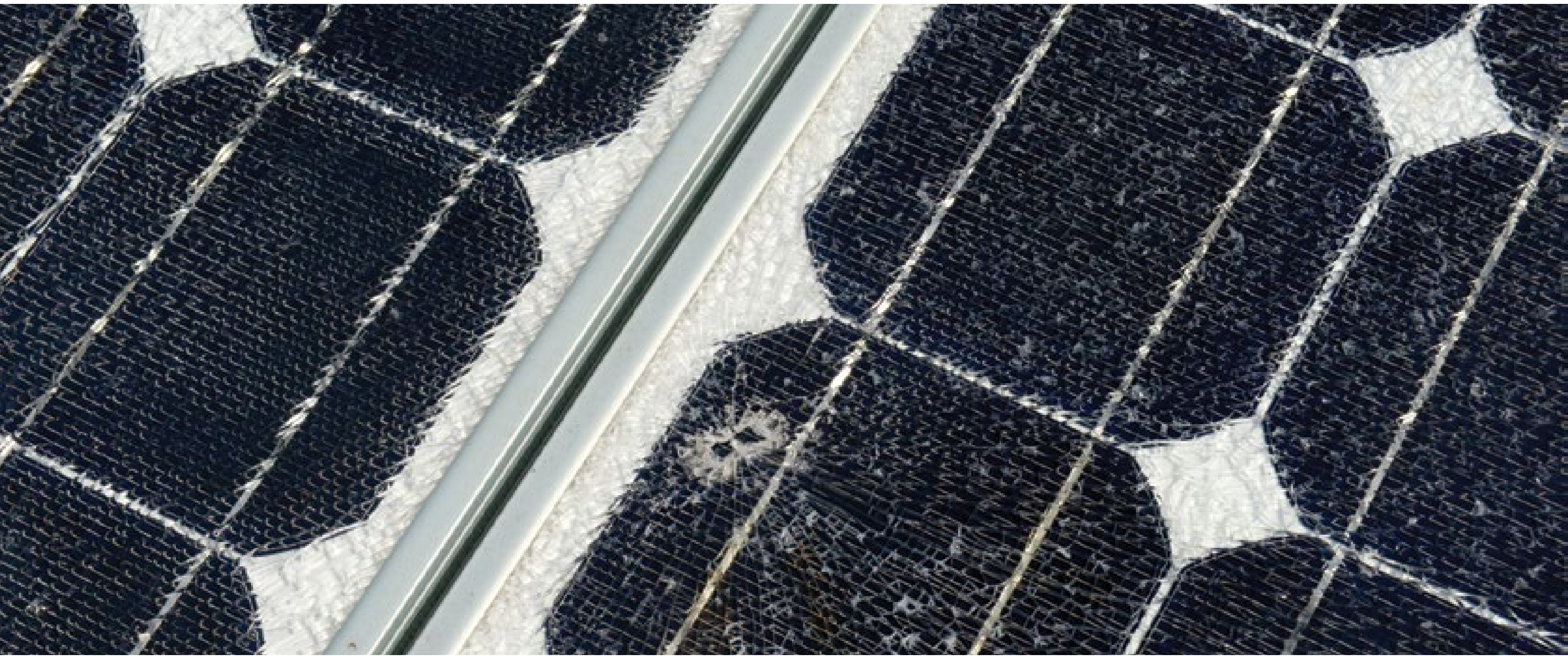
These imperfections can foretell problems for the whole system later. Further mechanical stress from transport, installation, or weather can cause these initial issues to propagate. So it's important to identify and remove damaged or imperfect parts from the production process to prevent faulty products. How do we do that?

FACTORY FLOOR REALITIES

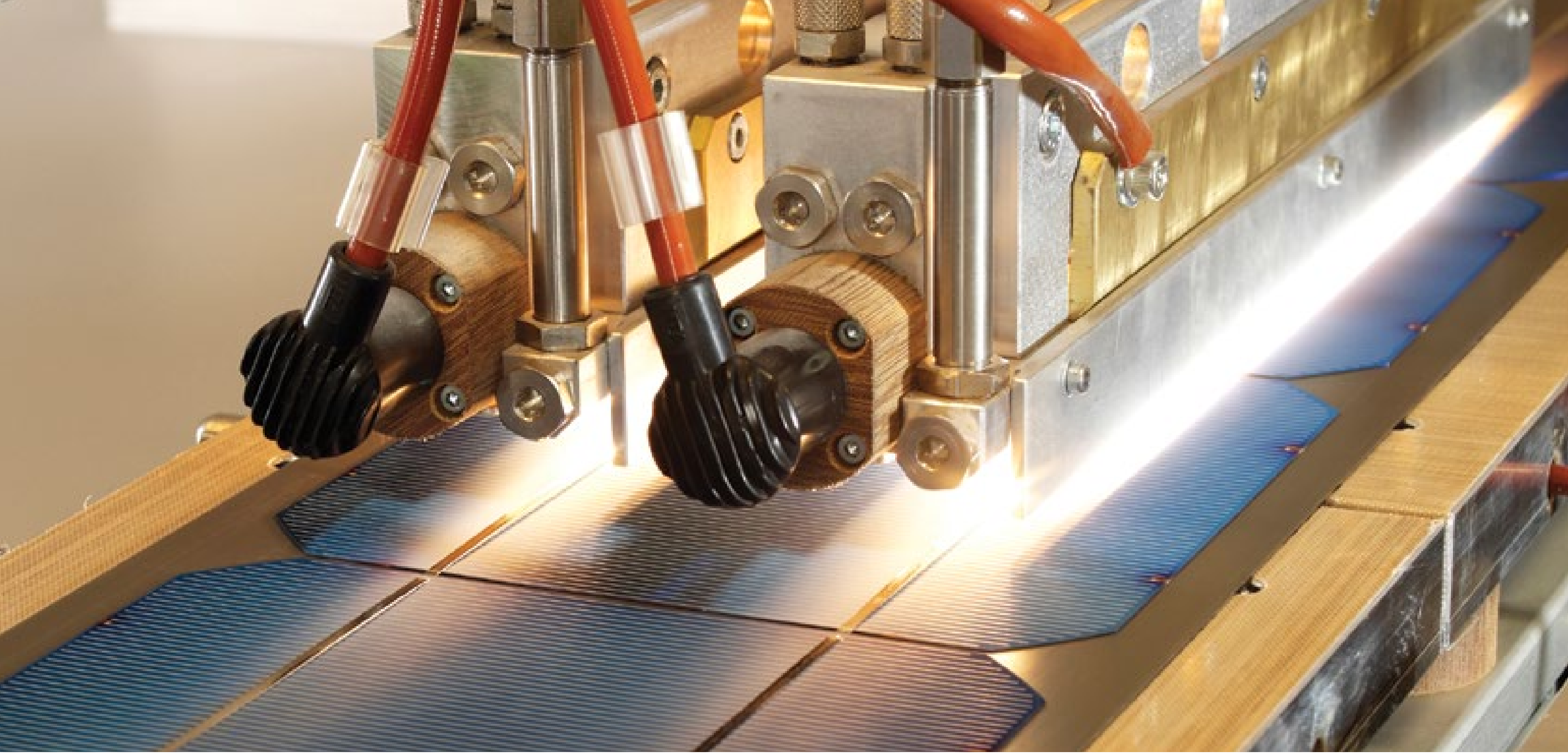
In 2021, machine vision is a key tool that manufacturers use to improve product quality and production efficiency while increasing the pace of product to meet demand. The challenge is detecting these tiny imperfections that are not yet problems, but will cause failures, yield reduction, and material damage down the road.

CCD- and CMOS-based cameras have been long used to for microcracks on the assembly line. Even with cooled sensors, these system can require long integration times in very dark conditions, slowing down the production line and introducing additional complexity. The latest high resolution, high speed linescan and TDI cameras now find extensive use in solar panel manufacturing.

Indium gallium arsenide (InGaAs) detectors are sensitive to NIR/SWIR wavelengths where the silicon substrate (by far the most common) becomes transparent, reducing light scattering is reduced. Manufacturers will typically apply voltage to the cells to make imaging easier: silicon and other photovoltaic cell materials will emit light that the IR sensors can reliably see, even at video rates. This helps manufacturers spot flaws in the top layers – from the optical layers down to the photodiode junctions in the cells.



Imperfections in the glass can lead to weaknesses to environmental hazards such as hail and debris.



Solar panel inspection

For example, IR imaging can detect temperature differences between parts of the module or between modules. Broken junctions cause inactive areas – and because they are not converting energy to DC power as designed, they produce more heat, slightly raising the temperature of that specific area enough for a camera to see. These are the kinds of defects that could lead to hotspots, decreased performance, and even fires years later.

This kind of scanning can also help identify cells that meet certain efficiency levels, allowing them to be matched with similar cells. This ensures that single cells are not holding back the power output of the whole module or panel.

No matter the type of imaging used in inspection, system performance is an important determinator of the success of the system – in terms of both speed and accuracy. Higher pixel counts, better contrast, dynamic range, lower noise, quantum efficiency, higher speeds, and precise system installation translate directly into better quality control and feedback on the manufacturer line.

FUTURE DEVELOPMENTS

There remain many directions that future developments can go. Cost and reliability will certainly lead among concerns. Both factors can go hand-in-hand, which is why the US government is funding in research to more double the expected lifespan of solar panels, which currently sits around 25 years.

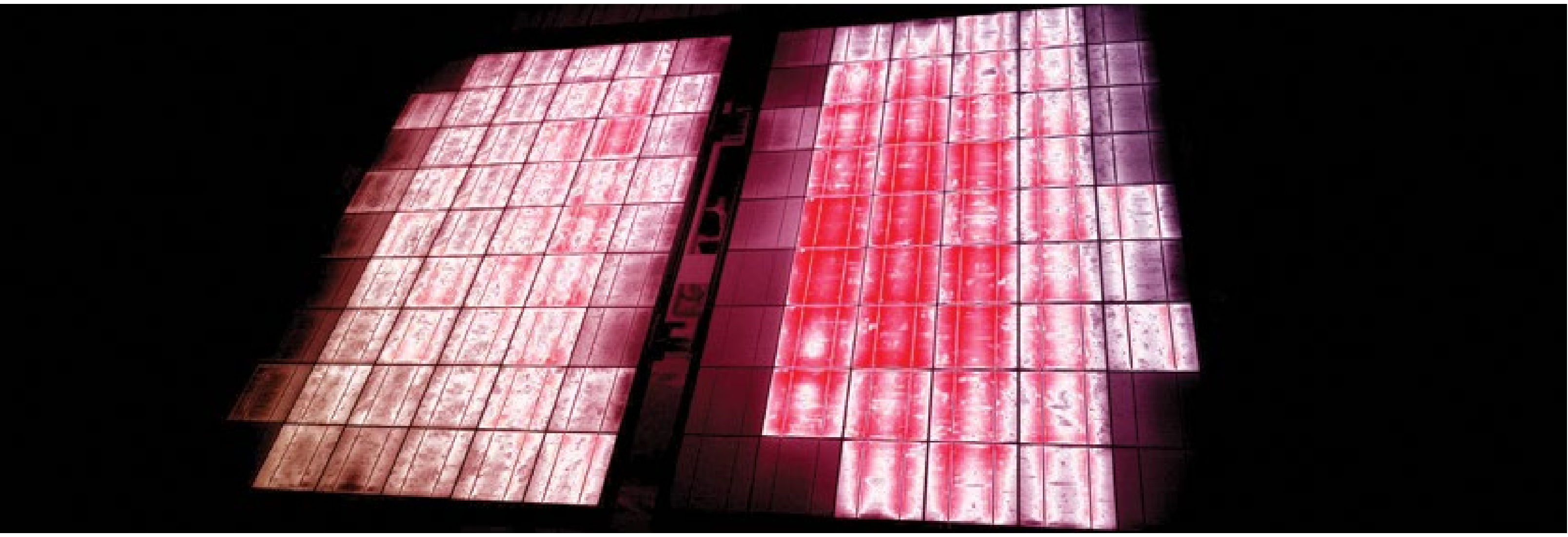
New materials offer opportunities, as well. Today almost 90% of solar panel cells are made from crystalline silicon, but that might be changing soon. Organic photovoltaics panels are particularly promising – the base materials are abundant, and chemical synthesis is simpler. They are also much lighter, opening up new possibilities for placement. They could even be printed! While they have yet to meet the performance levels of tried-and-true technologies, it seems that they could represent the future of solar panels. Compared to crystalline silicon solar module, which has an emission spectra peak at 1150nm, organic cells peak at slightly longer SWIR wavelengths (1200nm – 1400nm).

Climate change will continue to drive and shape solar demand in surprising ways. In Australia, aging fossil-fuel infrastructure has helped retail electricity prices to nearly double since 2005. In California, rolling blackouts to prevent forest fires affect most of the state in the summers. In Texas and Puerto Rico, extreme weather events damaged infrastructure and called into question the reliability of the whole electrical grid. In response to all of these events, both companies and individuals have driven a surge of interest in solar-driven systems that can fill the gaps created.

As old problems are solved, new ones arise. The result is a dynamic industry with enormous long-term potential. While it might be said for almost any industry, it is more true for solar power: it could make the world a better place.

SCAN
FOR MORE
INFORMATION

Improving Solar Panel Inspection
with Infrared Imaging



A night-time electroluminescence image of solar panels. *Image via the International Energy Agency*

INFRARED AND ELECTROLUMINESCENCE IMAGING CAMERAS ARE BEING USED ON TRIPODS AND AERIAL DRONES TO INSPECT MASSIVE FIELDS OF PHOTOVOLTAIC MODULES. INTERNATIONAL ENERGY AGENCY.

BY Possibility Editorial

In 2019, about two percent of the world's total electricity came from photovoltaic solar panels. In the United States, about 3.27 percent of electricity was generated by photovoltaic cells, and solar accounted for 4.37 percent of the United Kingdom's electricity.

Compared with twenty years ago, these are impressive numbers. But the transition from fossil fuels to renewable energy sources can't go fast enough. Solar power energy production is going to have to accelerate drastically within the next few decades if the world wants to cut carbon emissions and mitigate worst-case climate change scenarios. Photovoltaic (PV) modules—solar panels or cells—are not a low maintenance method of energy production. While the panels just sit in the sun gathering energy, the largest solar farms in the world require continual monitoring, calibration and repair. The largest solar power plant in the U.S. is called Solar Star and resides in the Mojave Desert in Rosamond, California, about an 80-mile drive north of Los Angeles. The 579-megawatt plant consists of 1.7 million solar panels spread across 13 square kilometers. Manual inspection of each panel across such a large space would require a prohibitive amount of effort.

Instead of manual inspection, companies are turning to automation to ensure panels are receiving light at peak efficiency. An aerial drone equipped with infrared or electroluminescence cameras combined with machine learning algorithms can cut inspection time in half.

USING INFRARED TO INSPECT PHOTOVOLTAIC MODULES

Imagine a flat screen television. A picture is emitted from the screen through its pixels, tiny areas of illumination that make up its surface area. When the television is in use, those pixels heat up, theoretically in a uniform way across the screen. If you wanted to inspect the performance of those pixels, you could use an infrared camera and determine if some of the pixels are operating at different temperatures.

Photovoltaic modules operate in a similar way. Given clear and consistent conditions, all the cells within the solar panel should heat up in the same way. Anomalies in the heat output from the surface area of a solar panel could be the sign of a faulty diode or another problem within the system. Infrared thermography (IRT) can detect these heat fluctuations and help engineers determine the source of the problem.

According to a 2018 report (PDF) from the International Energy Agency (IEA), common thermal abnormalities that can be measured with an IR camera in photovoltaic power plants include:

- Hot spots caused by breakage or glazing of the panel's glass; external shading such as from a nearby tree or bird dropping; or internal cell problems introduced in the manufacturing, transportation, or installation process.
- Heated bypass diodes caused by the module's junction box.
- Heated fuses within the combiner box of the PV module.
- Heated DC and AC cables and connection points. Light energy is captured in direct current form and must convert to alternating current before being introduced to the power grid.

Temperature gradients under 10 degrees Celsius are not considered problematic. Gradients over 20 degrees Celsius can cause degradation of a panel's output.

As part of the Net Zero Energy Installations (NZEI) initiative, the United States Air Force Academy installed a 6 megawatt solar power system to provide up to 15% of the base's electricity needs.

According to the IEA, the primary requirements for an IR camera for PV module inspection include:

- **Resolution:** lower class cameras will have a resolution of 160 x 120 pixels while professional class cameras will have a resolution of 640 x 480.
- **Thermal sensitivity:** is the granular measurement of heat. Lower end cameras will have a sensitivity of >70 mK while professional class cameras will have sensitivity of 50 mK or better.
- **Accuracy:** Professional cameras will have accuracy of plus/minus 1 degree Celsius.
- **Visible light digital camera:** IR camera systems should also be equipped with a digital camera with up to five megapixels resolution to take pictures of abnormalities.
- **GPS recording:** to add location metadata to each IR image.

The Teledyne DALSA Calibir GX series of IR cameras fit many of these requirements, with resolutions of 320 x 240 or 640 x 480 pixels. They can measure temperatures from -25 to 600 degrees Celsius and can cover the longwave infrared range of 8 – 14 microns, with a temperature accuracy of plus/minus one 1 degree Celsius.

How Electroluminescence Imaging is Used in Photovoltaic Inspection

Electroluminescence (EL) is the phenomenon in which a material emits light when applied with an electric current. When using electroluminescence imaging to inspect a solar panel, the photovoltaic module must first be applied with an electric current and then be imaged with a camera that is sensitive to the light wavelength of the material being observed (commonly a type of crystalline silicone). Electroluminescence imaging looks for defects within a PV module such as cracks, short-circuited cells, shunts or layer defects.

Electroluminescence imaging works best in low light situations and is typically done indoors during the inspection period after the manufacturing of a PV module, or outside in evening or nighttime scenarios. The camera needs to be perpendicular to the PV module and as close as possible, either with a special tripod or an aerial drone that can get very close to the inspection area. Electroluminescence imaging cameras tend to come with a Charge Coupled Device (CCD) or Complementary Metal Oxide Semiconductor (CMOS) sensors.

Electroluminescence imaging cameras can range from sophisticated devices with onboard cooling components, to modified consumer-grade DSLRs. Line scan and area scan cameras—including the CMOS-equipped Linea family of line scan cameras from Teledyne DALSA—are also used to inspect photovoltaic modules.

According to the IEA, the primary requirements for an EL imaging camera for PV module inspection include:

> Electroluminescence imaging cameras for PV module inspection include a CMOS sensor with Resolution >1 megapixel on the lower end to 5 megapixels for professional grade imaging.

Continued Growth for Renewable Energy

The U.S. Federal Energy Regulatory Commission (FERC) noted in autumn 2020 that the country's total available installed generating capacity included about 23.2 percent from renewable energy. About 63.3 percent of the new capacity added in the first two-thirds of 2020 came from renewables. Power from coal continues to fall (about 20.1 percent), with the reminder of generating capacity largely coming from natural gas.

Solar is a large part of that mix. The generating capacity of wind and solar combined was 13.3 percent, a figure that does not include residential rooftop solar, which is a rapidly growing market in its own right.

According to FERC, renewable sources of energy will grow to 27 percent of the country's capacity by 2023, led by new wind and solar installations.

The opportunity for green energy to grow is boundless . . . and necessary. The evolution of the power grid will require the development and maturation of new supply chains and processes, such as the increase in production of lithium-ion batteries, and quality assurance procedures, like making sure that solar panels are operating at optimal efficiency.

SCAN FOR MORE INFORMATION

An offshore wind turbine field near Copenhagen. Image via Wikipedia

How Thermal Imaging Can Help Prevent Wind Turbine Failures

THERMAL IMAGING VIA AERIAL DRONES CAN BE USED FOR PREVENTATIVE MAINTENANCE ON WIND TURBINES, DETECTING FAILING COMPONENTS BEFORE THEY BREAK.

BY Christian Loeb & Uwe Pulsfort

When seen from a distance, wind turbines appear to be no bigger than large trees. Majestically turning their blades in the breeze, providing us with abundant clean and renewable energy.

But if you stand up close to a turbine, you realize that they are massive machines, often the equivalent of a 32-story building from the base to a blade at the apex of its rotation. The blades can be up to 120 feet long and move between 10 and 20 revolutions per minute. These majestic machines are serious business with each blade on the turbine costing up to a million dollars.

Thus, keeping turbines in good working order is essential for efficient energy production, but also the safety of anybody in a turbine's immediate vicinity.

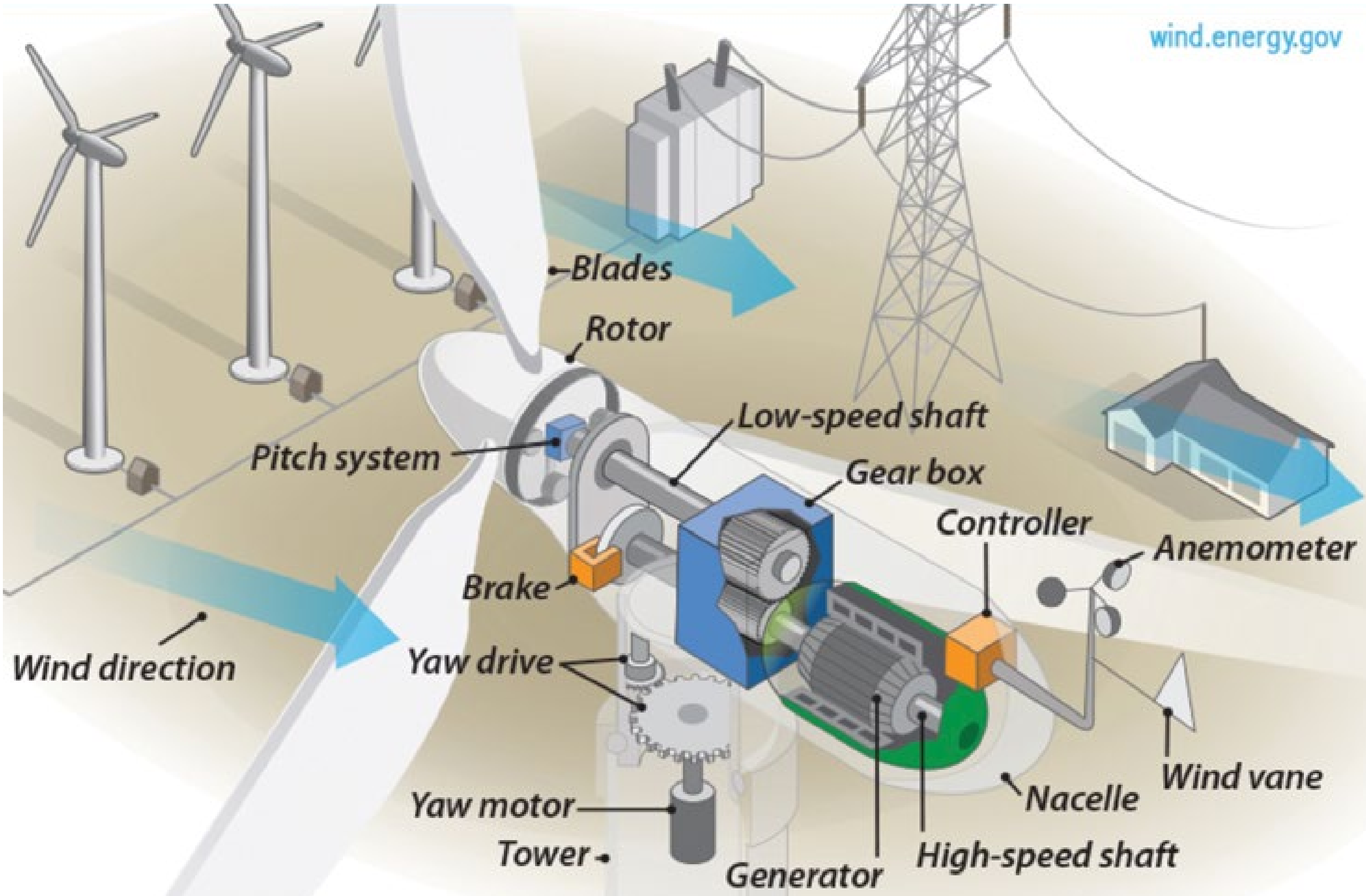
If the blades of a turbine become damaged, or spins too fast because the brake or gear mechanisms are damaged, a blade can snap from the turbine and cause significant, life-threatening damage.

The old method of inspecting turbines involved a team of people climbing up the tower and dangling down the sides of the blades for manual visual inspection. The process could take three days to inspect one turbine, a period when the machine is not producing energy. These days the process is not so onerous with the combination of thermal imaging equipment and aerial drones allowing engineers to inspect a single turbine in less than an hour.

WIND TURBINE COMPONENTS HEAT UP BEFORE THEY FAIL

A general rule for machines is that components will increase in temperature when they are about to break. For instance, a lightbulb will burn brightly for a moment before it burns out, or a photovoltaic cell will increase in temperature if it's operating inefficiently. In a machine with moving pieces, increased friction creates heat that could be the first sign that a part is about breakdown.

Wind turbines are simple machines. In addition to the long tower and the blades, a turbine's basic components consist of a gearbox, a controller, a brake, a generator to produce electricity, a yaw drive and motor (used to keep the turbine facing into the wind), and low- and high-speed shafts.

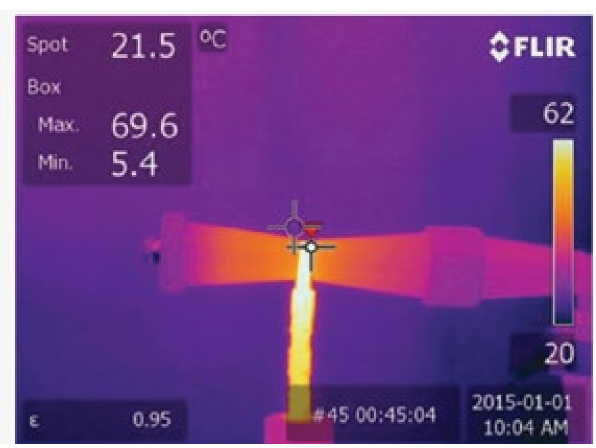


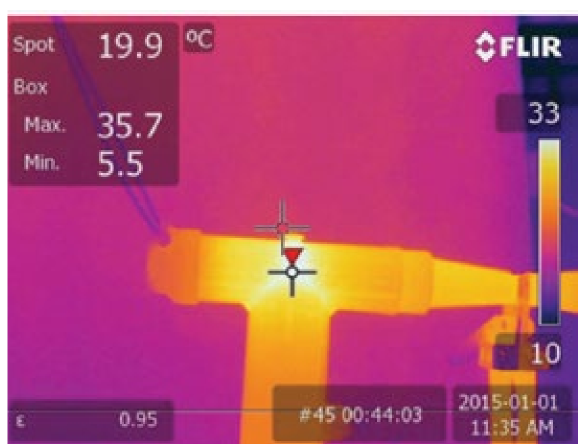
Above: The components of the average wind turbine. *Image via the U.S. Department of Energy*

An aerial drone equipped with thermal imaging equipment can detect these tell-tale heat signatures before a component breaks down entirely, causing the wind turbine to be out of commission for an extended period of time.

In the example below, a defect was purposely introduced into a dead break elbow termination of a wind turbine and then measured against that same termination with a shielding boot installed. The termination was subjected to 100 amperes of electric current for 15, 45, and 75 minutes and examined with thermal imaging equipment.

Below: A 45-minute test of dead break elbow termination applied with 100 amperes of current. On the left, the bare connector registers at 69.6 degrees Celsius. On the right, the shield boot registers at 35.7 degrees Celsius. *Image via FLIR*





Thermal imaging can also be used to detect defects within turbine blades. The blades are made from composite materials and are subjected to stress during the manufacturing, transportation and operation. Cracks can develop in the blades, which can affect the efficiency of the turbine and lead to potentially dangerous accidents. Defects in the blade can change its thermal signature, which can be thermal imaging, even while the blades are in motion. Thermal imaging can detect possible defects, such as splits or internal problems, that wouldn't register with a manual visual inspection.

THE BENEFITS OF THERMAL IMAGING FOR TURBINE PREVENTATIVE MAINTENANCE

An offline turbine is a turbine that is not creating electricity. An average wind turbine can generate enough electricity in 94 minutes to power an average home in the United States for a month. Downtime for turbines can be costly and put strain on the rest of the power grid.

Thermal imaging for preventative maintenance of wind turbines can allow operators to repair or replace components before a failure occurs, while also detecting exactly where the problem is occurring. Over the course of its lifetime, operating and maintenance costs can make up 20 to 25 percent of the total cost of electricity produced by the turbine. Thermal imaging via aerial drone is quicker than manual inspection, requiring no direct contact with the turbine, while also scanning large areas.

The U.S. Federal Energy Regulatory Commission (FERC) predicts that renewable energy sources such as wind and solar generate 27 percent of the country's electricity by 2023. Investing in preventative maintenance will allow renewable energy sources to scale more efficiently in the coming decades as the power grid continues to move away from fossil fuels.

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GREEN ENERGY

ESG: Enabling A Better Future with Technology

ENVIRONMENTAL, SOCIAL, AND GOVERNANCE IS ABOUT CONSIDERING THE BIGGER PICTURE FOR A BETTER FUTURE. TELEDYNE TECHNOLOGIES ARE HELPING COMPANIES AND GOVERNMENTS SEE WHAT'S NEXT.

BY Possibility Editorial

Often ideas are not even doubted until the very moment they are proven categorically false. The "black swan theory," popularized by essayist and statistician Nassim Nicholas Taleb, is based on an ancient European saying that presumed black swans did not exist — a saying which was reinterpreted when Dutch explorers found them in Australia more than a thousand years after the phrase was first popularized.

The theory attempts to explain the disproportionate role of high-profile, hard-to-predict, and rare events that are beyond the realm of normal expectations in history, science, finance, and technology. Such events, considered extreme outliers, collectively play much larger roles than regular occurrences.

Does it seem that 'once-in-a-century' events are happening quite frequently lately? Think of a not-so-hypothetical: a market bubble, or an invasion, a once-in-a-century weather event, or a global pandemic.

The practical aim is not to attempt to predict events—they are (by definition) unpredictable. Instead, the solution is to build resilience to negative events while still exploiting positive events. In the world of business and finance, one way to do that is by taking a larger view and considering more information when evaluating markets, risks, and opportunities.

CONSIDERING NEW FACTORS FOR BETTER PERFORMANCE

What should be considered in the larger view? One of the most popular approaches is what is known as environmental, social, and corporate governance (ESG) investing, which relies on independent ratings that help assess a company's behavior and policies when it comes to environmental and social impact as well as how the company is run. That can expand to analysis of how a company serves not just shareholders but stakeholders: workers, communities, customers, and the environment.

Global markets are taking a deeper look at this information as way to better predict long-term value creation in a business. There's evidence that ESG information can better predict which companies can adapt and even thrive under hard-to-predict events: industry, regulatory and market shifts, new technologies, climate change, social and legal changes, and even pandemics. For example, S&P Market Intelligence found that ESG funds outperformed their index in the first year of the COVID-19 pandemic.

ESG investing appears to provide downside protection, especially during a social or economic crisis. Corporate sustainability initiatives appear to drive better financial performance due to mediating factors such as improved risk management and more innovation, especially over the longer term. Robust ESG strategy and reporting enable companies to strengthen their narrative on the journey toward long-term value and sustainability.

ESG-ENABLING TECHNOLOGIES

How do scientists and engineers study climate change and predict weather? How can organizations develop new products and services that will succeed in future conditions? How can governments plan infrastructure, develop policies, and monitor compliance? In many cases, they are Teledyne's products that make sustainable environmental efforts, research, policy and information services possible.

Across dozens of companies, Teledyne has become a key player in environmental instrumentation and imaging solutions for earth science and carbon monitoring, ambient air quality monitoring, instrumentation for ocean science and climatology, measurement of key environmental parameters, and the manufacturing of key green technologies like rechargeable batteries, hydroelectric dams, windmills, and solar panels.

CARBON MONITORING AND ENVIRONMENTAL AND CLIMATE SCIENCE

NASA has confirmed that extreme weather events are increasing. High-quality measurements are required to best understand how our climate is changing, and how to take action. Global measurement from space is proven to be one of the most cost-effective and comprehensive tools for studying climate change and the effects of human activities. Specialized image sensors are the "eyes" of orbital satellites that can monitor the earth's atmosphere, continents, and ocean surfaces from space.

Teledyne's high-performance imaging sensors are playing a big part in this effort.

For example, the TRUTHS (Traceable Radiometry Underpinning Terrestrial- and Helio-Studies) mission will, for the first time, enable high-accuracy traceability of climate data and allow for the creation of a robust, space-based, top-of-atmosphere climate observation system. Its primary goals are to provide measurements for incoming and outgoing solar radiation between the earth and the sun, and to act as the primary calibration and bench-marking tool for orbital imaging and observation. Launching in 2026, TRUTHS will use short-wave infrared sensors from Teledyne e2v to drive its Hyperspectral Imaging Spectrometer (HIS) to monitor the solar radiance spectrum.

Greenhouse gases are just one aspect of atmospheric measurement. Also important is the radiation budget of the Earth — that is, how much

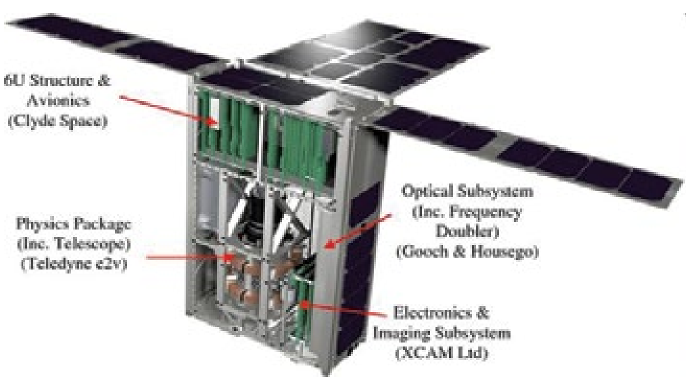
An artist's rendition of TRUTHS satellite mission. With high-performance sensors of unprecedented accuracy, the mission will test and advance the development of climate models, allowing more accurate climate change forecasting.
Image courtesy of NPL.

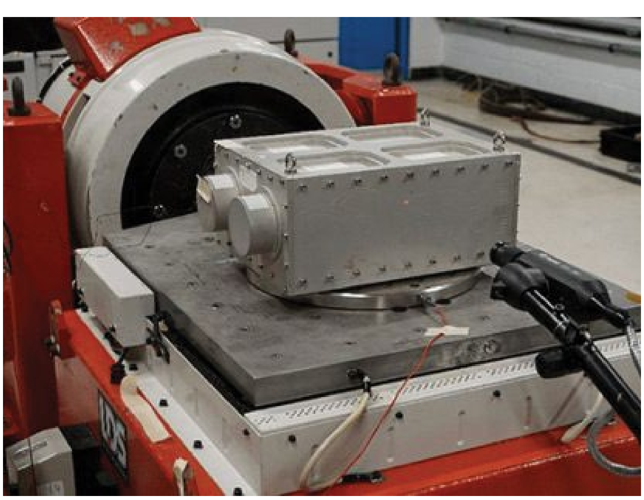
radiation is received from the Sun and how much is re-emitted to space. Imbalance in the radiation budget can cause global warming.

A new NASA Earth science mission planned for launch in 2024 may achieve a transformational advance in our understanding of the global carbon cycle by mapping concentrations of key carbon gases from a new vantage point: geostationary orbit. The Geostationary Carbon Observatory (GeoCarb) will use a grating spectrometer to collect 10 million daily observations of the concentrations of carbon dioxide, methane, carbon monoxide and solar-induced fluorescence (SIF) at a spatial resolution of about 3 to 6 miles (5-10 kilometers).

THE COLD ATOM SPACE PAYLOAD

(CASPA), is being led by Teledyne ev2 with partners including the University of Birmingham as science lead, XCAM, Clyde Space, Covesion, Gooch & Housego, and the University of Southampton. In space, cold atom gravity sensors could be used to carry out Earth observation to detect and understand mass transport processes which could lead to significant breakthroughs in our knowledge of and ability to monitor key components of the Earth system such as sea level, ice sheet melting and aquifer depletion.





The effect of changes in the Earth's climate is reflected (literally) in the light from plants. NASA's ECOSTRESS instrument on the International Space Station and NASA's Surface Biology and Geology (SBG) mission depends on Teledyne's visible-infrared sensors. ESA's Copernicus Hyperspectral Imaging Mission for the Environment (CHIME), which is similar to NASA's SBG mission, also will use Teledyne's advanced visible-infrared sensor

While all these missions are filling gaps in our understanding of climate science, next generation instruments are required. Teledyne is at the forefront in development of sensors for the next generation LandSat, next generation GOES, and new constellations of weather satellites.

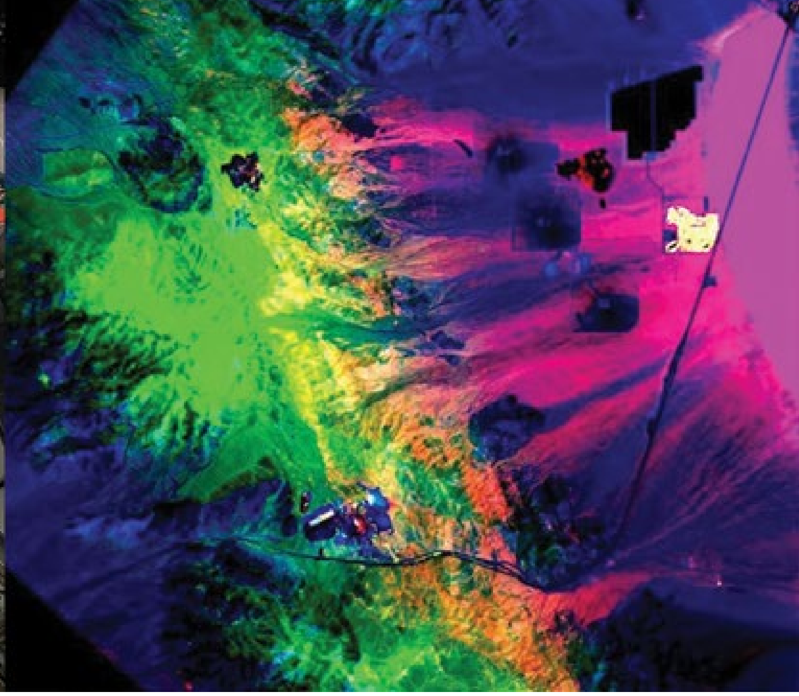
TACKLING GLOBAL PLASTIC CHALLENGES

Although plastic has only been around for 60 years, it has become inseparable from how we live our lives. One of the largest issues with plastic waste is that the majority of it is intended for single-use, causing many people to throw. 91% of plastics are not recycled, ending up in landfills, or worse, our oceans.

Today marine plastic debris is one of the most significant threats to oceans, preventing sunlight penetration that harms plant and algae life-cycles. Enormous aggregate points for trash and pollution form around natural circulation points in the ocean currents called "gyres". Understanding marine plastics is a challenge due to the remoteness of these sites.

Teledyne and The German Aerospace Center (DLR) are working together to bring imaging to help study marine plastic accumulation and clean up the world's oceans. It is now possible to collect imagery that reveals the composition and density of these debris fields. With the use of the DLR Earth Sensing Imaging Spectrometer (DESIS) sensor aboard the Teledyne Multi-User System for Earth Sensing (MUSES) pointing platform on the International Space Station (ISS), coupled with the ocean current model General NOAA Operational Modeling Environment (GNOME), investigators will be able to both predict the location of and characterize these collection points. This will allow scientists to study the extent, monitor changes, and plan mitigation actions for the accumulated debris in these areas.

Top: Model showing the layout and design of the 6U (approximate dimensions: 100 × 200 × 300 mm) cube satellite with solar panels deployed.
Bottom: Photograph of CASPA being vibration tested (X axis test) in Teledyne e2v's environmental test facility in Chelmsford.
Images courtesy Devani, D., Maddox, S., Renshaw, R. et al.



The DESIS hyperspectral imager, operating on the International Space Station, has been acquiring imagery since October 2018. DESIS is a "pushbroom" sensor with 235 bands in the visible through near-infrared spectral region and a 30 m ground sample distance.

DESIS is supporting resource and environmental monitoring and has collected over 125,000,000+ square kilometers of hyperspectral imagery of Earth. TBE has distributed DESIS data to 450+ customers and organizations to support business and research.

Space-based sensors are complimented by a variety of airborne instruments that focus on high resolution measurement of targeted areas. The Ocean Cleanup's aerial expedition used a combined LIDAR-Hyperspectral-RGB imaging solution from Teledyne Optech to gain a greater understanding of the depth and width of the debris polluting our oceans. It's considered the most efficient airborne bathymetric mapping system on the market, and uses lidar to sense what more conventional imaging systems can't.

The Teledyne Optech CZMIL Super Nova is a coastal and marine mapping system that can find objects 80 metres below the ocean's surface and produce high-resolution 3D data with its laser function, hyperspectral imaging and digital metric camera. This three-pronged approach collects information at a rate of 70,000 measurements per second, generating results with a very high degree of accuracy.

The sensor results, combined with other data will feed into the engineering behind the group's upcoming cleanup projects, where a v-shaped 100 kilometer-long floating barrier will act as an artificial shoreline. The barrier will move with the ocean's natural currents, collecting and concentrating the ocean trash for easier cleanup while minimizing harm to ocean life.

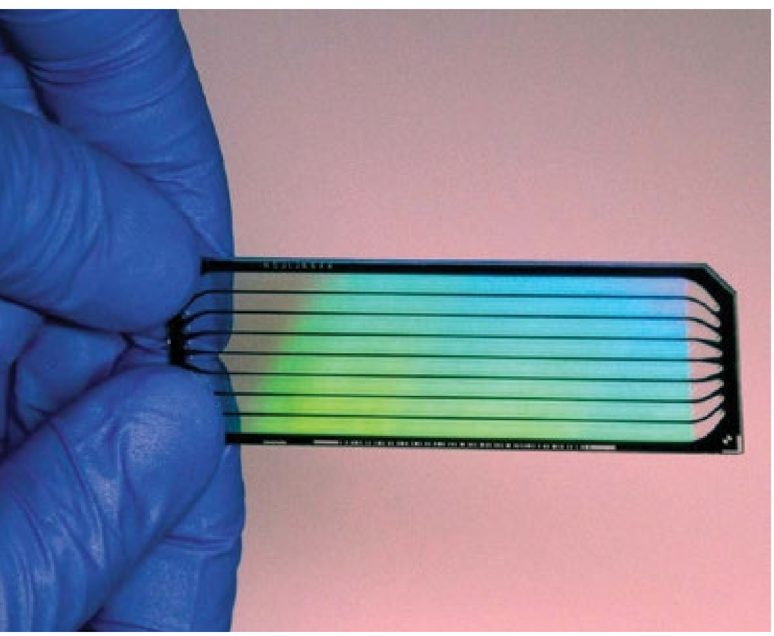
Teledyne DALSA also has a variety of vision solutions that are being used to help sort plastic, reducing costs of recycling and improving efficiency, and ultimately, keeping it out of our landfills and oceans. Line scan cameras are extremely useful in visible spectrum sorting where a machine vision solution that is able to distinguish between plastics and glass. Other solutions use hyperspectral imaging to sort recyclables, identifying the subtle differences between different types of hydrocarbons in paper, cardboard, and plastics.

Known as the "workhorse" of military planes, this C-130 Hercules will function as a flying scientific laboratory. Equipped with the a hybrid imaging system it flies low and slow to capture a broad surface area at extraordinary levels of detail.

With nearly 50 different types of plastics, everyone will need to work together toward reducing and eliminating the effects of plastic on the Earth. Plastic sorting enables efficient recycling, resulting in reduced costs and lowering greenhouse gases and toxins in our atmosphere. To learn more about sorting plastic using machine vision, see our other articles on the topic.

TRACKING THE PANDEMIC AND PROTECTING POPULATIONS

Throughout the COVID-19 pandemic, scientists and industries have turned to Teledyne vision solutions to fight back. Thermal imaging solutions helped authorities screen for fever symptoms in key locations like airports, factories and medical facilities. Imaging-based genome sequencing helped scientists track the virus and understand its mutations over time.



A technician holds a DNA sequencing flow cell at the Cancer Genomics Research Laboratory, part of the National Cancer Institute's Division of Cancer Epidemiology and Genetics (DCEG).

The NASA COVID-19 Dashboard features imaging data collected by a variety of earth-observing satellites and instruments aboard the International Space Station which carry Teledyne technology. The global maps are searchable by several categories of observable change, including economic indicators, such as lulls in shipping and construction activity, and environmental factors, such as water quality and climate variations, helping scientists study the pandemic's effects on the Earth system.

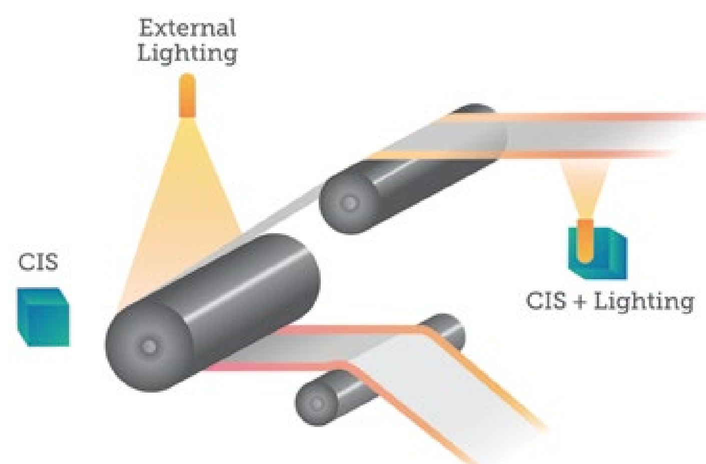
MAKING GREEN TECH SAFER AND MORE SUCCESSFUL

Wind turbines are massive machines, often the equivalent of a 32-story building from the base to a blade at the apex of its rotation. Keeping turbines in good working order is essential for efficient energy production, but also the safety of anyone in a turbine's immediate vicinity.

With the help of aerial drones equipped with thermal imaging equipment, these turbines can be examined in an hour instead of days. Cameras can detect the tell-tale heat signatures of material stresses long before a component breaks down entirely, causing the wind turbine to be out of commission for an extended period of time.

The transition to green energy in the coming decades will require a commensurate increase in battery production and innovation. Lithium-ion batteries will be the workhorse of a green energy revolution in the near to medium future, storing power for nearly everything, from electric vehicles and eventually airplanes, to homes and commercial buildings.

While lithium-ion battery production may be conceptually simple with coated electrode stacked sheets and an electrolyte solvent, the actual process is fairly complicated and sensitive. The thickness of the coatings on the electrodes can have a significant effect on a battery's performance or even its stability. Line scan cameras—such as the Linea family of cameras from Teledyne DALSA—are backed by machine learning algorithms that help automate and streamline the quality assurance stage of lithium-ion battery manufacturing.



Teledyne linescan cameras, contact image sensors, and 3D laser profiles can all be used for inspecting electrode sheets.

Solar panel manufacturing is similarly important, and faces many of the same challenges. Automation and inspection are both critical to high-quality, consistent, and high-throughput solar panel products. There are delicate components and multiple layers, all requiring precise placement and alignment. Material handling, cell cutting, and component bonding are all very automated in modern factories, but an error in any one of them risks lower initial performance, and shorter operational life for each solar panel.

This makes inspection crucial. End-of-line testing of electrical parameters like current voltage and peak power rating ensure that panels perform at expected standards. Imaging allows us to look for quality issues, such as cracks and misalignments that indicate initial quality, but also longevity of the panel itself in the field.

SO MUCH MORE THAN IMAGING

Teledyne's imaging solutions reach deeply into the efforts we're making to both understand and tackle our most daunting global challenges. And it doesn't stop at imaging. Teledyne companies also produce a wide range of air and water monitoring instruments, including autonomous systems that profile the world's oceans. Teledyne's product portfolio also includes sophisticated air and water quality monitoring instruments to help keep the air we breathe and the water we drink clean. The companies design, produce and distribute sophisticated air quality instruments that measure hazardous gases and particulate matter in real-time. They also have products designed to improve the efficiency of motors, motor drives and industrial automation systems to reduce energy consumption.

To learn more about the future vision and global scope of Teledyne's ESG-related efforts and solutions, download the 2022 Teledyne Technologies Corporate Social Responsibility Report, where they have compiled a global inventory of their emissions as well as their ESG and sustainability efforts and goals.

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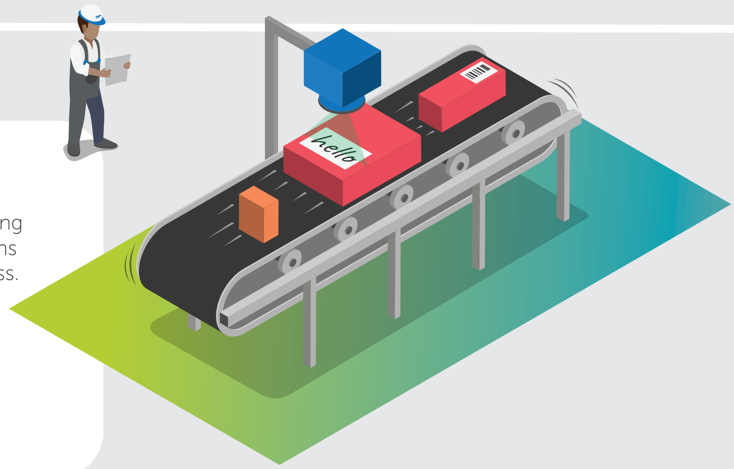
Machine Visi

A Postal and Parcel Logistics



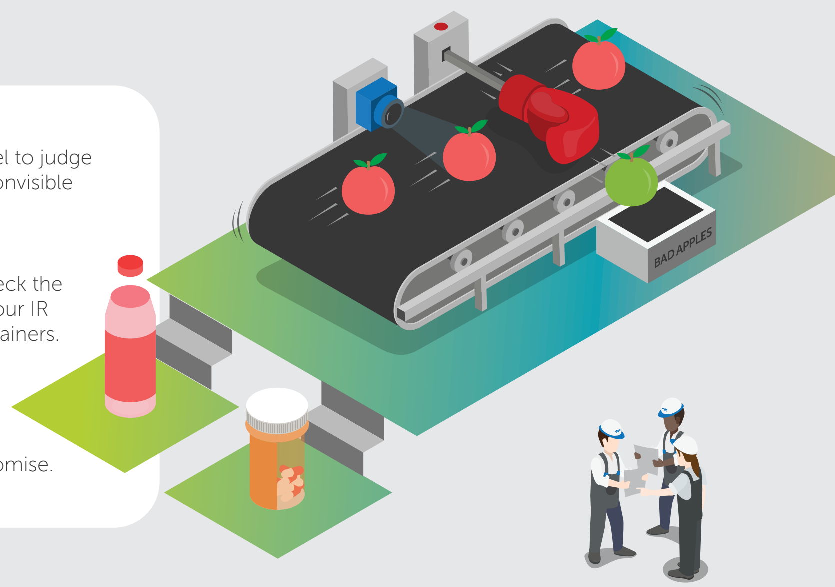
Label and barcode reading for Postal and parcel sorting/handling

The challenge: scan labels and addresses, sometimes handwritten, arriving at different heights and orientations, and at high speed. We offer solutions with the resolution, low light sensitivity, and throughput to power success.

Adaptable image processing

The challenge: compensate for missing, obscured, or damaged areas to allow decoding or OCR. We offer extensive real-time processing with advanced software libraries and easy to use vision tools.

B Food and Medical



Color, NIR, and hyperspectral imaging

The challenge: Take inspection and quality control to the next level to judge the ripeness of fresh fruits and vegetables. We offer solutions in nonvisible wavelengths to reveal hidden bruising or contamination.

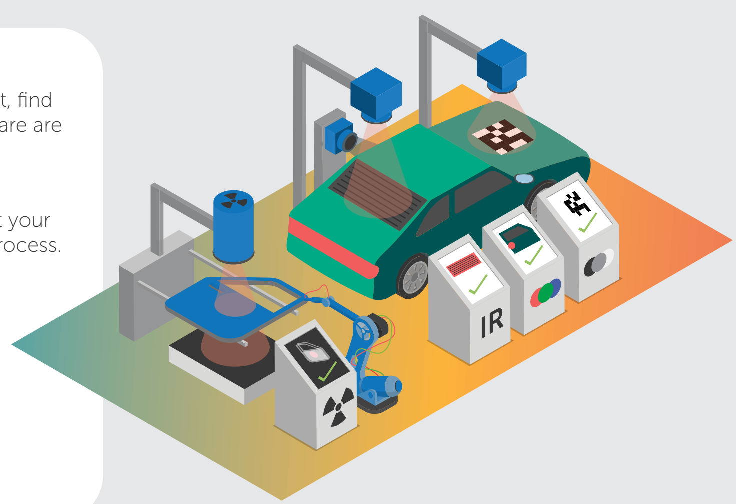
Infrared and X-Ray imaging

The challenge: inspect the invisible. Our infrared solutions can check the temperature of cooked or baked products to ensure food safety; our IR and X-Ray capabilities provide solutions for sealed or opaque containers.

Low-light imaging

The challenge: inspect delicate targets such as medicines or containers without damage from high temperature bright lights. Our low-light solutions deliver inspection success without compromise.

C Manufacturing



Factory Automation

The challenge: track components, measure tolerances, guide placement, find defects...boost quality and throughput. Our cameras, sensors, and software are vital to modern assembly automation.

Component traceability (bar code reading)

The challenge: identify parts and labels to ensure traceability throughout your product's life cycle and verify every step along the changing assembly process.

Component and Weld inspection

The challenge: non-destructive testing and grading of hidden components, assemblies, and welds. Our industrial X-Ray solutions enable amazing NDT insight.

Functional quality control

The challenge: verify appearance and performance. For example, test automotive windshield defrosters by "seeing" their heat with our infrared solutions.

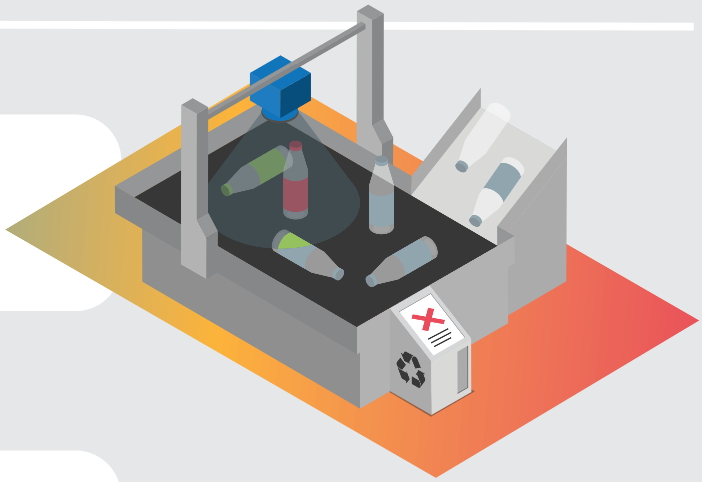
on

We work closely with our customers to develop successful, truly valuable solutions to the challenges of their businesses. Sometimes that means a standard product available quickly,smoothly, and reliably through our global distribution channels. Other times that means a unique,bespoke, never-been- done-before design tuned to the most challenging situations. Every time, we focus on listening to our customers, understanding their needs, and delivering them optimal solutions for competitive advantage.

D Recycling

Multispectral inspection

The challenge: sort recyclable materials not just by color and shape, but by type of material and chemical composition. SWIR, NIR, X-ray, and hyperspectral imaging can identify different kinds of plastics, glass, and paper to enable high speed automatic sorting.



E Electronics

Printed circuit inspection

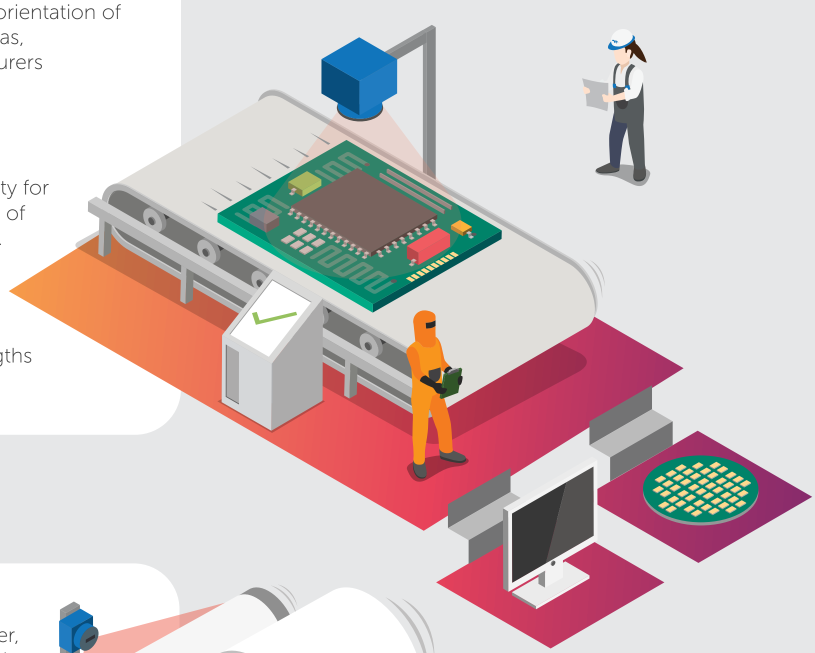
The challenge: Verify and measure the presence, location, and orientation of components, connections, and assemblies. Our sensors, cameras, frame grabbers and software help the world's biggest manufacturers find defects and boost both quality and throughput.

Flat-panel display inspection

The challenge: New generations of thinner OLED displays with higher pixel densities require ever-higher resolution and sensitivity for quality inspection at every step of production. The performance of our vision components and systems has made us world leaders.

Semiconductor inspection

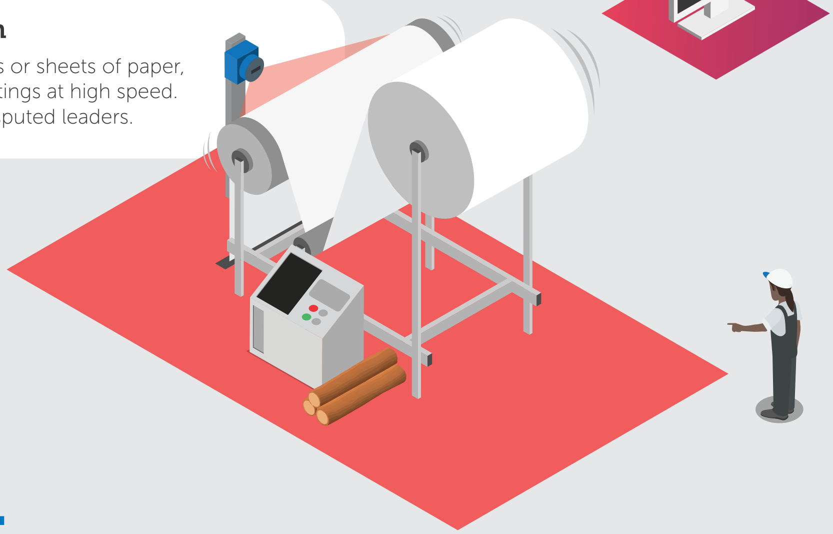
The challenge: leading-edge chipmakers use features so miniscule that visible light can no longer resolve them and inspection systems must use extreme ultraviolet (EUV) wavelengths for illumination. Our solutions are unmatched.



F Continuous Webs

Continuous linescan inspection

The challenge: Find defects in continuous rolls or sheets of paper, textiles, film, foil, plastics, metals, glass, or coatings at high speed. Our line scan solutions are the industry's undisputed leaders.



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