The 2016 Popular Mechanics Breakthrough Awards

The research, innovators, scientists, and students who've made the world a little better this year.

By Popular Mechanics Editors Sep 6, 2016

SINELAB

If you ever need evidence that this is a remarkable time, take a look at a billboard: Buy a car that runs on electricity! Visit the stratosphere in a space baloon! Clearly we live in the future, but it's a future that intends to keep moving. What you'll see here are hints at where we're going—the individual

developments that point in the direction of the next future. We can't wait to see what the billboards look like there.

The Rehab Exoskeleton

GRAHAM MURDOCH

Since DARPA began developing them in 2001, modern exoskeletons—the hydraulic bodysuits worn to enhance a wearer's strength and speed—have

been primarily used by the military. But the medical uses are obvious. In an exoskeleton, a person who has suffered a spinal-cord injury no longer needs a wheelchair. The suits also reduce repetitive-stress injuries when worn by construction crews. And now, they can be used to help stroke patients regain the ability to walk. This year, Ekso Bionics' Ekso GT suit became the first exoskeleton approved by the FDA for treating stroke victims, which means twenty times more patients can be treated. Here's how the GT works.

The benefit of the exoskeleton is that it helps the body find alternative routes to movement, working around muscles with limited function and creating new neural pathways, says Allan Kozlowski, an assistant professor at Mount Sinai's Icahn School of Medicine (who uses the GT in physical therapy with his patients).

A technology called Variable Assist allows Ekso to read how hard the suit is working to support the patient. A therapist reads this information, then adjusts the controls to personalize.

In contrast to other types of exoskeletons, the GT's motors can be individually controlled. If one side of the body works well on its own, as is the case with many stroke patients, the suit can leave it alone.

Backpack

The backpack holds the GT's batteries and also provides trunk support so users don't need walkers or arm supports to remain upright.

Seat

A patient sits in the suit as he would in a chair, fastening Velcro straps around his legs, torso, and feet. A therapist initiates the sit-to-stand

procedure, then controls the patient's movements using a Nintendo-like device on the back of the suit.

Knobs

The legs and torso are adjustable to fit nearly any body size.

Straps

Since many patients can't feel skin irritations, which can lead to abrasions, the suit straps are made of custom-sewn Velcro backstitched for maximum comfort.

Materials

The fifty-five-pound Ekso GT is mostly made of aluminum.

Hydroelectric Power—During a Drought

GRAHAM MURDOCH

Hydropower saves the equivalent of fossil-fuel emissions of thirty-eight million passenger cars each year. But it only works where you've got high-pressure water, and there are only so many waterfalls and dammable rivers in the country. Hydropower currently accounts for only 2.4 percent of U.S. energy output, but with a new technology from Alameda, California's Natel Energy, that number will soon rise. Natel's hydroEngine maximizes hydropower by collecting energy in two stages, once when the current enters the turbine and moves the blades up, and once when it leaves and the blades move back down. The engine makes thousands of low-pressure

streams and medium-size rivers viable power sources. So far, Natel has installed its turbines at projects in Oregon and Maine. Soon, there could be one creating power in your backyard, even if it's only big enough for a beaver dam.

HOLOLENS

GRAHAM MURDOCH

How it Works

HoloLens uses a suite of sensors to develop a deep understanding of its environment, so it can then fill it with holograms that look and sound real. (Check out our feature story on the HoloLens here.)

Creating a Map

1. Four environment-understanding cameras create a spatial map of the room.

2. The depth cameramaps the surfaces in the environment, allowing holograms to interact with things like walls and tables in a natural way.

3. The inertial measurement unit—a gyroscope, magnetometer, and accelerometer—tracks head movement thousands of times a second, so holograms appear to stay in the same place even as the wearer moves.

4. The holographic processing unit synthesizes the massive amounts of data coming from the sensors to create a coordinate system that apps use to place holograms.

5. Two pairs ofmicrophones isolate the wearer's voice for speech recognition.

6. An RGB camera captures what the wearer is seeing—both the real world and the holograms.

Deploying Mixed Reality

7. A pair of light engines shoots light through the device's inner lenses and into the eyes, creating holograms.

8. The waveguides—the inner lenses—are three-layer pieces of etched glass that reflect light from the light engines to create holograms that appear in specific locations in the environment.

9. Anambient light sensor measures the brightness of the room so the holograms are projected at the brightness that maximizes their clarity.

10. Spatial sound speakersproject sound into the ears at different angles so that sounds accompanying a hologram seem to come from its location.

HoloLens for Home Improvement

Having spent my professional life explaining mechanical concepts to our readers—as well as staff, friends, neighbors, family members, and folks who come up to me when I'm at the local home center—and having received instructions from experts in return, I can tell you that this new HoloLens from Microsoft fills in the crucial missing links that occur when you're trying to explain something complicated to somebody. Mechanical problems,

electrical work, plumbing—all of this is difficult to talk someone through, especially over the phone. There are variables. Pieces don't fit. Things break. Problems arise because the references you used are wrong or out of date, or you've fouled something up and can't find your way back. Or any number of other reasons. The HoloLens is the next best thing to an expert guiding you through. As the teacher, you can see what your pupil is doing. You can draw imaginary circles in the air around the wire he is supposed to choose—and he can see it! DIY magic, I tell you.

I can foresee a day when you, our reader, calls a Popular Mechanics editor, and we talk you through that faucet replacement, or the woodworking project that we just ran in the magazine, or any other project, because we can both put on our HoloLenses and see what the other person is doing. So, yeah, it's very cool that the HoloLens can let researchers explore Mars as if they were there, but I'm just as excited (okay, maybe a little more) about being able to see your leaky kitchen sink and showing you—live and in person, from a thousand miles away—how to fix it. —*Roy Berendsohn*

The Miner Who Learned to Code

GETTY IMAGES

When the largest coal-mining operation in the U.S., Peabody Energy, filed for bankruptcy in April, joining Walter Energy, Arch Coal, and Patriot Coal, most news reports worried that miners were headed toward low-wage jobs or destitution. But to coal miner Rusty Justice, that idea is absurd. Doctors can split wood and construction workers can write books. Why couldn't a coal miner transition to a different career? He found the stereotype so insulting that he decided to prove it wrong.

Though Justice and his partner M. Lynn Parrish still run a functional excavation company, Jigsaw, they bought a former Coca-Cola bottling plant with the intention of founding an enterprise to help their friends. Their goal: Hire laid-off coal miners and teach them how to code. The new company, which they named Bit Source, sent out a call for applications in late 2014, planning to hire about ten coders and pay them with government grants while they trained. More than nine hundred people applied. Those first ten students have since been through a twenty-two-week program, and the

company has garnered a half-dozen contracts. Bit Source plans to become profitable this year—much faster than a lot of other tech startups.

THE OMNISCIENT TRAIN

Transportation that can stop itself to prevent disaster.

GRAHAM MURDOCH

The deadly Amtrak train crash north of Philadelphia in May 2015 may have been the first time many people heard about positive train control (PTC), a system of controlling trains through sensors built into tracks. But Amtrak and Congress have been trying to implement it for nearly a decade. Problem is: Retrofitting Amtrak's infrastructure takes time and money—more than Congress expected when, in 2008, it gave an initial deadline of 2015, and billions of dollars. This year, as Amtrak continues to update its railways (now to be completed by 2020), California's Sonoma-Marin Area Rail Transit (SMART) will become the first-ever rail line to begin service fully equipped with PTC. SMART uses a fiber-optic network that sends pulses down the entire rail system. Transponders on the bottom of each train pick up those pulses, so that SMART operators can see exactly where each car is on the tracks, and control the train's speed. If a conductor does not slow down within sixty seconds of entering a reduced-speed zone, a computer code automatically halts the train, keeping passengers and crew safe.

A Fat That Saves You From Sugar

GRAHAM MURDOCH

You eat a lot of sugar, you gain weight. Most of us know that. But few of us realize that simple sugars like those found in a can of Coke can also damage thousands of genes in your brain, including those related to Alzheimer's, heart disease, and depression. That's exactly what UCLA professors Xia Yang and Fernando Gomez-Pinilla discovered in May. Luckily they also found some good news: An omega-3 fatty acid called DHA, which is found in fish, including tuna and salmon, reversed the damage.

CHEAPER SOLAR ENERGY

GRAHAM MURDOCH

A solar panel that follows the sun throughout the day makes sense. Building that solar panel out of several thousands of dollars' worth of parts that can't withstand weather does not. In 2011, Leila Madrone and Saul Griffith of the San Francisco–based company Sunfolding decided to reinvent the mechanism that allows a photovoltaic cell to move with the sun. They simplified the system, replacing expensive and unreliable parts with mass-produced polymers. Instead of hundreds of gears, motors, wires, and bearings, Sunfolding trackers move using compressed air pistons, which have no wear surfaces. Even if the new parts break, which happens much less frequently, they are cheap to replace. In 2015, the California Energy Commission awarded Sunfolding a $1 million grant to build panels capable of handling 300 kilowatts. You'll see them on rooftops by the end of this year.

A Faster Vaccine To Halt Zika Transmission By 2018

A DNA vaccine consists of viral DNA and an electrical pulse tha pushes that DNA into the cell nucleus.

GRAHAM MURDOCH

Current vaccine development schedules are the stuff of epidemiologist nightmares. Imagine if Ebola or Zika spread near uncontrollably for ten years while scientists tried to create a vaccine that is safe, effective, and abundant enough to administer to large groups of people.

Inovio Pharmaceuticals, the drug company behind what looks to become the fastest vaccine ever to come to market, may be able to halt such a spread before it gets out of control. The company shocked the medical world in June by announcing that its Zika vaccine had already received FDA approval for human clinical trials, just nine months after the race to prevent

Zika began. If all goes well, its shot will be available to the public as soon as early 2018.

Once inside the nucleus, the vaccine tells the body's own cells to create proteins from the virus envelope.

GRAHAM MURDOCH

Inovio's secret is that it's using a completely new form of vaccination. In first-generation vaccines, a weaker or dead form of the virus triggers your immune system to develop antibodies that could shut down the real virus. Newer vaccines include only outer pieces of the virus—the envelope—that specifically trigger the antibodies. These vaccines are safer, because there's no way for them to copy themselves until they make you sick, but they can take a long time to create in a lab.

The virus envelope proteins (red)
GRAHAM MURDOCH

Inovio's vaccine is a third-generation vaccine, a DNA vaccine. All it contains are DNA instructions to build the virus envelope. "If the Zika virus were a Mercedes-Benz, we're just making the front grille. Everyone recognizes the three-pointed star as a Mercedes, but it's not the actual car," says Dr. J. Joseph Kim, president and CEO of Inovio. The instructions are made out of simple, readily available chemicals. Once a doctor injects the instructions into your arm, your own cells build the envelope. Then your immune system fights the envelope and you're safe from the real virus. It's sort of like outsourcing the work of creating a vaccine to the human body—no long wait times or biohazard suits required.

COMPUTERS THAT UNDERSTAND CONTEXT

Alice drove down the street in her car.

You understand what that sentence means. But a computer might not. Taken literally, it could mean that Alice was driving on a street that existed inside her car.

This May Google released SyntaxNet, software that breaks down sentences into a format that computers can analyze, leading to more accurate searches. Just as you did in eighth-grade English, the software diagrams sentences. After every word is tagged with a part of speech, an algorithm explores possible relationships between the words, with a likelihood assigned to each one. SyntaxNet also learns from itself, getting stronger each time it's used. The algorithm isn't perfect, but it's close. The English plug-in, called Parsey McParseface, reads with 94 percent accuracy. Which might even be better than you.

Fusion's Big Solution

Jetsons-style clean power in real life.
TRI ALPHA ENERGY

Nuclear fusion is a complicated—and expensive—process. The U.S. government sets aside $1 billion a year for nuclear and fusion energy research, resulting in very few critical breakthroughs. But last year, without any of that federal money, a privately funded California company called Tri

Alpha Energy overcame a major obstacle. It figured out how to keep fusion plasma stable.

Nuclear fusion works like this: When two very light atoms bond together, they make an atom that has less total mass than the two that formed it. The missing mass is given off as energy, which can then be captured and used. There are several problems with this. The first is that two atomic nuclei don't want to fuse. They're both positively charged, so they repel each other. We solved this already: If you heat the atoms until they become plasma, they lose electrons, becoming fusible. The bigger problem? The temperature required to make fusible plasma is hotter than the core of the sun. Oh, and it requires immense pressure to force those atoms together. Even if scientists can overcome both of these obstacles, keeping the atoms in the appropriate state long enough for fusion to occur can cost more energy than it creates.

This year, however, Tri Alpha held a plasma stable for five milliseconds—ten times longer than ever before, and much longer than you need to achieve fusion. The plasma wasn't quite at the core-of-the-sun temperature, but CTO Michl Binderbauer is confident it can be done: The temperature barrier is generally considered to be an easier challenge than stability. Binderbauer projects that Tri Alpha will be able to solve the problem in the next three or four years. Seven to ten years after that, it hopes to have a facility that can send electrons to the grid.

Local Motors Self-Driving Bus

GETTY IMAGES

In 2014, car manufacturer Local Motors received its first Breakthrough Award for creating a 3D-printed car. This year, it applied the same technology to public transportation with a 3D-printed, twelve-passenger, self-driving shuttle called Olli. The vehicle was introduced in June in National Harbor, Maryland, and service should begin in Miami by the end of the year. Olli has a thirty-two-mile range per charge and can be used on its own or in a fleet, as a shuttle or a point-to-point alternative to Uber. It all depends on the city and the need. Every Olli on the road is connected, learning from itself and constantly calculating the most efficient routes. And thanks to a partnership with IBM's Watson technology, Olli can interact with its passengers, answering questions about the weather, how long it will be until you reach your destination, and where you might want to grab dinner when you arrive. The only thing it can't do is get you the reservation. Although that can probably be solved in the next software update.

THE COLDEST PLACE IN THE UNIVERSE

SPENCER LOWELL

The latest mind-bending project from NASA's Jet Propulsion Laboratory, the mystical California birthplace of miracles like Jupiter probes and space clocks, is the Cold Atom Lab. It's an appliance about the size and shape of a sideways filing cabinet that is scheduled for launch to the International Space Station early next year. It shoots atoms with lasers and radiation until they get so incredibly chilly that they turn into a rare, strange fifth state of matter, called a Bose-Einstein condensate (BEC). Scientists know hardly anything about BECs other than that the atoms in them behave like waves,

giving BECs properties that could be useful for future miracles like infinite batteries and atom-based lasers.

Lasers are usually hot, but in laser cooling, they counteract the movement of individual atoms, slowing them down by tapping them like bumper cars. A second stage of cooling employs a radioactive wind to blow ″hotter″ atoms away. Once cold enough, the ato

Why the ISS? Gravity tends to work against the cooling process that creates condensates. In space, these BECs could be a trillion times colder than the coldest places in the universe and a hundred times colder than anything ever artificially created on earth. In addition to potentially changing physics forever, this will be fun for astronauts, because BECs are visible with the naked eye. "You can actually see the tiny cloud in there," says Anita Sengupta, the lab's project manager. "You have to turn the lights off, but you can see a little ball." This will come in handy if the astronauts ever get tired of looking out the window.

A NEW WAY TO ELIMINATE CARBON DIOXIDE

GETTY IMAGES

Simply reducing the amount of carbon dioxide that spews into the atmosphere each year isn't enough to save the environment. We also need a way to get rid of what's already out there. This year, a team of engineers and scientists from Columbia University, the University of Iceland, and the University of Copenhagen figured out a way to do just that: They'll turn the gas into rock. In Iceland.

CO_2 is dissolved in water and pumped into basalt stores. There, it reacts with the rock itself, becoming carbonate.

Because of Iceland's volcanic activity, geothermal plants there drill into the earth to tap volcanically heated water for power, releasing carbon dioxide and hydrogen sulfide. In the past, CO_2 that escaped during this process was captured, then pumped back underground into former gas or oil reservoirs. That technique worked for awhile. But there was no way to guarantee that people wouldn't accidentally pierce those reservoirs in the future, releasing the stored CO_2 back into the atmosphere. This new process ensures that that will never happen.

Now, the CO_2 is still pumped underground, but first it is dissolved into water. The engineers pump the mixture into natural formations made of basalt—a porous lava rock that likes to react with carbon dioxide. When the water floods into the basalt, the carbon reacts with the rock to form a chalky mineral called carbonate. It was previously thought that this process took hundreds or thousands of years, but the researchers have already found that it can happen extremely quickly. In two years, 90 percent of the injected CO_2 has solidified.

Because basalt is a common rock found all over the world, the team in Iceland thinks that this technique can be applied in many other countries. For now, it may be costly, but so is running an air conditioner when it's 120 degrees outside.

MORE SENSITIVE SCANNERS FOR THE MEDICAL INDUSTRY

YURI HASEGAWA

The problem with science awards is that you only really hear about the big discoveries. No one wants to celebrate basic research—the nitty-gritty explorations into atoms and cells that make advances like spaceflight possible—because it can seem unexciting. Mona Jarrahi, associate professor in charge of the University of California, Los Angeles' Terahertz Electronics Laboratory, could have this problem, because what she does is integrate semiconducting nanostructures into lasers to convert light into terahertz waves, then converts those waves into an electrical—see? But the thing is, the Department of Defense, President Obama, and the Nobel Prize Committee are all interested in Jarrahi's "basic research," because essentially what she has done is increase the sensitivity of terahertz scanners —those body scanners you get to pose in every time you go to the airport— by five orders of magnitude.

Much like X-rays, terahertz scanners can see through clothes and inside organs, but because they employ a longer wavelength, they don't damage DNA and can detect unique chemical signatures from substances like water. This makes terahertz waves ideal for locating both hidden explosives and cancer tumors. With the increase in power that comes from Jarrahi's work, she's been able to build scanners as small as a deck of cards. One day, she hopes, they'll replace mammography machines, and doctors will be able to spot breast cancer with an iPhone. Currently, she is partnering with the MedStar Washington Burn Center to see if her tiny scanner can determine the depth of injury in burn victims.

A Better Understanding of Earthquakes

We know why earthquakes happen: Tectonic plates in the earth push against each other until the pressure is too great and they have to shift, bend, or break. But figuring out where those shifts will happen? That has always been a challenge. For decades, scientists have tracked the Pacific and North American plates as they move side to side. Up and down, however, isn't so easy. The latter movement is caused by seismic forces but also by factors such as pumping out groundwater for irrigation. This year, researchers from the University of Hawaii at Manoa, the University of Washington, and the Scripps Institution of Oceanography created an algorithm that removed nonseismic factors from the data. For the first time, scientists could see the rise and fall of pockets of land along faults in California. The movement is small—a few millimeters each year—but it has big implications. Not only does it give scientists an idea of the energy available for an earthquake, it helps them understand where those earthquakes might strike.

THE PLANETARY SECRETS Of JUPITER

NASA

NASA's Juno probe entered Jupiter's orbit on July 4, 2016, ending a five-year journey from Cape Canaveral. The satellite is larger than a basketball court, thanks to three thirty-foot-long solar panels, which have more than eighteen thousand solar cells. Because Jupiter receives just one twenty-fifth the solar power of Earth, the satellite will need every one of them. Juno will spend the next year and a half collecting data from about three thousand miles above Jupiter's surface, offering the closest look we've ever gotten of the largest planet in our solar system. The more we learn about Jupiter—

what it's made of, how its magnetic fields and radiation work—the more we might learn about the origins of Earth.

A BRAIN IMPLANT THAT OVERCOMES PARALYSIS

In a spinal-cord injury, the pathway between the brain and the muscles is interrupted, and signals from the brain make it only as far as the damage in the cord. Many treatments focus on attempting to repair that path, but researchers at Ohio State University and the Battelle Memorial Institute did something different: They bypassed the spinal cord completely. This year the team, lead by Ali Rezai at Ohio State, published the results of a study in which they implanted a small chip in the motor cortex of a twenty-four-year-old quadriplegic. As the patient attempted to replicate basic hand movements he saw on a screen, the chip recorded the neural firing patterns for each gesture. When the patient's forearm was wrapped in a sleeve of electrodes and he was hooked up to the computer, he could think of a movement, and the chip would recognize the neural pattern and broadcast the appropriate signals directly to the electrodes, moving his hand in response. Using the new technology, the patient was able to swipe a credit card, play Guitar Hero, and stir cream and sugar into a drink. And all he had to do was think about it.

Two Cheaper Ways to Get to Space

You can already buy and name stars—one of the least romantic anniversary gifts out there, for the record—but this year two new products were released that will let you own lights in space.

Jekan Thanga, an assistant professor at Arizona State University's School of Earth and Space Exploration, leads a team of students that created the SunCube FemtoSat satellite (pictured above). At a tiny size of twenty-seven cubic centimeters, it costs only $500 to buy and $3,000 to send into low Earth orbit. (Companies such as NanoRacks will do the latter for you.) That's one-fifth the cost of the cheapest spacecraft in use today. The minisatellite uses photovoltaic cells for power and has a three-megapixel camera and an eight- to thirty-two-bit processor, depending on the data computation you plan on doing.

Meanwhile, a team of researchers led by Mason Peck at Cornell University has developed Sprites, bitsy satellites about the size and shape of a Cheez-It cracker. At about $30 apiece, Sprites include a circuit board, solar cells, radio transmitters, and sensors that can detect direction and movement.

Both projects provide opportunities for exploration without extreme cost. "Right now so many people are denied the opportunity to participate in space exploration just by virtue of the cost effects," Peck says. "With this approach, with relatively little money, you can put one of these together yourself." Researchers will be able to send probes to previously unexplored parts of space, with very little at stake—and without the help of anyone named Musk or Bezos.

PROOF THAT EINSTEIN WAS RIGHT

One of the most complicated scientific instruments on earth is right here in the USA.

Few people had heard of the Laser Interferometer Gravitational-Wave Observatory before it shared news in February that it had confirmed the existence of gravitational waves, a phenomenon Albert Einstein predicted back in 1916. But that doesn't mean it wasn't there. LIGO, which is actually two enormous L-shaped scientific instruments called laser interferometers—one in Hanford, Washington, and another in Livingston, Louisiana—first opened in 1999 and ran for years before upgrading in 2007.

That initial run was sort of an experiment. No one had ever tried to find gravitational waves before. The ripples in space-time are caused by events

like stars collapsing and black holes colliding. The only way to know if one has passed is to detect a tiny signal, the result of microscopic stretching and compression of the earth, on two identical laser interferometers, set many miles apart. The interferometers work by splitting a beam of light in half and sending it down both arms of the L simultaneously. Each beam hits a mirror at the end of its arm, which sends the beam back to a photodetector. When the beams reach the detector, they cancel each other out. The sensor sees nothing until a gravitational wave bounces through, stretching space so that the arms themselves lengthen and shorten by a distance as small as one ten-thousandth the diameter of a proton and some light waves make it to the sensor. In those first eight years, scientists found nothing. But they did learn how to increase potential signal and decrease noise from things like earthquakes. So they closed the facilities down and built an even better version.

When the new, improved LIGO opened in 2015, just months before it detected its first wave, the lasers were twenty times more powerful, the mirrors were more reflective, and it had a souped-up vibration-isolation system—a four-stage hanging setup that passively reduces shaking by a factor of a trillion, and a two-stage seismic-reduction platform that actively counteracts the motion of the earth. "The analogy I like to give is that the first interferometer was a family sedan, but the new one is a Ferrari," says LIGO executive director David Reitze. And now it even has a bunch of awards on the dash.

CLEANER OIL

Cheap and widely available heavy fuel oil (HFO) is what keeps maritime shipping afloat, but burning the sulfur-rich substance emits as much air

pollution as fifty million cars every year. Field Upgrading of Calgary, Alberta, created a solution: Combine HFO with molten sodium, which reacts with the sulfur in the oil to create sodium sulfide. Separate out this compound using a centrifuge, and you're left with clean oil. Cleaner, at least. For now, a test facility produces ten barrels per day, but by 2019 that number should be closer to ten thousand.

For more Breakthrough Awards, check out our youth awards here.

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