[Emerging field of plant Nanobionics or ePlants turn plants into sensors that can detect explosives, warn of pollutants and environmental conditions such as drought]

MIT engineers have created sensors that can be printed onto plant leaves and reveal when the plants are experiencing a water shortage. This kind of technology could not only save neglected houseplants but, more importantly, give farmers an early warning when their crops are in danger, says Michael Strano, the Carbon P. Dubbs Professor of Chemical Engineering at MIT and the senior author of the new study.

Earlier, Engineers from MIT turned spinach plants into sensors that can soak up explosive molecules from groundwater, detect their presence and then transmit that information to a handheld device. The plants were designed to detect nitroaromatics, which are often used in landmines and other explosives. When one of these chemicals is present in the groundwater sampled naturally by the plant, carbon nanotubes embedded in the plant leaves emit a fluorescent signal that can be read with an infrared camera.

The development from a team at MIT is said to be one of the first demonstrations of engineering electronic systems into plants, an approach dubbed plant nanobionics. “The goal of plant nanobionics is to introduce nanoparticles into the plant to give it non-native functions," said Michael Strano, the Carbon P. Dubbs Professor of Chemical Engineering at MIT and the leader of the research team.

Two years ago, in the first demonstration of plant nanobionics, Strano and Giraldo used nanoparticles to enhance plants' photosynthesis ability and to turn them into sensors for nitric oxide, a pollutant produced by combustion. Plants are ideally suited for monitoring the environment because they already take in a lot of information from their surroundings, Strano says. "Plants are very good analytical chemists," he says. "They have an extensive root network in the soil, are constantly sampling groundwater, and have a way to self-power the transport of that water up into the leaves."

Recently, Researchers from Sweden have introduced the concept of electronic plants (e-Plants), an organic bioelectronic technology capable of forming analog and digital circuits inside the leaves and xylem vascular tissue of Rosa floribunda, respectively.

For example, a Swedish group recently demonstrated how a rose from a garden may be converted into a supercapacitor. The cut rose was dipped in a polymer solution. The polymer was absorbed by the stem, leaves, and the flower, creating electrically conductive filaments within, which allowed a large amount of charge to be transferred to the flower. Team member Eleni Stavrinidou reported, "We have been able to charge the rose repeatedly, hundreds of times without any loss on the performance of the device. The levels of energy storage we have achieved are of the same order of magnitude as those in supercapacitors."

One of the goals of Synthetic Biology is the creation of bioengineered microorganisms (and possibly other life forms) that can produce pharmaceuticals, detect toxic chemicals, break down pollutants, repair defective genes, destroy cancer cells, and generate hydrogen for the post petroleum economy.

Plant Nanobionics

Plant nanobionics is a new field of bioengineering that inserts nano particles into the cells and chloroplasts of living plants, which then alter or amplify the functioning of the plant tissue or organelle. For example materials like carbon nanotubes have been uptaken by plants when spayed onto foliage; the carbon nanotubes are able to pass through stomata of the leaf and lodge between the mesophyll cells inside the leaf. When inside the plant tissues, the nanotubes respond to the chemical changes occurring inside the leaves. Leaf cells and chloroplasts readily uptake the carbon nanotubes which can pass through cell membranes and lipid bilayer membranes of organelles.

Plants are renewable, large-volume, and high-performing machineries that represent an untapped source for the production of advanced materials, electronics, and energy technology. One strategy to further advance plants as technological systems, and to dynamically control their physiology, would be to manufacture integrated electronic systems that selectively convert chemical compounds into electric signals and energy, and vice versa, at a high spatiotemporal resolution.

Integrated electronic systems are typically composed of contacts, wires, interconnects, and components. From a circuit perspective, forming a biofuel cell technology or a sensor-and-actuator system integrated inside a living plant would require electronic charge transport over long distances (wires) and charge storage with low electrical loss (capacitors).

"Up to now the devices and circuits have been manufactured in localized regions of the plant due to limited distribution of the organic electronic material. Here we demonstrate the synthesis and application of a conjugated oligomer that can be delivered in every part of the vascular tissue of a plant and cross through the veins into the apoplast of leaves. The oligomer polymerizes in vivo due to the physicochemical environment of the plant. We demonstrate long-range conducting wires and supercapacitors along the stem. Our findings open pathways for autonomous energy systems, distributed electronics, and new e-Plant device concepts manufactured in living plants," write Eleni Stavrinidou and others.

Sensors applied to plant leaves warn of water shortage

The new MIT sensor takes advantage of plants' stomata—small pores in the surface of a leaf that allow water to evaporate. As water evaporates from the leaf, water pressure in the plant falls, allowing it to draw water up from the soil through a process called transpiration.

They found that it takes stomata about seven minutes to open after light exposure and 53 minutes to close when darkness falls, but these responses change during dry conditions. When the plants are deprived of water, the researchers found that stomata take an average of 25 minutes to open, while the amount of time for the stomata to close falls to 45 minutes.

To create their sensor, the MIT researchers used an ink made of carbon nanotubes—tiny hollow tubes of carbon that conduct electricity—dissolved in an organic compound called sodium dodecyl sulfate, which does not damage the stomata. This ink can be printed across a pore to create an electronic circuit. When the pore is closed, the circuit is intact and the current can be measured by connecting the circuit to a device called a multimeter. When the pore opens, the circuit is broken and the current stops flowing, allowing the researchers to measure, very precisely, when a single pore is open or closed.

The MIT team is now working on a new way to apply the electronic circuits by simply placing a sticker on the leaf surface. In addition to large-scale agricultural producers, gardeners and urban farmers may be interested in such a device, the researchers propose.

“It could have big implications for farming, especially with climate change, where you will have water shortages and changes in environmental temperatures,” Koman says. In related work, Strano’s lab is exploring the possibility of creating arrays of these sensors that could be used to detect light and capture images, much like a camera.

Spinach plants modified to detect

explosives

Strano’s lab has previously developed carbon nanotubes that can be used as sensors to detect a wide range of molecules, including hydrogen peroxide, the explosive TNT, and the nerve gas sarin. When the target molecule binds to a polymer wrapped around the nanotube, it alters the tube’s fluorescence.

We first designed carbon nanotube based sensors that selectively respond to nitroaromatics,’ explains Wong. ‘These nanotubes quench in fluorescence intensity in the presence of nitroaromatics’.Using a technique called vascular infusion, Researcher applied a solution of nanoparticles to the underside of the leaf, they placed the sensors into a leaf layer known as the mesophyll, which is where most photosynthesis takes place.

They also designed a reference sensor that is invariant in signal intensity.’ This embedded carbon nanotubes that emit a constant fluorescent signal that serves as a reference.This allows the researchers to compare the two fluorescent signals, making it easier to determine if the explosive sensor has detected anything. If there are any explosive molecules in the groundwater, it takes about 10 minutes for the plant to draw them up into the leaves, where they encounter the detector.

To read the signal, the researchers shine a laser onto the leaf, prompting the nanotubes in the leaf to emit near-infrared fluorescent light. This can be detected with a small infrared camera connected to a Raspberry Pi, a $35 credit-card-sized computer similar to the computer inside a smartphone. The signal could also be detected with a smartphone by removing the infrared filter that most camera phones have, the researchers say.

“This is a novel demonstration of how we have overcome the plant/human communication barrier,” says Strano, who believes plant power could also be harnessed to warn of pollutants and environmental conditions such as drought. “Plants are very environmentally responsive,” Strano says. “They know that there is going to be a drought long before we do. They can detect small changes in the properties of soil and water potential. If we tap into those chemical signaling pathways, there is a wealth of information to access.” “This setup could be replaced by a cell phone and the right kind of camera,” Strano says. “It’s just the infrared filter that would stop you from using your cell phone.”

Michael McAlpine, an associate professor of mechanical engineering at the University of Minnesota, says this approach holds great potential for engineering not only sensors but many other kinds of bionic plants that might receive radio signals or change color.

“When you have manmade materials infiltrated into a living organism, you can have plants do things that plants don’t ordinarily do,” says McAlpine, who was not involved in the research. “Once you start to think of living organisms like plants as biomaterials that can be combined with electronic materials, this is all possible.”

References and Resources also include:

- http://news.mit.edu/2016/nanobionic-spinach-plants-detect-explosives-1031
- http://thcbiomed.com/topic/plant-nanobionics-plants-can-tell-us-how-they-feel-what-they-smell-and-taste/
- https://www.theengineer.co.uk/spinach-plants-modified-to-detect-explosives/
- https://www.chemistryworld.com/news/explosive-sensing-plant-lights-fuse-for-nanobionics/1017631.article
- http://www.pnas.org/content/114/11/2807.full
- https://phys.org/news/2017-11-sensors-shortage.html