Synthetic fish provides data to design fish-friendly hydropower facilities

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PNNL's improved Sensor Fish is a small tubular device filled with sensors that analyze the physical stresses fish experience as they pass through dams and other hydropower structures. The device's latest version costs about 80 percent less and can be used in more hydro structures than its predecessor, according to a paper published in the journal Review of Scientific Instruments.

In the Pacific Northwest, young salmon must dodge predatory birds, sea lions and more in their perilous trek toward the ocean. Hydroelectric dams don't make the trip any easier, with their manmade currents sweeping fish past swirling turbines and other obstacles. Despite these challenges, most juvenile salmon survive this journey every year.

Now, a synthetic fish is helping existing hydroelectric dams and new, smaller hydro facilities become more fish-friendly. The latest version of the Sensor Fish—a small tubular device filled with sensors that analyze the physical stresses fish experience—measures more forces, costs about 80 percent less and can be used in more hydro structures than its predecessor, according to a paper published today in the American Institute of Physics' *Review of Scientific Instruments*.

"The earlier Sensor Fish design helped us understand how intense pressure changes can harm fish as they pass through dam turbines," said lead Sensor Fish developer Daniel Deng, a chief scientist at the Department of Energy's Pacific Northwest National Laboratory.

"And the newly improved Sensor Fish will allow us to more accurately measure the forces that fish feel as they pass by turbines and other structures in both conventional dams and other hydro power facilities. As we're increasingly turning to renewable energy, these measurements can help further reduce the environmental impact of hydropower."

Abundant renewable resource

More than half of the United States' renewable energy came from hydropower in 2013, representing 7 percent of the nation's total power generation that year. The vast majority of that power came from traditional, large hydroelectric dams. Today, there is also a growing interest in small hydro facilities such as small dams that generate less than 10 megawatts of power and pumped storage hydroelectric plants.

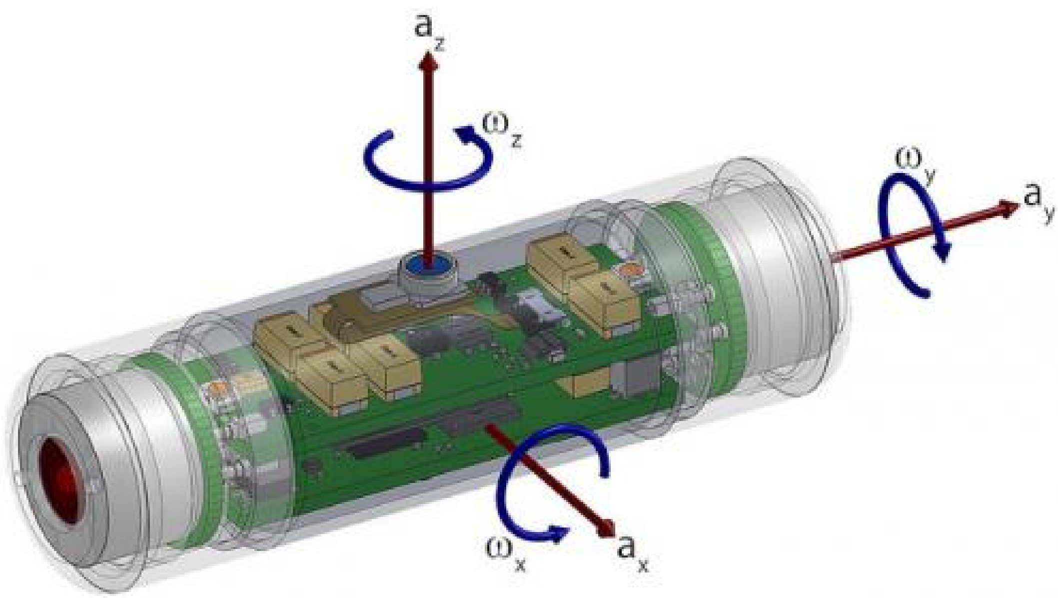
Most large dams in the U.S. were built in the 1970s or earlier and will soon need to be relicensed—a process that includes evaluating and often reducing a dam's environmental impact. Key to that evaluation is examining how fish fare when swimming through dams.

PNNL began developing the Sensor Fish in the late 1990s to improve fish survival at hydroelectric dams along the Pacific Northwest's Columbia River Basin. The earliest design featured basic circuitry, sensors and two AA batteries encased in a six-inch-long, fish-shaped piece of clear rubber. Though the appearance was fish-like, the design didn't fully capture the experience of real juvenile salmon swimming through dams.

High-tech solution

So PNNL staff went back to the drawing board and devised the current, tubular design around 2004. Similar to the latest design, the 2004-issued Sensor Fish featured a hollow tube of clear, durable plastic that was stuffed with various sensors, a circuit board and a miniature rechargeable battery.

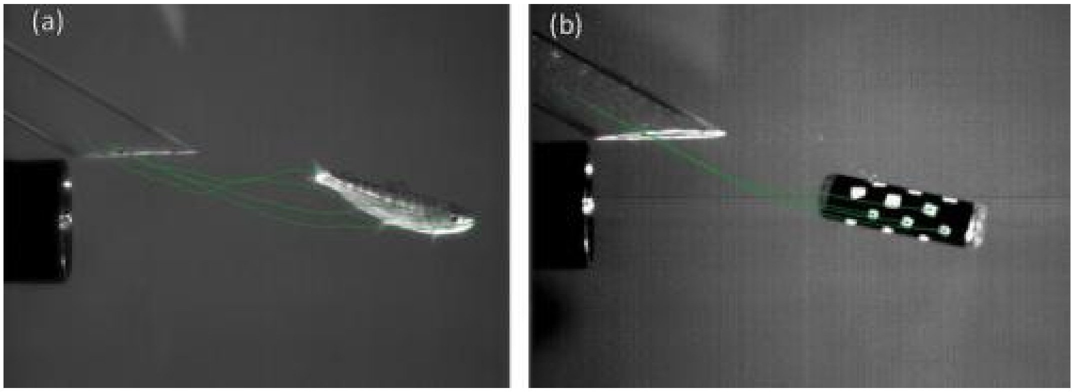
Using this version of the device, which has been dubbed the first-generation Sensor Fish, PNNL researchers measured the various forces juvenile salmon experience as they pass through dams. Back then, the Sensor Fish was specifically designed to evaluate dams equipped with a common type of turbine along the Columbia River, the Kaplan turbine. The pressure change, they found, is akin to traveling from sea level to the top of Mount Everest in blink of an eye.



A technical drawing of the latest version of the Sensor Fish, illustrating the various directions in which the device's motions are recorded.

Many people assume fish swimming through dams are only injured when turbine blades hit them, but PNNL's research has shown there are many different forces that can harm fish, including abrupt pressure changes in dam turbine chambers. That knowledge is helping redesign dam turbines so they create less severe pressure changes while maintaining or even improving power production. Many of America's aging hydroelectric dams will be undergoing retrofits in coming years that include installing newly designed turbines.

The need to retrofit old dams, combined with interest in building new hydropower facilities here and abroad, triggered a redesign of the Sensor Fish about three years ago. The latest version—called the second-generation Sensor Fish—can be used in different kinds of hydro facilities, including unconventional, smaller hydropower plants and conventional dams with either Kaplan or Francis dam turbines.



A live juvenile fish (left) and the previous version of the Sensor Fish (right) are shown side-by-side as they're exposed to a simulated dam turbine environment. This test helped PNNL researchers correlate the injuries some fish experience with the Sensor Fish's measurements.

The new device also measures forces more precisely—it measures nearly twice as much pressure and acceleration as before, for example. And the Sensor Fish is now significantly cheaper to make: the revamped devices cost $1,200 each, while the earlier ones cost $5,000. Other features were also added, such as a temperature sensor, an orientation sensor, a radio transmitter and an automatic retrieval system that floats the device to the surface after a predetermined amount of time.

Test-proven, ready for the field

Researchers successfully field-tested the new and improved Sensor Fish in two Washington state dams: Ice Harbor on the Snake River and Boundary on the Pend Oreille River. Lab tests also showed the second-generation device worked well after facing up to 600 times the force of gravity.

The latest version of PNNL’s Sensor Fish floats in water and flashes its LED lights after a test. LED lights help researchers see and retrieve the device.

Over the next year, the second-generation Sensor Fish is slated to evaluate three small hydro projects in the U.S., a conventional hydroelectric dam in the U.S., irrigation structures in Australia and a dam on the Mekong River in Southeast Asia.

Deng and his colleagues are currently manufacturing the new Sensor Fish by hand in PNNL's Bio-Acoustics & Flow Laboratory. To further reduce the Sensor Fish's cost and expand its use, PNNL would like to transfer the technology to a company that could manufacture it for hydropower operators and research institutions.

Funding for the second-generation Sensor Fish came from DOE's Office of Energy Efficiency and Renewable Energy and the Electric Power Research Institute. Earlier versions were supported by DOE, the

Bonneville Power Administration and the U.S. Army Corps of Engineers.

Pacific Northwest National Laboratory scientists have developed an electronic sensor fish that is designed to record some of the environmental conditions fish may encounter while passing through hydropower turbines. The original six-inch rubbery fish (pictured) has since been revised into the form of a 3.6-inch plastic tube.

The Sensor Fish is part of a large set of tools PNNL has developed to improve fish survival at hydropower facilities. PNNL's other tools include the Juvenile Salmon Acoustic Telemetry System, advanced water modeling and more.

More information: Z.D. Deng, J. Lu, M.J. Myjak, J.J. Martinez, C. Tian, S.J. Morris, T.J. Carlson, D. Zhou & H. Hou, "Design and

Implementation of a new Autonomous Sensor Fish to Support Advanced Hydropower Development," *Review of Scientific Instruments*, Nov. 4, 2014, DOI: 10.1063/1.4900543.

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