Echoing the Bats

Ultrasound Maps the Ragged Walls of Caves

by W.I. Sellers and A.T. Chamberlain

Few things see caves as precisely as the bat – even in total darkness. These flying mammals dart smoothly and unerringly through winding underground chambers that bedevil even modern surveying equipment. Bats send out pulses of ultrasound and analyze the timing and strength of the echoes to "see" where the walls are.

Taking our cue from nature, we built and tested a device that works rather like a bat's sonar system to solve the difficult and time-consuming process of surveying archaeological sites in caves, which can be archaeological treasure chests.

Our device, like the bat, directs a beam of ultrasound at the walls of the cave and records the reflected echo. Back in the lab, this echo signal is analyzed and used to build a picture of the cave. Instead of measuring the geometrical relationship of a few points, as in traditional surveying, we measure the positions of hundreds of points on the walls of the cave. This system should be equally suitable for surveying other irregular or enclosed structures, such as tunnels, tombs, well-shafts, and mines.

Caves are an important and challenging archaeological resource. They can contain artifacts left by human inhabitants and the bones of humans and other animals that either lived in the cave, were dragged in as prey, or fell through holes in the roof. They provide unique preservation conditions, and some extraordinary finds have been made in them, not least of which is the 3.6 million-year-old hominid skeleton recently reported from a cave in South Africa.

Standard surveyors' tools – theodolites, ranging poles, levels, and laser distancing equipment – work well for precisely mapping archaeological digs on the surface. It's a lot tougher underground. In many caves, there simply is no room for standard surveying gear. Most caves are relatively cramped, some with tortuous sets of tunnels where even standing upright is a luxury. The three-dimensional structure of caves also complicates things. Setting up a survey grid works well on a reasonably flat surface, but it can be impossible in narrow, steeply-sloping passageways.

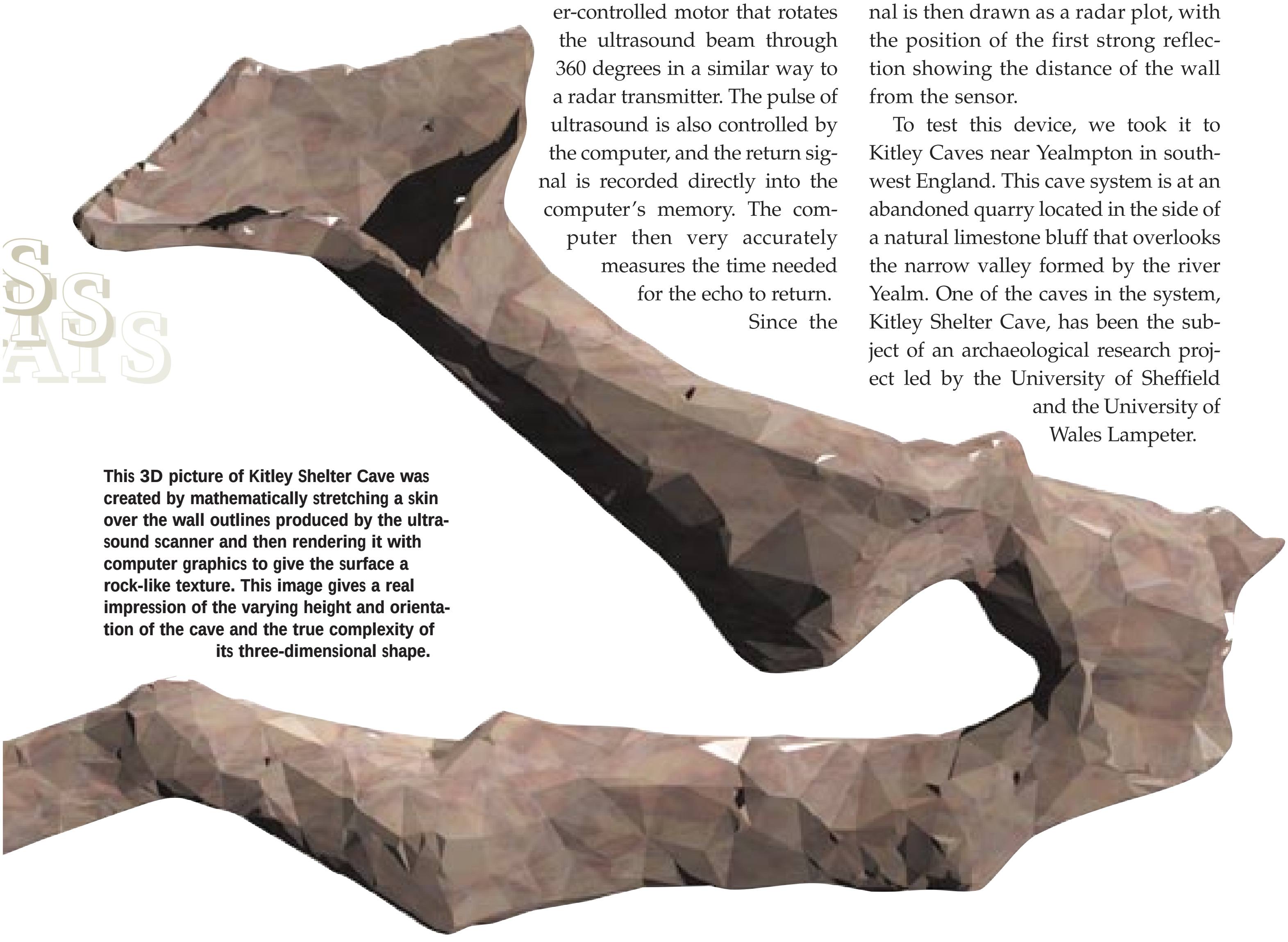
In addition, classical surveying techniques rely on specific points: the corner of a building or edge of a ditch, for example. Caves rarely offer such convenience. Points on the uneven, rounded walls of caves must usually be provided artificially – often by drilling holes in the rock and attaching bolts.

Despite the difficulties, caves can be surveyed by traditional means. This, however, does not record the actual shape of the cave, unless a very large number of points are recorded, and that is extremely time-consuming.

Our proposed solution consists of a small ultrasound transmitter and receiver (very like the ultrasound units in some TV remote controls). This is attached to the axle of a computer-controlled motor that rotates the ultrasound beam through 360 degrees in a similar way to a radar transmitter. The pulse of ultrasound is also controlled by the computer, and the return signal is recorded directly into the computer's memory. The computer then very accurately measures the time needed for the echo to return. Since the speed of sound in air is more or less constant, the longer the echo takes, the further away the wall is. This signal is then drawn as a radar plot, with the position of the first strong reflection showing the distance of the wall from the sensor.

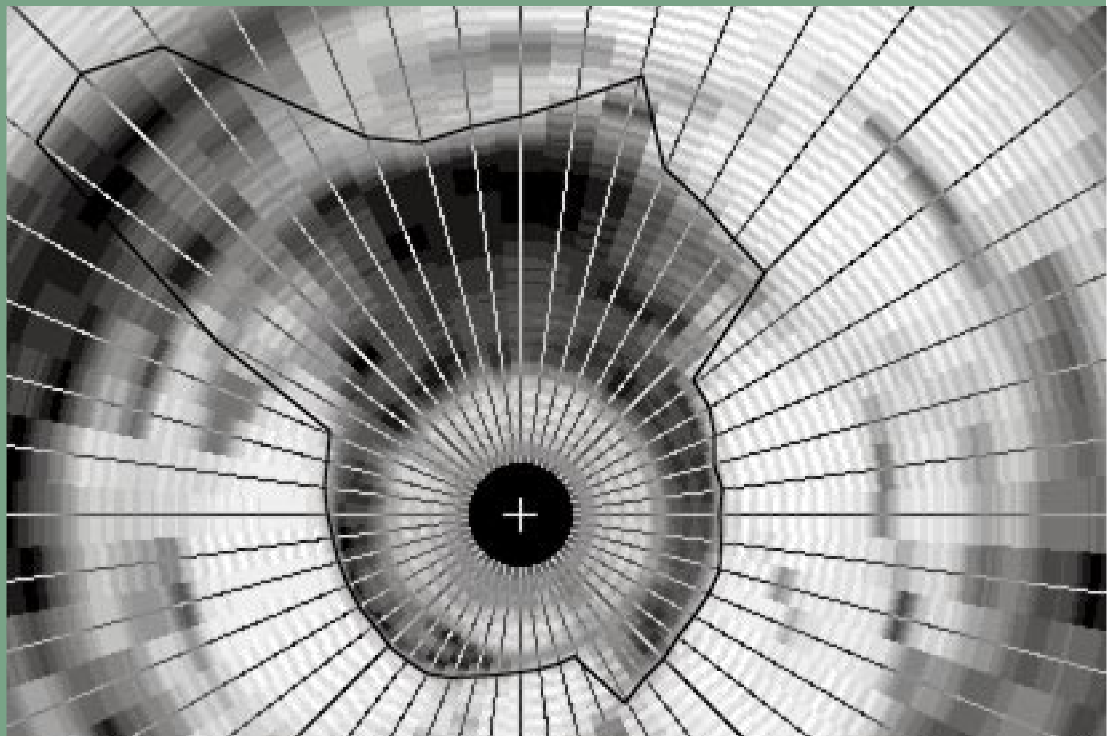
To test this device, we took it to Kitley Caves near Yealmpton in southwest England. This cave system is at an abandoned quarry located in the side of a natural limestone bluff that overlooks the narrow valley formed by the river Yealm. One of the caves in the system, Kitley Shelter Cave, has been the subject of an archaeological research project led by the University of Sheffield and the University of Wales Lampeter.

The prototype ultrasound system mapped the interior of Kitley Shelter Cave, although, as its narrow entrance shows, using conventional survey equipment would have been difficult.



This 3D picture of Kitley Shelter Cave was created by mathematically stretching a skin over the wall outlines produced by the ultrasound scanner and then rendering it with computer graphics to give the surface a rock-like texture. This image gives a real impression of the varying height and orientation of the cave and the true complexity of its three-dimensional shape.

This is a computer image of the cave-mapping process. The radial lines represent ultrasound “pings” sent from the scanner – the cross, which is about 80 centimenters or 2.2 feet from the cave floor. Variations in brightness of the concentric rings mark the echoes bounced off the cave. The dark, irregular line represents the cave wall.



The scanning unit sends an ultrasound beam from its transmitter and, by measuring how long it takes the echo to return, calculates the distance to the cave wall.

During the excavations, the locations of archaeological finds and faunal remains were recorded using bolts drilled into the cave roof as reference points. An accurate survey of the accessible part of the cave was needed to gain a visual impression of the structure and to determine the spatial relationships between finds in different parts of the cave system.

The scanner unit was moved through the cave and set up at approximately half-meter (20 inch) intervals. Its precise position was recorded by measuring its distance, bearing, and inclination from a known point within the cave. After each scan was taken and saved in the computer, the scanner was moved to its next location. The process takes five to 10 minutes per scan – although it took longer in the narrower parts of the cave because of the difficulty of moving about.

Back in the lab, we calculated the positions of the walls in relation to the scanner throughout the cave by tracing the outline produced by the first large reflection (the echo) received from each of the scans.

The next stage was to build a 3D image of the whole cave. This was done by transferring all the wall position data into a CAD package, then drawing the walls between the data points. The result is an accurate, three-dimensional computer model of the cave that can be displayed, rotated, and even walked through.

This image can now be used to locate finds and to provide information about directions, gradients, and volumes within the cave, which can tell us a great deal about how earth and its fossil and artifact load flowed into the cave.

As the fields of medical imaging and structural analysis have shown, ultrasound is a powerful measuring tool. It has none of the exposure risks of X-rays and allows us to non-destructively obtain a picture of the inside of an object. Archaeologists have primarily used ultrasound as a technique for cleaning artifacts; now we can use it to explore caves.

One disadvantage of this technique is that the methodology is so similar to that used by bats that the ultrasound signal itself is likely to upset them. In fact, any human activity in caves disturbs bats, so the best idea is to pick times of the day or year when bats are not around.

A fully automated system would be ideal – perhaps a flying robo-bat with an inertial navigation system. □

WILLIAM I. SELLERS is at the Department of Biomedical Science, University of Edinburgh, U.K. ANDREW T. CHAMBERLAIN is at the Department of Archaeology and Prehistory, University of Sheffield, U.K.