Ultrasonic Cave Mapping

Bill Sellers*[1] and *Andrew Chamberlain*[2] describe an ultrasonic instrument for automatically recording a 3D model of a cave chamber.[3]

Abstract: Surveying the internal structure of a cave is an important part of any archaeological or palaeontological excavation. However, using standard topographical surveying techniques is extremely difficult due both to the irregular nature of the structure and to the difficult working conditions. This study uses a novel method based on ultrasound reflections to produce an accurate 3D model of Kitley Shelter Cave, an archaeological cave in Yealmpton, Devon. This model allows the easy location of finds and enables the cave system to be visualised allowing better understanding of the taphonomy[4] of the site.

Materials and Methods

The basic approach used for the system is a rotating ultrasound emitter mounted so that the beam scans the walls of the cave in a vertical plane. The system is able to calculate the distance of the wall from the emitter at any point in this sweep and so is able to calculate the profile of the cave in the scanning plane.

By moving the emitter through the cave system a set of profiles is built up as a stack of slices. These slices can then be reassembled in a CAD program to reconstruct the 3D shape of the cave system.

Schematic Diagram of the System

The ultrasonic scanner consists of an ultrasound emitter and receiver mounted on the spindle of a stepper motor. The stepper motor and the ultrasound transmitter are controlled via a laptop computer which also reads the signal picked up by the ultrasound receiver.

The emitter sends out a pulse of ultrasound and the echo is picked up by the receiver. The time taken for the echo to arrive depends on the distance from the transmitter to a solid object such as the wall of the cave. The stepper motor then rotates the transmitter and receiver through 7.5° and the process is repeated. A complete circular scan is built up in very much the same way as radar with the computer storing the ultrasound echo at each of the 48 scan orientations and then plotting them on the screen as a radial map. The illustration to the right is a schematic of the electronics.

Description of the Process

The scanner produces a radial scan perpendicular to the axis of the stepper motor. To produce an accurate 3D reconstruction both the position and orientation of the axis needs to be known. To map a cave system, a zero point at the entrance is first defined using standard surveying techniques. Then a series of secondary markers are set up at convenient places within the cave and surveyed by measuring their distance, bearing and inclination from each other and from the zero point as convenient.

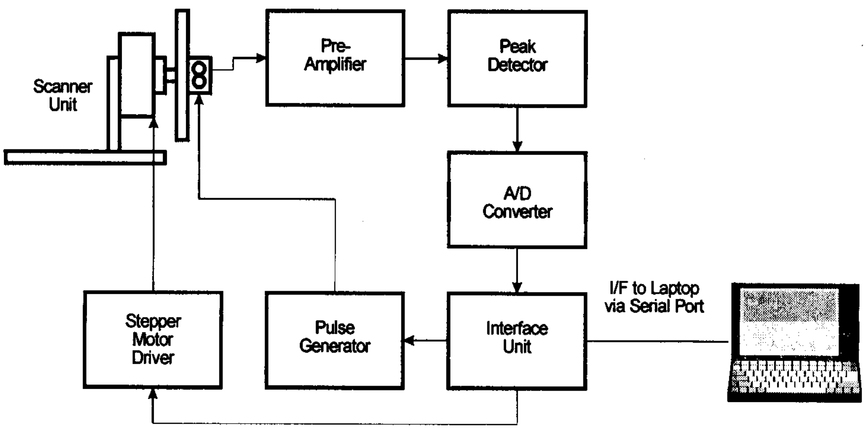
The scanner unit is then moved through the cave. It is set up at convenient points at approximately 0.5m intervals and the bearing and inclination of the spindle recorded. In this particular case, the spindle was always held horizontal, though there is no particular requirement to do this. The position of the spindle was defined by the distance, bearing and inclination from one of the previously surveyed markers.

At each known point, a scan is recorded. This is then converted into an outline of the passage wall by tracing the "radar" image by hand. This process is illustrated in the series of figures on the next page. Once the passage wall outlines have been obtained they can be imported into a 3D CAD package and used as guides for an automated "skinning" process which produces a fully rendered 3D visualisation of the cave system. An example is also shown on the next page.

Discussion

As mentioned before, accurate surveying is a vital part of palaeontology. Traditional techniques are at best inefficient in cave systems and at worst impossible to do. The ultrasound scanning technique presented here allows accurate surveying and visualisation to be performed in restricted spaces relatively quickly.

There are two areas where improvements could be made. Firstly, the main cause of inaccuracy in ultrasonic surveying is due to the width of the ultrasound beam. This can be ameliorated by either using a narrower beam (Gibson, 1991), or by using an array of receivers rather than just a single one so that different parts of the beam can be resolved. This requires considerably more sophisticated equipment, but is in principle achievable by increasing the cost of the unit and by improving the data capture hardware and software (Altes, 1995). Similarly, using wideband sonar techniques can also allow improved spatial resolution (Wehner, 1987).



Schematic diagram of the data capture system. The computer program controls the position of the stepper motor and sends out ultrasound pulses in known directions. The echo signal is recorded for each ultrasonic pulse and used to build up an image of the cave walls.

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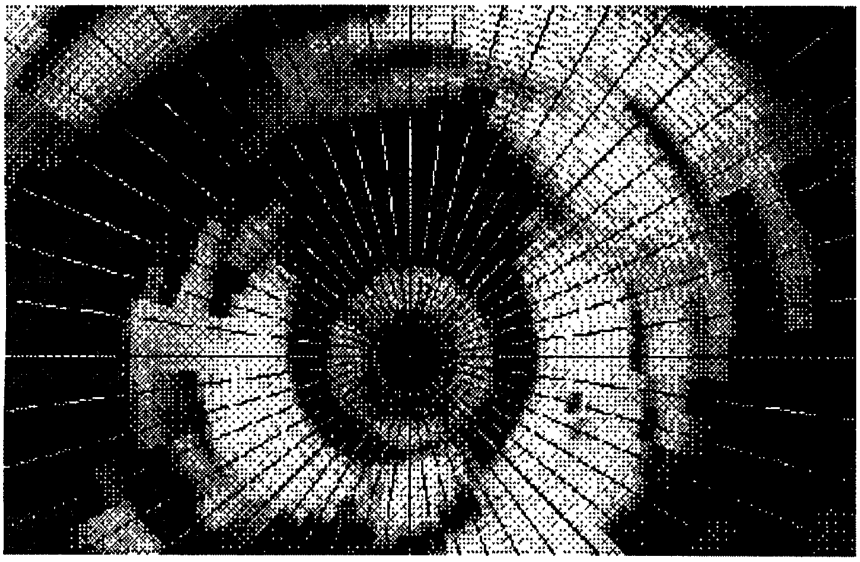
[3] This is a transcript of a paper read at the BCRA Science Symposium, Huddersfield, March 1997.

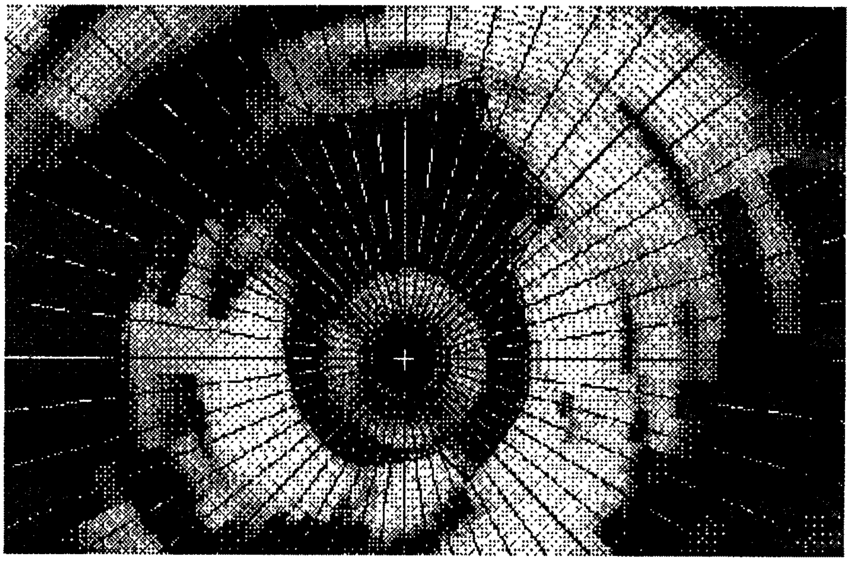
[4] Taphonomy is the process by which an object becomes buried. It includes death (in the case of an animal or plant) and burial. Subsequent mineralisation can create fossils, but this is irrelevant for archaeology. –Ed.

The second area for improvement is the reconstruction software. Currently, a lot of the work needs to be done by hand and could be automated using image recognition style algorithms. Image recognition is notoriously unreliable, but this problem is quite well circumscribed. In addition, the conversion from a set of profiles to a 3D model is currently manual and this could be relatively easily automated.

However, the results obtained from this relatively cheap system are very encouraging as they provide accurate 3D models of the complex geometry of a cave system in a comparatively short space of time.



This figure shows the raw output from the scanner program. The diagram should be interpreted in very much the same way as a radar. The distance from the centre represents the echo time, and the brightness of the shading represents the strength of the reflected signal. The superimposed 48 point star indicates the centre of the beam.



This figure shows the raw data overlaid with a trace representing the estimated position of the wall of the cave. This is generally the first large reflection signal.

Acknowledgements

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References

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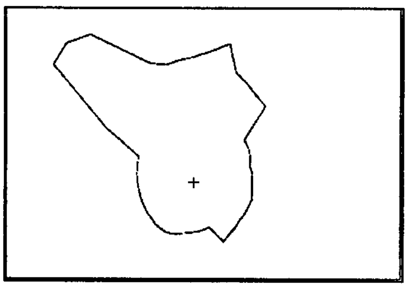
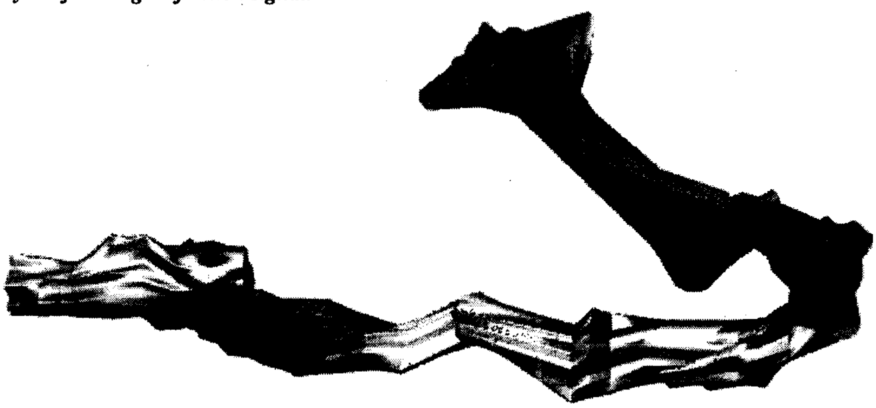


This figure shows the profile of the cave obtained from the figures above.



This figure shows the fully rendered 3D representation of the Kitley Shelter Cave systems.