Constructing Real-Time Immersive Marine Environments for the Visualization of Underwater Archaeological Sites

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Abstract. Realistic real-time immersive interaction and visualization of underwater archaeological sites using contemporary graphics hardware has the potential to provide scientists, archaeologists and the general public with access to these otherwise inaccessible locations. This paper provides an overview of some of the techniques available for the generation of these marine environments. Initially we describe a sonar technique that can be used for the generation of accurate marine bathymetry. We subsequently suggest techniques for increasing the realism of a computer rendered underwater environment including a novel technique for rendering marine life in real-time. We conclude by describing power wall and hemispherical immersive display technologies that are applicable to the visualization of marine environments.

1. Introduction

Instantly recognisable archaeological sites such as the pyramids at Giza, Egypt have been shared and enjoyed by millions of people who have experienced firsthand the beautiful work of the ancient Egyptians. An equally recognisable, yet comparatively inaccessible, archaeological site is the resting place of The Titanic which sank on her maiden voyage in 1914 with the loss of over 1500 lives (Ballard et al. 1995). Although there is a huge interest in this shipwreck, only a select number of scientists and extremely wealthy thrill seekers have been fortunate enough to travel the 2 mile trip down to the ocean depths in order to experience first hand the resting site of the Titanic.

The use of computer graphics and virtual reality (VR) for facilitating our understanding of onshore archaeological sites is well documented (Chalmers 2002) yet the computer graphics and archaeological communities have been slow to investigate the potential of immersive visualization of data collected from underwater archaeological sites. With today's contemporary computer graphics processing power and the improvements of data acquisition and recording tools, it is now possible to generate extremely accurate computer models of submerged archaeology and provide scientists, archaeologists and the general public with access to these otherwise inaccessible sites. These proposed visualizations will provide the viewer with a wealth of new information that would not have been feasible using existing methods of non interactive videos (from underwater video cameras), photographs and textural descriptions from log books.

All the algorithms and software described in this paper have been developed using C++ and the Open Scene Graph open source libraries (OSG 2004). The Hull Immersive Visualization Environment (HIVE[1]) provided the necessary virtual reality and display hardware for the marine visualizations. Examples of the work described in this paper and associated material can be downloaded from our website dedicated to the visualization of the marine environment www.marinevis.com.

2. Archaeological Marine Visualization

Fig. 1 describes four typical components required for the realistic and immersive marine visualization of archaeological data. Section 3 briefly introduces the reader to 3D marine bathymetry and sonar relating to the acquisition of seabed topography around an area of interest (our site). Careful modelling of the underwater environment using computer graphics is considered in Section 4 focussing on real-time visualization of marine life. Display devices are a fundamental element of any immersive display. Consequently, we present two immersive display devices in Section 5 which we feel to be particularly relevant to the visualization of marine data. Artefacts, models and metadata are beyond the scope of this paper as we are more concerned with marine rendering techniques as opposed to artefact cataloguing and metadata (Doerr 2003).

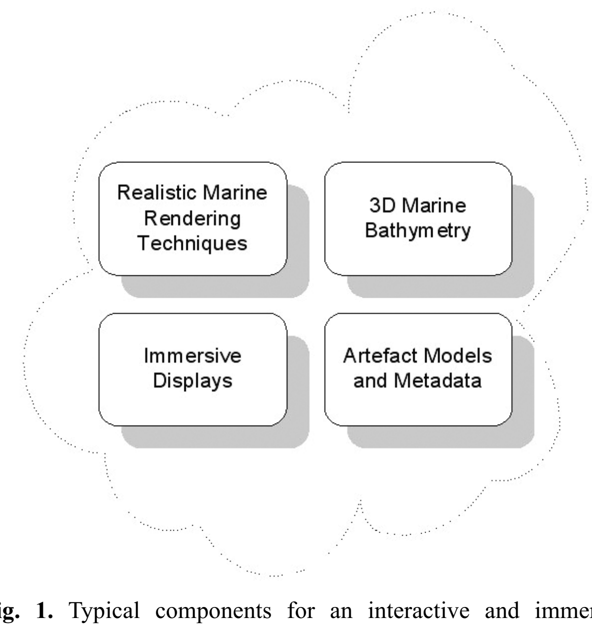

Fig. 1. Typical components for an interactive and immersive archaeological marine visualization system.

3. Data Acquisition

Sonar technology is the preferred method for seabed imaging. Sonar, an acronym for Sound Navigation and Ranging, is a technique for determining the distance and direction of underwater objects by acoustic means (Fish and Carr 1990) (Urick 1975). Sound waves are reflected (or emitted) from the object and are detected by sonar apparatus and analysed for the information they contain. Sonar was initially considered as a method for the detection of submarines and icebergs. By 1918 an operational system had been built by U.S and British scientists.

There are a number of different sorts of sonar systems, each with their own advantages, disadvantages and peculiarities. Pratson and Haxby (1997) provide an excellent explanation of the different categories of sonar systems. The sonar system that we propose for the acquisition of data relating to seabed topography is a multibeam bathymetric system (although a side scan system may initially be used for site location purposes). The multibeam system will provide us with accurate 3D soundings that can be used to generate an accurate model of the seabed relating to the area of interest.

Multibeam sonar reflects sound off the seafloor to determine ocean depth and uses an array of sound sources and listening devices mounted on the hull of a survey vessel. The sources emit a burst of sound energy at a predefined frequency that reaches only a slim strip of seafloor aligned perpendicular to the ship's heading (Pratson and Haxby 1997). The listening devices simultaneously begin recording the reflected sound from the seabed. This multibeam system can detect sounds emanating from within a series of narrow seafloor strips aligned parallel to the ship's heading. The sound reflections received at the ship emanate from the seabed where the strip of transmitted sound and the listening corridors overlap. The timing of these reflections provides a profile of seafloor depth and by recording such profiles a continuous swath of coverage can be collated around an area of interest such as a shipwreck. Multibeam sonar can therefore be used to generate accurate 3D digital terrain maps of the seabed. In an earlier work, Chapman et al. (1999) described how an accurate visualization of the SS Richard Montgomery shipwreck could be generated by performing a high resolution bathymetric sonar survey around and over the wreck in order to generate the necessary digital terrain maps. The original engineering drawings of the vessel were then used to generate an accurate CAD model of the vessel which was then carefully overlaid onto the sonar returns.

4. Realistic Marine Visualizations

Visualizations of data gathered offshore are generally displayed using abstract rendering techniques. Abstract visualizations would typically provide archaeologists and scientists with the ability to gain an improved understanding of the collected data. Visualization by its very definition infers gaining 'insight' into the data. Some examples of abstract marine visualizations could be the use of hypsometric hints i.e. colouring the seabed as a function of depth in order to identify seabed anomalies (Chapman 2001). Popular software for abstract visualizations of marine data includes Fledermaus (Nautronix 2000) and CFloor (Smedvig 2000).

Sometimes realism is the primary goal and any form of visual abstraction will detract from the sense of immersion that we desire from the final rendering. Examples may include training an ROV (Remotely Operated Vehicle) pilot to fly an ROV submersible using a simulator. The pilot's main information source will be from the video cameras mounted on the virtual ROV. The display from these cameras will be computer generated graphics of the underwater environment where realism is the key. Immersive visualizations are not limited to training purposes. For example we may wish to provide school children with a simplified ROV control system and ask them to locate and investigate an archaeological site on the seabed at a specific Easting and Northing.

Some key ingredients for a realistic marine environment include:

- Underwater fog for depth perception
- Lighting effects
  - God rays
  - Caustic effects
- Silt modelling for providing the viewer with an indication of current flow
- Bubbles
- Marine life
  - Fish shoals
  - Vegetation

Pixar's box office hit 'Finding Nemo' (Disney and Pixar 2004) is an excellent example of state of the art realistic marine rendering. Excluding the talking fish elements of the film, Pixar demonstrate extremely realistic marine rendering techniques[2]. However, the penalty paid for accurate marine rendering techniques employed by Pixar is the overhead in the processing time required for rendering. A single frame of animation for these types of films can take as long as 90 hours to produce. Any form of real-time interaction is not feasible due to the processing time required to calculate a dynamically changing display.

4.1 Modelling Marine Life in Real-time

As described previously, extremely accurate and realistic graphical depictions of marine environments have been achieved using off-line rendering. However, user interaction is imperative for our archaeological marine model and therefore modelling and rendering of the marine environment must be in real-time.

Recent advances in graphics hardware, specifically developments in the graphics processor unit (GPU) have provided the graphics programmer with a lot more control over the way they render. For example, the development of Cg which is a high-level shading language that makes graphics programming faster and easier (Fernando and Kilgard 2003). We propose a technique for realistically rendering a swimming fish in real-time by modifying the vertices of the fish using the graphics processor and the Cg vertex shading language.

Vertex shaders provide the ability to transform the coordinates of input vertices through the application of complex mathematical functions which include trigonometric functions. A first observation of a fish in motion suggests a sine wave travelling along the body of the fish. This motion is similar in nature to other deformable animals such as snakes and worms. Initial modelling attempts investigated the implementation of a pure sine wave function but the deformation of the fish appeared rubbery and with large deflections in the head that did not conform to the fish's general heading. Subsequent investigations considered a linearly attenuated sine wave which improved the appearance of the subject heading but it was noted that the severity of the attenuation needed to be increased towards the head. Consequently our real-time fish function evolved into a square attenuated sine algorithm which is briefly described below. The website www.marinevis.com contains a complete derivation of the functions described (which is outside the scope of this paper) and includes animations and other mathematical functions that can be applied (via Cg) to 3D models of marine plant life.

For our example fish modelling exercise, we shall use a Neon Tetra 3D fish model (*Fig. 2*) kindly donated for research purposes by Toucan Ltd. Fig. 2 and Fig. 3 show a 3D and plan view of our model.

Let the set of vertices making up the fish in model space be S, and any vertex i within it be specified by

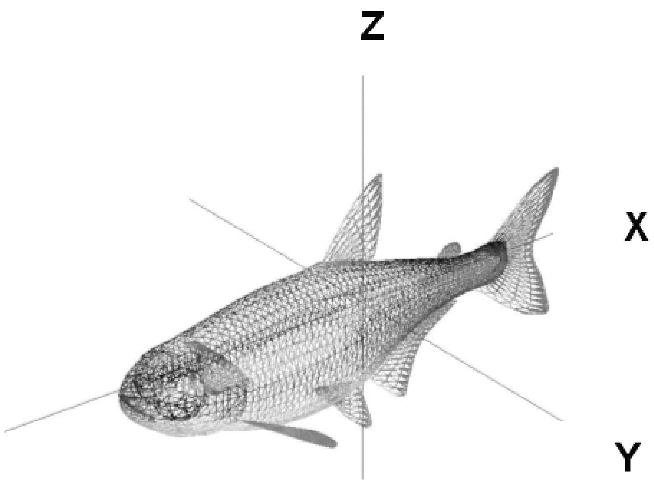

Fig. 2. Fish model in three-dimensional space.

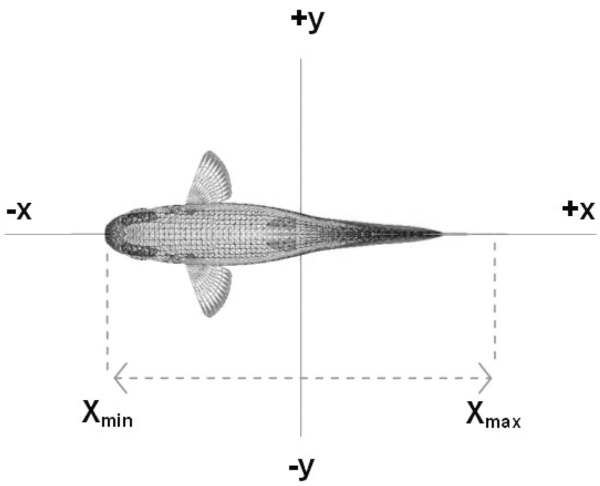

Fig. 3. XY Plane view of fish.

$$P_i \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} \quad \text{so that} \quad S = \{P_i | 1 < i < n_s\}$$

where n_3 is the number of vertices making up the fish model. *Fig. 4* describes an attenuating square function that is defined by two points: the point of maximum attenuation along the fish's lateral as a fraction of the length of the fish, K, and the amplitude of deflection at the tip of the fish's tail (maximum amplitude), A_s.

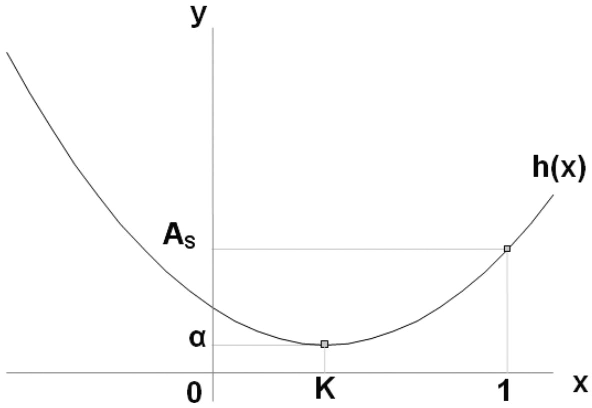

Fig. 4. Square function for attenuation.

Where

$$h(x) = (A_s - \alpha)\left(\frac{x-K}{1-K}\right)^2 + \alpha$$

To control the fraction of a full sine wave period applied to the length of the fish body and to investigate the quantity that gives the best results, we introduced a factor, β, such that $0 \leq \beta \leq 1$. To translate the wave across the body of the fish, we make use of a time-varying phase angle, θ, such that $0 \leq \theta \leq 2\pi$

We represent our square function f_S for modifying our fish vertices as:

$$f_S(P_i) = \begin{bmatrix} x_i \\ y_i + \left(C_0(x_i - C_1)^2 + \alpha\right) \cdot \sin(C_2(x_i - X_{\min}) + \theta) \\ z_i \end{bmatrix}$$

Where:

$$L = X_{\max} - X_{\min} \qquad M = \frac{\sqrt{A_s - \alpha}}{1-K}$$

$$C_0 = \frac{M_s L - \alpha}{\{L(1-K)\}^2} \qquad C_1 = X_{\min} + KL$$

$$C_2 = \frac{2\pi\beta}{L}$$

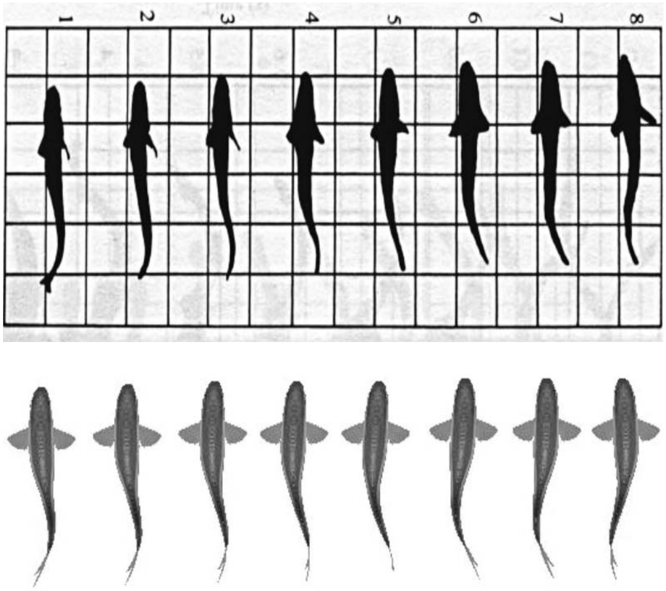

Fig. 5. Comparison of real fish motion (top) (Blake 1983) and simulated fish using the square-attenuated sine algorithm (bottom).

The outputs from the square attenuated sine algorithm were compared with the photograph of a real fish in motion (Blake, 1983) to determine how closely they matched the expected behaviour. To do this, the phase angle was varied and top view images of the resulting deformed models taken for comparison. Although the results are not perfect they do provide a reasonably realistic effect of fish motion that can be applied in real-time using contemporary GPU technology.
As can be seen from the comparison, it was possible to approach the appearance of deformations in real fish by varying the phase angle in the square attenuated sine algorithm. It allows for the upper body to experience minimal curvature while the tail flaps through sufficiently high displacements. The movement in the head of the fish is also appropriately controlled by the a parameter.
Multiple instances of our fish model can be dynamically modelled as a shoal of fish by implementing a flocking algorithm as a basis for group behaviour in a school of fish. In this method, general flocking behaviour is simulated via three components. Specifically: separation steering, cohesion steering and alignment steering (Reynolds 1987). Each of these behaviours is determined by observing individuals within the region of visibility of any fish under consideration. This region or neighbourhood of the fish is defined by a viewing angle and a distance. An example of a shoal of fish can be seen swimming in an immersive 3D environment in Fig. 6. Two minor constrains placed on our fish models in order to improve the realism of the scene include no rolling or vertical swimming.

5. Immersive Displays for Marine Visualization

We briefly describe two immersive display technologies that we have found to be appropriate for the visualization of marine environments. Specifically the power wall and hemisphere display systems.

Fig. 6. Power wall. 3D stereoscopic view of underwater environment for multiple seated participants.

5.1 Power Wall

The power wall based within the HIVE at Hull is a large 6x3m stereo rear projected system located within an auditorium (*Fig. 6*). LCD flicker glasses provide the participants sitting within the auditorium with a stereographic 3D display. Rendering the marine environment using the power wall gives the impression of standing next to a large glass window that contains a deep water aquarium. Careful calibration and definition of the stereo view parameters results in the stereo effect appearing behind the wall (the 3D effect is apparent behind the display and not 'jumping out' at the viewer).
The HIVE also contains a number of tracking devices which permit a single viewer to be head-tracked. Consequently the computer can update the stereo view projection based on the position and orientation of the user's viewpoint. The main disadvantage of the power wall is that it is not portable. Other popular immersive stereo display technologies include helmet mounted displays (HMDs) that are extremely portable but have a limited field of vision and resolution. Hemisphere displays, such as those marketed by Elumens Ltd can provide a portable immersive solution for marine visualization.

5.2 Hemisphere Display

Displays such as the VisionStation (Elumens 2002) are immersive, multi-user single projector hemispherical display systems. The VisionStation Display is a 1.5m diameter parabola display similar in appearance to an oversized satellite dish. The user sits within the parabola and a projector with a specially designed lens projects a pre-distorted image onto the parabola's surface. The viewer's entire view (including periphery vision) is consumed within the display and consequently the sense of immersion experienced is extremely high.
For the projected rendering to appear correctly displayed, our planar images must be pre-distorted for projection onto the hemispheric display. Elumens kindly provide an SDK down-loadable from their website that can easily be implemented within OpenGL programs. For high resolution animations, the company also provide a 3D Studio Max plug-in for generating distortions offline.

Fig. 7 shows a flat section of seabed and pipeline that has been spherically distorted ready for projection.
Fig. 8 shows the viewer sitting inside the hemisphere display viewing the pre-distorted image.
The hemisphere display is ideally suited to the immersive visualization of underwater environments because the parabolic nature of the display is similar to the parabolic 'glass bubble' window found in deep sea submarines.

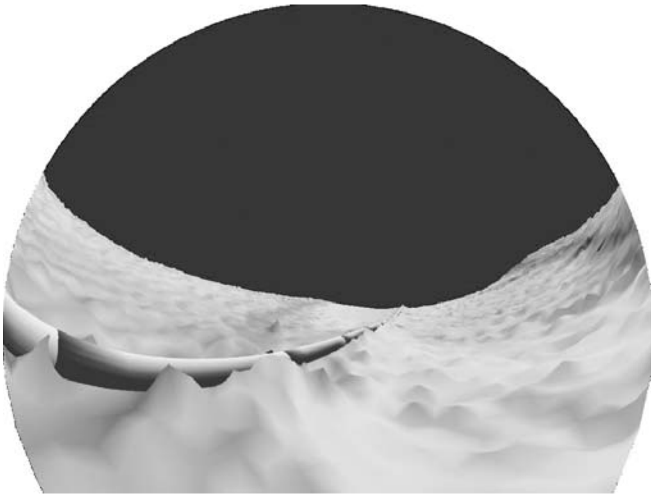

Fig. 7. Flat section of seabed and underwater pipeline that has been hemispherically distorted for projection onto hemisphere display.

Fig. 8. User sitting in hemisphere display that can be used as an effective virtual submarine 'glass bubble' window into the marine environment.

6. Conclusions

Advances in computer graphics hardware, virtual reality systems and offshore sonar technology coupled with improved site recording and collaborations between archaeologists and computer scientists will result in members of the public, archaeologists and scientists being able to experience virtual representations of fragile underwater archaeological sites. Accurate marine environmental modelling linked to archaeological site databases and immersive display technology has the potential to significantly improve our awareness and understanding of these inaccessible underwater archeologically sites in their original habitat.
Readers interested in the work outlined in this paper should visit www.marinevis.com a website dedicated to both abstract and realistic rendering of our seas and oceans using computer graphics. More information relating to the Hull Immersive Visualization Environment (HIVE) may be found on the internet at www.hive.hull.ac.uk.

Notes

1 HIVE - Hull Immersive and Visualization Environment www.hive.hull.ac.uk

2 A trailer for this film demonstrating offline high resolution marine rendering techniques can be downloaded from http://www.pixar.com/featurefilms/nemo/theater/index.html

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References

Disney/Pixar http://www.pixar.com/featurefilms/nemo/ (visited 1/7/04)

OSG, 2004, Open Scene Graph http://www.openscenegraph.org (visited 1/7/04)

Ballard, R. D., Archbold, R. and Crean, P., 1995. *The Discovery of the Titanic.* 1 edn, Warner Books.

Blake, R. W., 1983. *Fish locomotion.* Cambridge, Cambridge university Press.

Doerr, M., .2003. The CIDOC CRM – An Ontological Approach to Semantic Interoperability of Metadata, *AI Magazine* 24(3).

Chalmers, A., 2002. Computer Graphics in Art History and Archaeology. *Computer Graphics and Applications* 22(5).

Chapman, P., Wills, D., Stevens, P. and Brookes, G., 1999, Visualizing underwater environments using multi-frequency sonar. *IEEE Computer Graphics and Applications* 19(5).

Chapman, P., Wills, D., Stevens, P., Brookes, G., 2001. 'Visualization Viewpoints: Real-time Visualization in the O?shore Industry', *IEEE Computer Graphics and Applications* 21 (4), 6–10.

Fernando, R. and Kilgard, M., 2003. *The Cg Tutorial :The Definitive Guide to Programmable Real-time Graphics*, Aw Professional.

Fish, J. and Carr, A., 1990. *Sound Underwater Images.* LowerCape Publishing.

Nautronix (2000), Nautronix Company Website. www.nautronix.com (visited 1/1/04).

Pratson, L. F. and Haxby, W. F., 1997. Panoramas of the Sea Floor. *Scientific American* (June) 67–71.

Reynolds, C. W., 1987. Flocks, herds, and schools: A distributed behavioral model. *Computer Graphics* 21(4), 25–34.

Smedvig 2000, RoxarWorld Website http://www.smedtech.com. (visited 1/1/04).

Urick, R.J., 1975. *Principles of Underwater Sound*. New York, McGraw-Hill.