A GRAPHIC APPROACH TO SONAR SIMULATION

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BIOGRAPHICAL INFORMATION

Mr Kevin Butcher is the Sub Surface Account Development Manager for GEC-Marconi Simulation and Training Division and lives in Weymouth, Dorset, UK.
He has 17 years experience in the design, development and implementation of Training Systems for the Naval sector, with a particular interest in the Anti-Submarine and Mine Warfare. Mr Butcher has been involved in most major ASW and Submarine Command Team Trainers built for the Royal Navy in the past 15 years. He has also assisted in the development of the Training Needs Analysis methodology for the Royal Navy and has worked

1. ABSTRACT

The current dramatic rise in the development and applications of modern graphics processors is evident in the world of 'virtual reality', but the immense power of these 'reality engines' and their suitability for other processing applications may, as yet, not be widely appreciated.

The similarity in the insonification of sea bottom objects by a 'high profiling' sonar and the illumination of the same from a visual camera provided just such an application to explore these possibilities.
The paper outlines a unique approach in the combination of the acoustic and visual simulation requirements within a host graphics processor for the production of high fidelity real time simulation in a complex mine-hunting scenario. It also demonstrates the benefits of improved performance and cost savings in the now familiar climate of cost efficient readiness, and how these techniques can be applied with similar results to other applications.

The implementation of the design concept and some of its remarkable features are highlighted in a system developed for the Sandown Class Single Role Minehunter Combined Operator Trainer which is now in service with the Royal Navy.

2. INTRODUCTION TO THE MINEHUNTING ENVIRONMENT

At the best of times the sea can be a hostile place, in a combat situation even the suspicion of mines increases that hostility; obstructing the passage of shipping, disrupting vital trade, limiting the deployment of naval interests, and prejudicing naval missions.
The best mine countermeasures vessels are essential but to ensure the survival of ship and crew the operators must be the best and work as a team. This means comprehensive training which must be as realistic as possible, precisely repeatable in a variety of conditions without risk, expenditure of stores or fuel and without wear and tear on the ship.
The requirement for the Sandown Command and Operator trainer was also set in this type of environment, where the demands on the project team were just as technically challenging. The trainer represents accurately the configuration of the actual operations room using as much of the real equipment as was economically possible to meet the stringent training fidelity requirements of the system.

The ships main minehunting sonar has search and classification for long range initial detection . It is important that once having located a possible mine then it should be classified accurately , located so that it can then be safely destroyed. Having detected and classified the object as a possible mine threat, the ship's crew then deploys a Remotely Operated Vehicle (ROV) which can be guided by means of an umbilical cable to the location of the suspected mine. The ROV itself carries a short range high definition sonar and a television camera to help guide it towards the object. A second camera mounted adjacent to a manipulator arm then enables; an explosive charge to be accurately placed near to the mine, or a mine mooring cable to be cut, all from the safety of the mother ship some distance away.
The search operation can then resume and the painstakingly thorough mine clearance process can then continue, all the time mapping the track so that the operation can be repeated at a later stage and any differences immediately detected (route survey).

3. ACOUSTIC REQUIREMENT

The typical acoustic environment in which a Minehunter operates is littoral waters, within a complex acoustic profile, and with high probabilities of influence from sea bottom, sea surface and mid water volume reverberation and scattering causing multi path propagation and interference of the acoustic wave. Shallow water is therefore by definition unpredictable and the modelling by consequence difficult. To maximise the performance in these conditions sonar systems tend therefore to be short range and high frequency, enabling reasonable profiling of sea bed, buried, floating or tethered objects.
The primary training requirement for the acoustic simulation was to produce accurate and high fidelity sonar images on the search, and classification sonar displays of the main Variable Depth Sonar (VDS). There was also the secondary requirement, but equally important; to generate the sonar images from the ROV necessary to facilitate accurate low speed manoeuvring of the vehicle in the proximity to a suspected mine.

Acoustic highlights are generated in these conditions by the reflection and scattering of the acoustic wave on the contours of mine or mine like objects. The characteristics of these vary considerably with frequency, pulse length, elevation and aspect, and add the critical classification detail to the general acoustic shadow cast by the sonar illumination of the target. To model the wide range of mine like objects to sufficient fidelity in a dynamic environment which is accurately repeatable requires therefore not only a high data processing load but also significant data storage.

Figure 1 shows a representation the sonar display where a ground mine is lying at an angle of approximately 60 degrees casting a shadow onto the seabed behind it. The shape and size are critical as the main sonar's Computer Aided Classification system uses this information to determine target size and mine -like probability.

4. VISUAL REQUIREMENT

The Remotely Operated Vehicle (ROV) and its visual capabilities are in many ways similar to the acoustic ones where the operating environment is almost as complex. The littoral shallow waters are generally clouded by sediment and bio-chemical organisms, causing defraction and filtering of the light rays. Operating ranges of the visual cameras can therefore be very short (1 to 10 metres). Search lights are carried by the ROV to illuminate search area and assist in location, manoeuvring and neutralisation operations.
The primary training requirement for the visual simulation of the TV images from the ROV was also similar to that of the acoustics , to facilitate slow speed manoeuvring of the vehicle in close proximity to a suspected mine,

There were a number of secondary requirements including; mine identification, where visual highlights similarly provide the characteristic detail for mine classification. Also the visual control of the manipulator arm using an additional monochrome camera and the additional effects of operating underwater in poor visibility and lighting conditions for both cameras were also important to meet the overall training requirement.

Figure 2 shows a visual example of a typical ground mine corresponding to the sonar image shown in Figure 1.

5. IMAGE PROCESSING

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The correlation between the sonar and visual modelling and the high fidelity representations of this environment were paramount, and whereas previous generations of this type of trainer had typically used completely separate modelling and hardware to present what was essentially the same "picture", the availability of new powerful "graphics engines" provided the opportunity to explore the advantages of a common technology approach.
The visual simulation was implemented using the same hardware designs as for the main sonar and the same software for the generation of the sonar image. It required only minor adaptations to provide the correct visual field of view and lighting models, since the basic lighting model is very similiar to the insonification model.
The same scenario model and seabed and entity databases could therefore be used for each of the following;

- Main Detection/Classification Sonar
- ROV Locator sonar
- ROV Locator camera (colour)
- ROV Manipulator arm camera(monochrome/low light)

The simulation of the monochrome and colour cameras is catered for as an accurate representation of how they appear on the command console remote displays.

The visual scene is three dimensional, viewed with a true perspective projection and with the same fields of view as the operational cameras i.e. 77 degrees horizontally by 60 degrees vertically for the black and white camera and 50 degrees horizontally by 40 degrees vertically for the colour camera. The simulation also provides the capability for full six degrees of freedom movement of the view point.
The visual scene content is composed of a number of objects including when in view mines and mine like objects , parts of the ROV , sea bottom ,contours and features, Bubbles are also introduced to give the impression of motion and relative speed through the water when not near the surface or bottom.
The visibility range (turbidity) can be selected by the instructor with ranges up to 30 meters in exceptional conditions.
The shade represented on the visual scene is determined by the depth of the ROV and the turbidity factor. The intrinsic shade for each face is selected to result in a value representative of its actual appearance in typical underwater visibility conditions at a range of 2 metres. The above surface ambient lighting factor is also selectable by the instructor appropriately for the time of day whilst the undersea ambient lighting factor is calculated as a function of the vehicle depth.
This also takes into account the complex effects of lighting variations caused by the ROV search lights.
For the monochrome camera a single shade value is calculated, and this is further modified to take into account the low light capability of the camera.
The control of the two ROV displays used for both the sonar and visual displays are both physically and functionally identical to these on board.
The ROV sonar was emulated using the same process as for the main hull mounted sonar and the same software for the generation of the intermediate stages with only minor adaptations necessary to reflect the different viewpoint and sonar specifications.

The total image process as shown in figure 3, and represented by the following processes:

(i). Image processing stage one (virtual 3D image)
The first stage of the process is to create and access realistic object modelling, which is fundamental to the quality of the system. A proprietary modelling tool Multigen was used to create realistic 3D models of mines, mine like objects and features in an open flight format. The seabed topography was digitised from Admiralty charts in the same way, to provide a realistic scene and the necessary repeatable operating area. The model format allows for enhancement and the introduction of new objects, seabed texture and seabed features.
Figure 4 shows the common Database library of seabed, sonar and visual models as used as precise location of mines and correlation between the main sonar , the ROV sonar and the camera visuals.

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(ii). Image processing stage two (intermediate sonar image)
This stage of the process is to combine information from the seabed, seabed features, mines and mine like objects into a virtual image of what sonar array “can see.” This image is called the Intermediate Sonar Image (ISI) and is represented by;- azimuth Vs the slant range.(the 3 dimensional distance from the sonar array to the object echoing surface).
To create the ISI, a technique called the Pseudo Visual Image (PVI) was used, which is an adaptation of the 3D visual simulation technique of depth (Z) buffering. It is used to perform

the hidden surface removal and the generation of acoustic shadows in the visual and sonar images.

This technique is shown in Figure 5 which can be seen to the provide the following advantages:

- The seabed can be scanned in any order
- Targets and seabed processed by the same process
- Generates target and seabed shadows automatically
- Seabed is processed on line (reduced memory requirements)

Figure 6 shows the generation of the Intermediate Sonar Image(ISI).

(iii). Image processing stage three (sonar image)

The final stage is to create the full Sonar Image(SI) by introducing the real world effects of the environment such as background noise, reverberation effects and the sensor inverse beamforming and pre-processing, time dependant gain characteristics which are necessary to provide a realistic stimulus to the sonar systems.

Figure 7 Shows the importance of the common database and library of sonar and visual models and the correlation between the main sonar , the ROV sonar and the ROV camera visuals.

5. SYSTEM REQUIREMENTS

Because of the requirement for constant range resolution throughout the range scale of the main sonar the resolution requirements were typically 10cm in a range scale of 1500m over 90deg field of view. The system also has a high update rate to accommodate the sonar's short transmission interval/refresh rate and to minimise the effects of latency in response to the dynamic steering the ROV cameras and sonar beams by the operators. The data processing and database requirements were therefore extremely large;
(10cm x 1500m x 90deg = 1.3million) pixels in the final image.

The system configuration selected to meet this demand was a Silicon Graphics Onyx reality engine using a total of 10 processors. The scale of the sonar simulation problem is put into context when it is considered that 8 of these were required for the main sonar and only 1 for the camera visuals. The system build was as follows;

(a)Graphics processors

- Main sonar ~ 8 processors
- ROV sonar ~ 1 processor
- ROV visuals ~ 1 processor

(b)Memory

seabed database ~ 70Mbyte

The software was written in 'C' in a UNIX environment.

6. BENEFITS

The benefits of a combined approach for this application are clear, in not only providing overall improved fidelity but in the important feature of

visual and acoustic acuity. Within the total training environment this has the ultimate effect of improving reality, tension, performance and therefore training effectiveness.
Other benefits can also be identified in the rationalisation and support of hardware, software, modelling, databases and the cost savings achieved over using conventional DSP technology.
All in all this has the significant advantage of providing not only realistic training but also significant savings in cost.

Figure 6 shows examples highlighting the advantages of providing this common simulation approach.

7. APPLICATIONS

The use of this approach and its undoubted success in service raises the interesting question of whether similar applications, opportunities or potential benefits exist for other projects or users?

The use of high performance graphics processors for applications where high processing rates and high data storage (mapping) are required may open the door for just these type of applications.

The possibilities for this may not be restricted to training systems and could of course be many but within the scope of this forum they could include:

(a) Simulation

- Navigation radar simulation
- Weather radar simulation
- Active sonar classification simulation.
- Sidescan sonar simulation
- Under ice sonar simulation

(b) Other

- 3D sonar processing
- 3D radar processing

3D sonar processing is particularly interesting where image enhancement offers the potential for improved detection and classification performance?.

8. SUMMARY

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To ensure operational effectiveness any navy needs thorough and realistic training on appropriate training equipment. Using dynamic interactive simulation on the latest high powered graphics processors has provided a high fidelity virtual combat environment where even the most complex and dangerous situation can be replayed over and over again for a single operator, or a full command team in perfect safety.

The complex training problem posed by this original requirement has been resolved by a unique approach, resulting in a solution which provides all the necessary requisites of high fidelity, high quality, high processing power and high data storage capacity. All of these attributes are fundamental in the world of high quality visuals and virtual reality, but can also be seen to have potentially exciting applications and benefits in other disciplines, particularly in the training world and also in the rapidly advancing world of real time sonar processing .

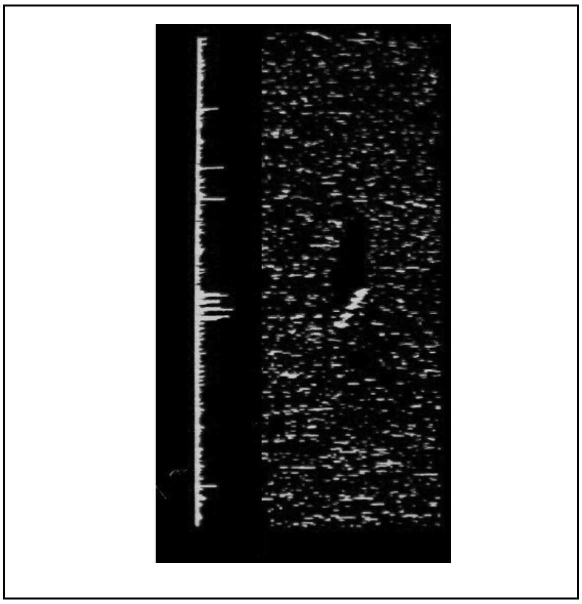

Figure 1. Typical sonar display

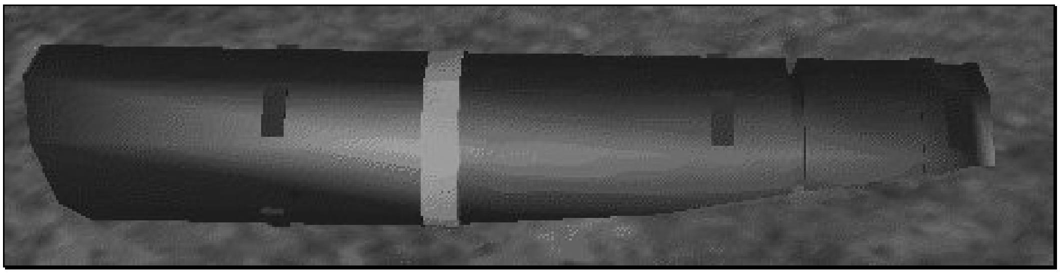

Figure 2. Visual camera view

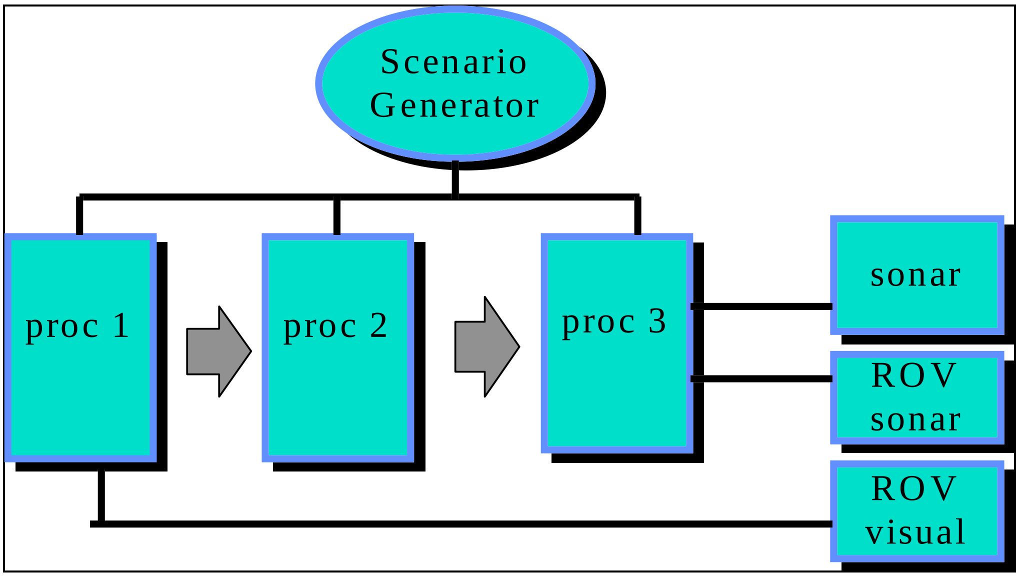

Figure 3. Combined Processing

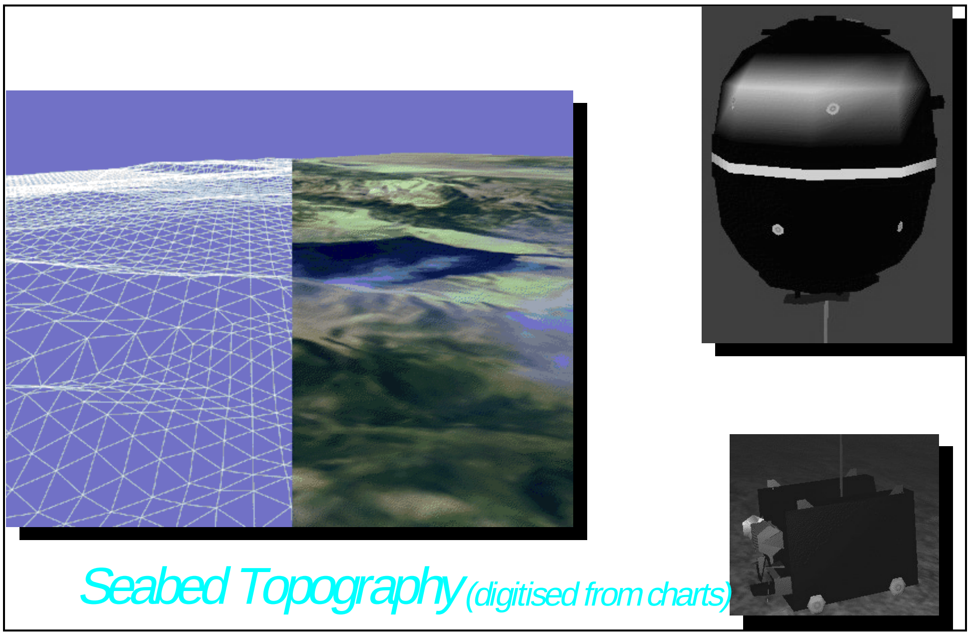

Figure 4. Database Library

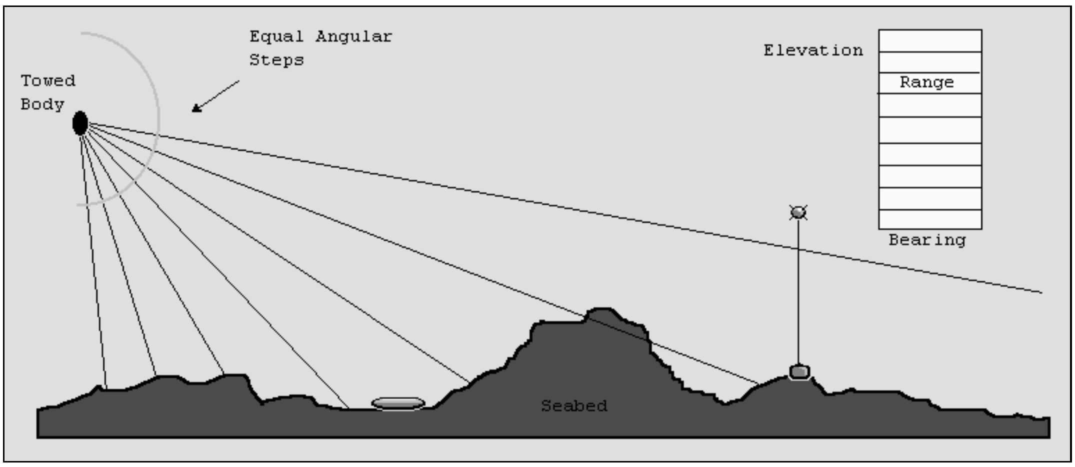

Figure 5. Pseudo Visual Image

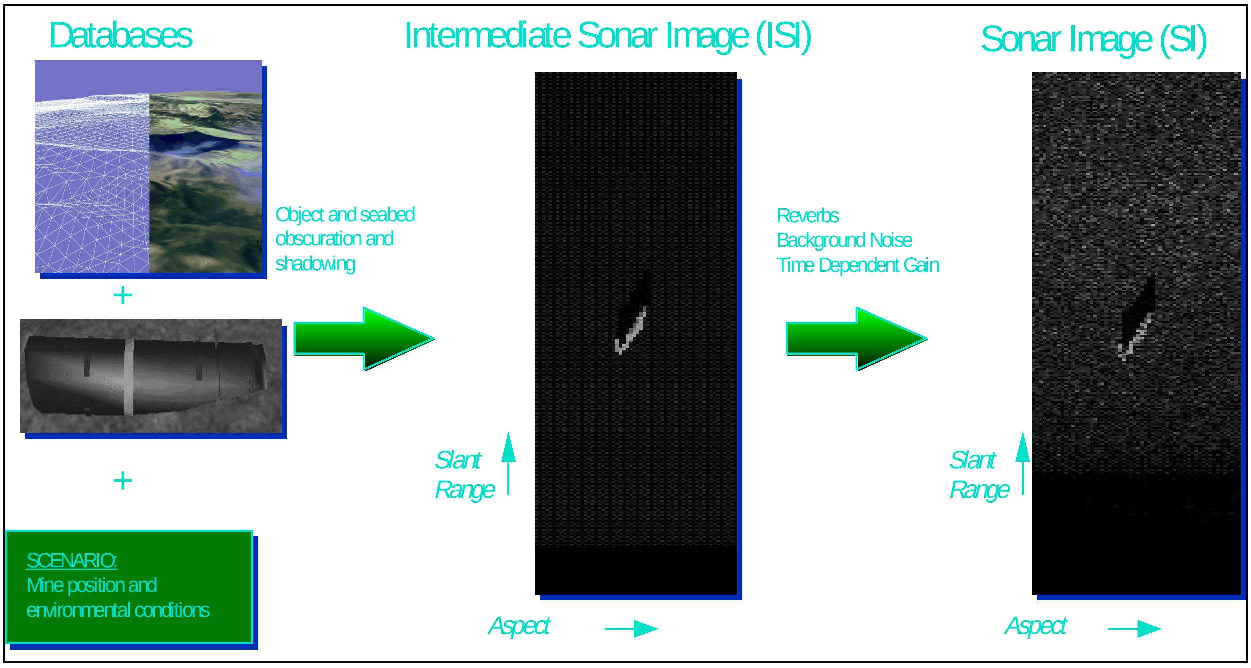

Figure 6 Sonar Image

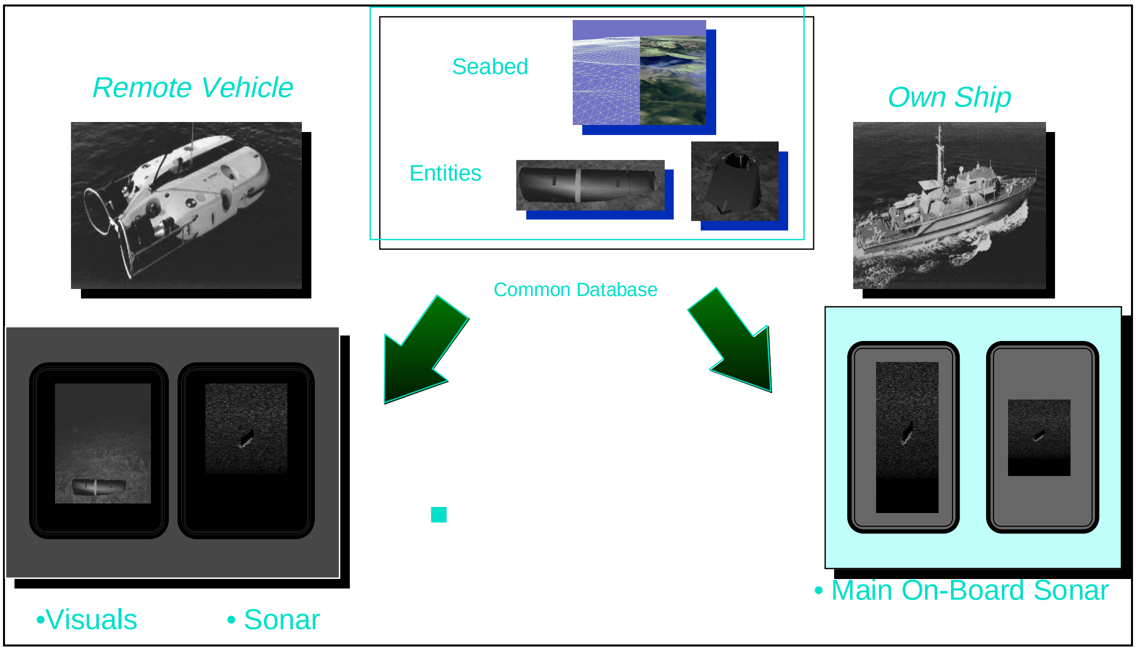

Figure 7 Complete Image Processing System