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Short communication

Remote multi-camera system for *in situ* observations of behaviour and predator/prey interactions of marine benthic macrofauna

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Abstract There are few options for obtaining information on intra- and inter-species behavioural interactions between marine animals other than direct observation. Underwater video and infrared lighting can be used to overcome some of the biases and limitations associated with diver observations. We outline the assembly and application of a multi-camera underwater video system consisting largely of moderately priced components produced for the security surveillance industry. Signals from up to eight cameras on the seafloor are processed on a floating pontoon into a single video stream and transmitted to a remote monitoring station for viewing or recording. High-red and infrared lights are used for night viewing to minimise disturbance. Experiments incorporating this system have provided high-quality data on predation and behaviour of lobsters.

Keywords underwater video; animal behaviour; predator/prey interactions

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INTRODUCTION

With the building emphasis on multi-species and ecosystem-based management of fisheries (Constable 2001), behaviour and interactions at the level of individuals have been increasingly recognised as key issues in understanding ecosystem function, organisation, and response to perturbation (Piraino et al. 2002; Butler 2003). Models capable of capturing the dynamics of individuals within a system (e.g., Werner et al. 2001; Butler 2003) depend on data collected at a resolution only attainable through direct observation.

Direct observations of marine animal behaviour are restricted to varying degrees by the harsh operating environment. Physiological limits to dive duration and physical limits to range of visibility complicate such studies under water. Behaviour of animals being observed is likely to be altered by the close proximity of divers (e.g., Rutecki et al. 1983). These difficulties are compounded when observing animals such as lobsters that are most active at night (Mills et al. 2004). Not only does diving become more hazardous, animals are also likely to respond to the presence of visible light required for observation.

Underwater video, time-lapse recording technology, and lighting at wavelengths invisible to animals have been adopted to overcome these problems. The use of single camera, fixed video systems has enabled constant monitoring of a limited area for periods of hours to days (Chapman & Howard 1979; Burrows et al. 1999; Jury et al. 2001). Although the use of video overcomes many of the problems and biases associated with diver observations, a single, fixed camera has a limited field of view. This problem is compounded at night when field of view is further limited by lighting. Possibilities to overcome this limitation include the use of remotely controlled cameras with zoom, pan and tilt functions, or the use of multiple cameras. We chose to adopt the latter as we believe it offers a simple, robust system with greater versatility. This paper provides details of a multi-camera system

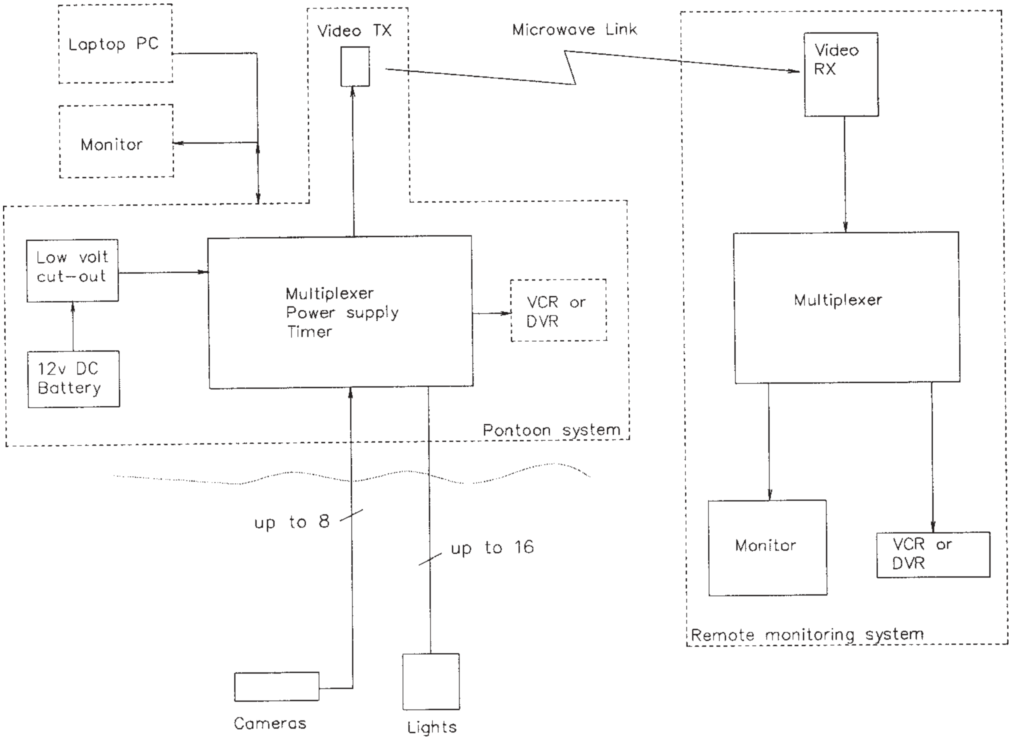

Fig. 1 Schematic representation of camera system. Pontoon system provides power to lights and cameras, and receives the signals from up to eight cameras. These are processed into a single data stream, and transmitted (TX) to the remote video receiver (RX). Camera settings and frame rates can be altered using a computer via a physical connection to the multiplexer unit. Multiplexed video signal can be recorded to a single storage medium (e.g., video cassette) at a remote station or on the pontoon.

constructed predominantly using off-the-shelf items designed for the security surveillance industry.

System assembly

The camera system has three main component types: an underwater system consisting of cameras and lights; a surface pontoon system including power supply, video processor and transmitter; and a remote monitoring system including video receiver, decoder, and recording device (Fig. 1).

Cameras were low light (0.05 lux) black and white 1/3″ CCD (charge couple device) image sensors with a 3.6 mm lens (GoVideo 3619 modules) providing a 42° viewing angle in water. Black and white CCDs were used as they have a broader wavelength detection capability than colour modules, enabling viewing with infrared light. Camera modules were protected in waterproof housings, and linked to the surface system by 30 m polyurethane-sheathed copper cables. To guarantee a clean power supply for the cameras, a switch-mode DC-DC converter (Cosel ZUS151212) was fitted providing regulated 12 V DC.

We constructed high-red lights emitting a wavelength of 680 nm and infrared lights with wavelength of 845 nm for use in different circumstances. Choice of wavelength of lighting sources is critical. Absorption of light in water increases dramatically as wavelength increases into the red region of the visible spectrum, and then increases exponentially at infrared wavelengths. Increases are particularly marked at c. 700 nm for red light and 850 nm for infrared light (Kirk 1994). Applying formulae presented in Kirk (1994) we find that in water 72% of 680 nm high-red light is transmitted at a distance of 1 m and this reduces to 14% at infrared wavelengths of 845 nm.

All lights consisted of an array of 40 high intensity light emitting diodes (max. radiant intensity c. 120 mW/sr @ 100 mA) encapsulated in resin for

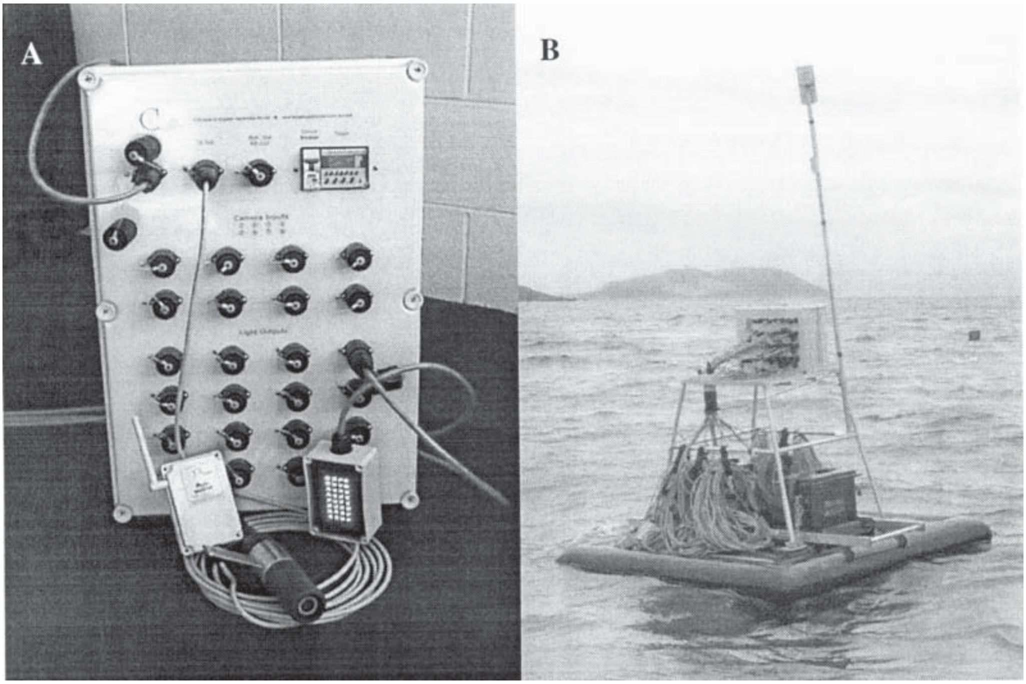

Fig. 2 **A**, Main multiplexer, power supply and timer unit with weatherproof connectors for camera inputs (eight connectors) power supply to lights (16 connectors) and multiplexer control, transmitter out and power in from batteries (one connector each). Also shown are a camera (lower centre) transmitter (lower left) and high-red light (lower right). **B**, Pontoon with light and camera cables coiled on frame ready for deployment. A moulded plastic hood covers the top of the system once deployment is complete.

protection and waterproofing, and connected to the pontoon system via a 30 m polyurethane-sheathed cable. Two of these lights were deployed with each camera and together are capable of effectively illuminating an area of seafloor not greater than 0.8 × 0.8 m from a distance of c. 0.8 m.

Camera and light cables are connected on the surface pontoon to a weatherproof housing (Fig. 2A) containing the camera power supply, a timer to allow lights to be switched on and off when appropriate, and a multiplexer. A duplex time-division multiplexer (AND MPC8DX) is central to the functioning of this system. The multiplexer receives the signals from up to eight cameras simultaneously, samples the video inputs from each camera sequentially, and interleaves sampled frames into one composite video signal. This coded signal from all cameras can then be recorded directly on a single recording medium, or transmitted to a remote monitoring station. To view the signal, whether live or from videotape, a decoding multiplexer reassembles the frames into single camera video streams. Images can be viewed with several cameras displayed on a split screen, or a single camera can be viewed in full-screen resolution. The penalty for using a multiplexed signal is that the frame rate from each camera is reduced to a degree defined by the number of cameras being monitored. For example, when recording 24 h of footage to a 3 h videotape with eight cameras connected, a frame is captured from each camera at c. 1 s intervals. Multiplexer settings, including individual camera brightness and contrast, frame capture rate, and on-screen displays can be adjusted using a laptop computer interfaced to the multiplexer via a weatherproof connector on the housing.

Power is provided to the system by 2 × 165 amp-h deep-cycle lead acid batteries (Trojan 5SHP) housed in waterproof boxes on the pontoon (Fig. 2B) connected in parallel. Batteries must be exchanged at intervals of 24 h. Solar panels could be used to extend time between battery changes although they would be susceptible to damage during system deployment. A low-voltage cutout unit is connected in series after the batteries. If circumstances such as poor weather do not allow for battery changes, this prevents over-discharge and subsequent damage to the batteries.

The camera signals are transmitted to a remote monitoring station using a microwave video link operating in the 2.4 GHz license-free band. Output power is low (10 mW) and transmission range varies greatly depending on weather, location, and antenna type. With a directional parabolic antenna on the receiver, range may be up to 1.6 km. Although this short transmission range was suited to our application, a system with a range of in excess of 10 km could be built using a video server coupled with a wireless network hub. The remote monitoring station may be set up on a boat or on land, and consists of a video receiver, multiplexer to decode video signals, a monitor, and a recording device. Camera signals can be recorded using a 12 V time-lapse VCR (e.g., Mitsubishi HS-7424EDC) or similar digital device. Where there is no convenient site to establish a remote station, the signal can be recorded on the pontoon. This system has the disadvantage that access to the pontoon is required to change recording media.

The pontoon base was constructed from three squares, one inside another, of welded polyethylene tubing (250 mm diam., 12 mm wall thickness). The outer square has sides of 1.7 m. This provides sufficient buoyancy and stability to support the camera system and up to two people during battery changes and deployment. Cameras and lights are deployed by lowering them to the seafloor through a 0.3×0.3 m hole in the centre of the pontoon. An aluminium frame supports the weatherproof housing (and recording device if used) c. 1 m above the water surface. A plastic hood (not shown in Fig. 2B) is placed over the housing once the system is deployed. The pontoon is held in place and stabilised by three anchors connected by chain and rope to the sides of the pontoon. This prevents the pontoon from turning and tangling camera and light cables. The system can be deployed by three operators in a vessel as small as 7 m. Operators should consider the potential navigational hazard presented by the pontoon, and provide navigation lighting as prescribed by local regulations.

This system has the capacity to generate immense quantities of video data. For review purposes, a video signal splitter was built that enabled the signal to be fed to two multiplexers, and thus up to eight cameras could be viewed simultaneously on two split screens. When an event of interest occurred, single cameras were brought up in full screen view for detailed observation. Signals recorded in 24 h time-lapse were reviewed at standard video speed, thus taking a minimum of 3 h to review 24 h of footage from up to eight cameras.

System applications

Using this system we have observed and quantified behaviours and interactions between lobsters and predators that were previously unknown and difficult to observe by other methods. Oliver et al. (2005) monitored the fate of tethered lobsters, identifying major predators (Fig. 3A) and determining survival time and diel variations in predation rates. These same data were used to test the validity of tethering trials in determining spatial variability in survival rates (Gardner et al. 2004), and showed that without detailed information on predator suite composition, tethering results could be very misleading. Lobster catch rates in traps are routinely used as a measure of abundance for stock assessment purposes, and a simple linear relationship between catch and abundance is assumed. Green (2002) used this camera system to observe behaviour of lobsters in and around traps (Fig. 3B), and demonstrated that the trap catch was influenced by a complex mosaic of interactions before, during, and after entering a trap, with only 13% of the observed lobsters being caught. These experiments illustrate the versatility of the multi-camera approach, using the cameras to observe simultaneous experimental replicates (Oliver et al. 2005), or to build a composite picture of a larger area with images from several perspectives (Green 2002).

Different lighting sources were used in the two experiments. Green (2002) was interested in lobster behaviour and interactions between lobsters. The anatomy of *Jasus edwardsii* eyes is such that they are incapable of perceiving red light of wavelength greater than 600 nm (Meyer-Rochow & Tiang 1984). Accordingly, high-red lights were used without concerns about influencing behaviour. As the extinction of high-red light in water is substantially lower than that of infrared light (Kirk 1994), high-red lights provide brighter illumination than infrared lights for the same power consumption. Oliver et al. (2005) were interested in the behaviour of lobster predators including fish and octopus. The complex eyes of these predators can likely perceive high-red light, so infrared lights were used.

The versatility of this system will see it used in the near future in diverse projects observing octopus behaviour around lobster pots, predation on invading sea urchins, comparative behaviour of lobsters on natural and artificial reefs, and spawning behaviour in reef fishes. We believe that the use of video

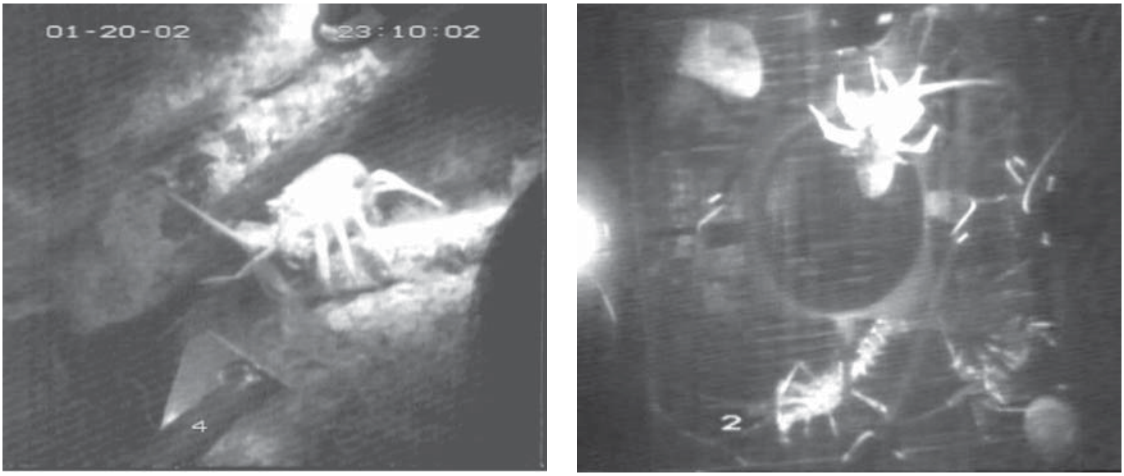

Fig. 3 **A**, Adult wild lobster observed at night under infrared light just after capturing a small tethered lobster. **B**, Lobster trap viewed from above at night using high-red light. One lobster is exiting the pot, while several other lobsters can be seen within the pot.

systems as described in this paper will become an integral component of research to address questions relating to ecosystem-based management and the effects of fishing on the marine environment.

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