INSTRUMENTATION FOR REMOTE CONTROL OF A DREDGE

G. L. Cavanough [1], M. Kochanek[2] , J. Cunningham[3] and Simon Prebble[4]

ABSTRACT

Remote control of a dredge requires reliable measurement of key operating components of the dredge. The development of strategies to measure these components are presented in this paper and include:

- Measurement of rope position by using a inexpensive, bow mounted sonar sensor in conjunction with GPS data. When the dredge approaches the limit of the side-to-side slew, one rope passes under the bow sonar and it is detected. At that time, the GPS heading is recorded and the location of the rope is calculated using the known geometry of the dredge and cutter. Similarly the position of the other rope can be determined as the dredge swings to the other slew limit. From then on, the system can track the location of the cutter and ropes to alarm if a collision is imminent. The system can accommodate changes in the anchor position because it automatically updates each time the dredge swings to the limit of the slew.
- Measurement of pond depth using several inexpensive non-scanning sonar sensors. Scanning is achieved by the motion of the dredge and the allocation of a depth measurement to a location as per the GPS data.
- Measurement of spud position and height using vertical scanning lasers.
- Measurement of mine face position using a horizontal scanning laser at the bow of the dredge.
- Measurement of vibration, video and audio signals using digital devices.
- Communication of measurement data and control signals via a redundant path digital wireless network.

Keywords: Dredging, mining, mineral sands, automation, control systems.

INTRODUCTION

The potential to remote or automate the operation of a dredge has been demonstrated by some successfully completed projects. Remote control and automation in mining applications are expanding and have generally involved special situations rather than standard industry practice. The retro-fit of remote control to existing mining applications often requires additional sensor technology to compensate for the loss of operator observations. Remote control is applied especially where safety rather than economics is of particular concern. (Hardgrave et al, 2003, Cunningham and Gipps, 3003) Remote control dredge projects include cleanup of radioactive sludge in ponds and the dredging of contaminated lagoons. To allow remote or automated operation instrumentation has been developed or adapted to particular measurement tasks (for example Schulte et al. (2001)).

This paper reports on a dredge research and monitoring project. The objective of this project was to develop, install and trial a system to monitor all of the critical sensory activities required if the dredge were controlled remotely. Based on results from the monitoring, another objective was to provide a high level design and plan for installation of a dredge remote control system. Discussions in this paper will focus on the instrumentation systems/strategies developed as part of this project following a brief description of the mining operation and normal method of dredging.

[1] Engineer, CSIRO Division of Exploration and Mining, QCAT, Technology Court, Pullenvale, Qld 4069 Australia T: +61-7-3327-4148, F: +61-7-3327-4566, Email: gary.cavanough@csiro.au

[2] Physicist, CSIRO Division of Exploration and Mining, QCAT, Technology Court, Pullenvale, Qld 4069 Australia T: +61-7-3327-4178, F: +61-7-3327-4566, Email: mark.kochanel@csiro.au

[3]Stream Leader, CSIRO Division of Exploration and Mining, QCAT, Technology Court, Pullenvale, Qld 4069 Australia T: +61-7-3327-4178, F: +61-7-3327-4699, Email: jock.cunningham@csiro.au

[4] Operations Manager, Consolidated Rutile Limited, PO Box 47, Dunwich Qld 4183 Australia, T: +61-7-3409-6800, F: +61-7- 3409-6801, Email: simon.prebble@iluka.com

Description of Mining Operation

Mining is conducted from a 50 tonne dredge floating on an artificially created freshwater pond (refer Figure 1). The pond advances as the dredge undermines the mine face creating a continuous failure and collapse of sand into the pond. The sands recovered by dredging are processed through a floating wet process plant (Concentrator – refer Figure 1) to produce a first stage concentrate. The waste sand is re-deposited behind the pond and forms an advancing beach into the pond. Depth of mining within the pond is set at approximately 15 m below water level with a production rate of between three and four thousands tonnes per hour.

Figure 1. Mining showing dredge, concentrator and mine face.

Normal Method of Dredging

When the dredge is operating in its' typical mode, mining the face along a given centre line, the operator will sweep the dredge back and forth across the face in a regular arc about the anchored point of the spud (refer Figure 2). In this mode of operation, the main controls used are the slew lines that run from two fixed anchor locations, high on the top of the face on opposite sides of the dredge, and along to the ladder (structure supporting cutter and slurry pipes that can be raised and lowered – refer to Figure 4). The dredge operator controls this movement by means of cable reeling drums near the base of the ladder, shortening one line while lengthening the other in order to swing the nose of the vessel to either starboard or port.

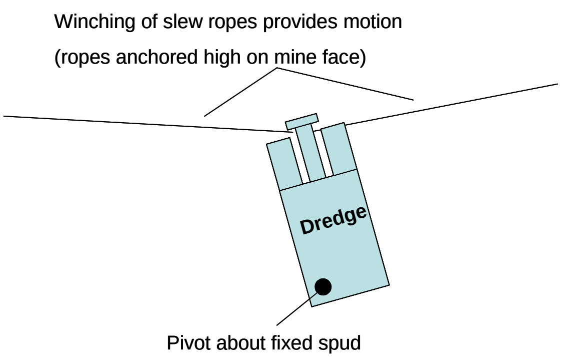

Figure 2. Description of normal dredge motion.

INSTRUMENTATION

Pond Level Detection

Commercial sonar scanning systems were investigated and the equipment costs were found to be between $AUD200 000 and $AUD500 000. Further investigation and past experience in the processing industry determined that equipment used to measure the bed depth of mineral processing thickener tanks may be suitable for pond depth measurement. Consequently, a site test was conducted using the Royce Interface Level Analyser (ILA-refer Figure 5) instead of the more costly instruments. The test involved taking depth measurements around the dredge using the ILA and comparing them with readings taken simultaneously using a weighted rope measurement line. Comparison of results showed that the ILA was within 1cm of the correct pond depth. Consequently three ILA's were installed on the dredge. One ILA was installed at the bow, one at the forward end of the main spud slot (approximately at the middle of the dredge) and one on the float line near the third float from the dredge.

In addition to a real time measurement of pond depth at three positions along the dredge, a method to generate and plot a pond depth profile was deduced. This method uses the GPS data to store the pond depth measurement and the physical location of each sensor every 7.5 seconds. As the dredge moves across the pond the bottom profile is built up from this data and plotted as a colour depth map on the operator screen (refer Figure 3).

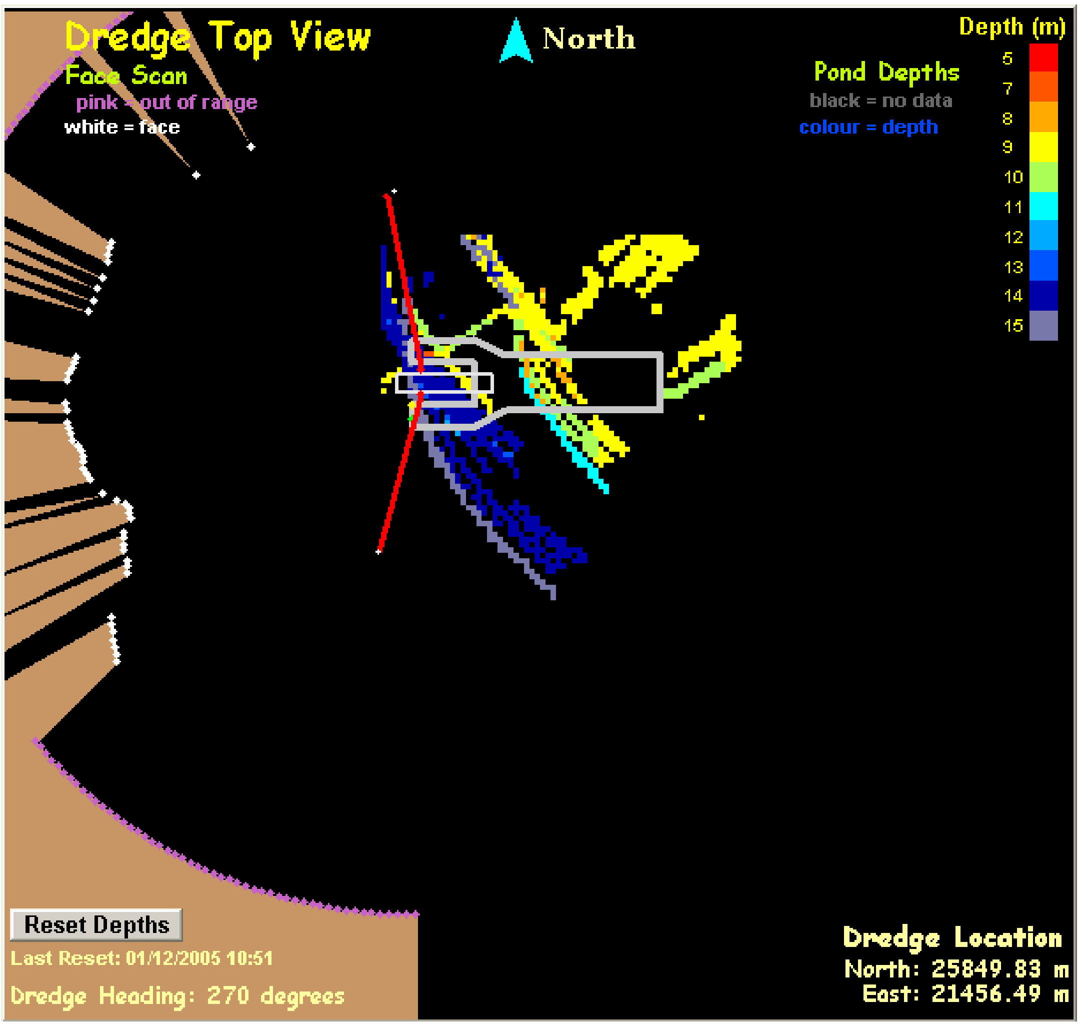

Figure 3. Display screen showing dredge with pond depth data (note rope position is red lines and parts of face are beyond the 80m range of the laser).

Rope Position Measurement

The dredge has two slew ropes. Each rope is attached to an anchor located at the top of the face. From the anchor position, the ropes pass down the face into the pond and over a sheave wheel to a winch drum located on the deck of the dredge (refer Figure 4). A commercial device is available to measure the angle of the sheave wheel (and hence rope angular position). However, rope angle was not identified as critical parameter for remote control. Instead the proximity of the rope to the cutter was identified as the critical measurement.

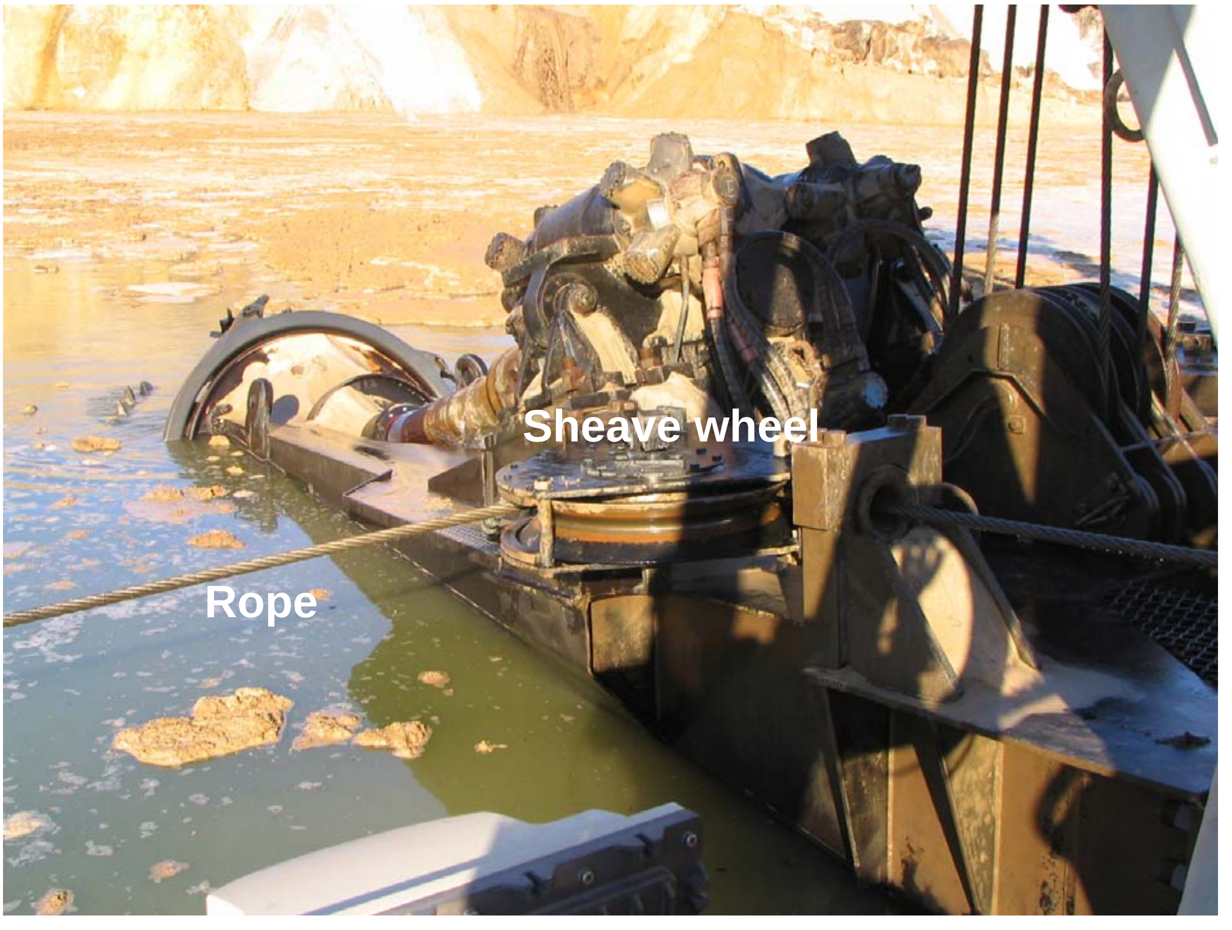

Figure 4. Cutter lifted to show sheave wheel and rope.

The rope position was determined by using a combination of "Global Position System" (GPS) location/bearing information and a Royce Interface Level Analyser (ILA) (refer to Figure 5)

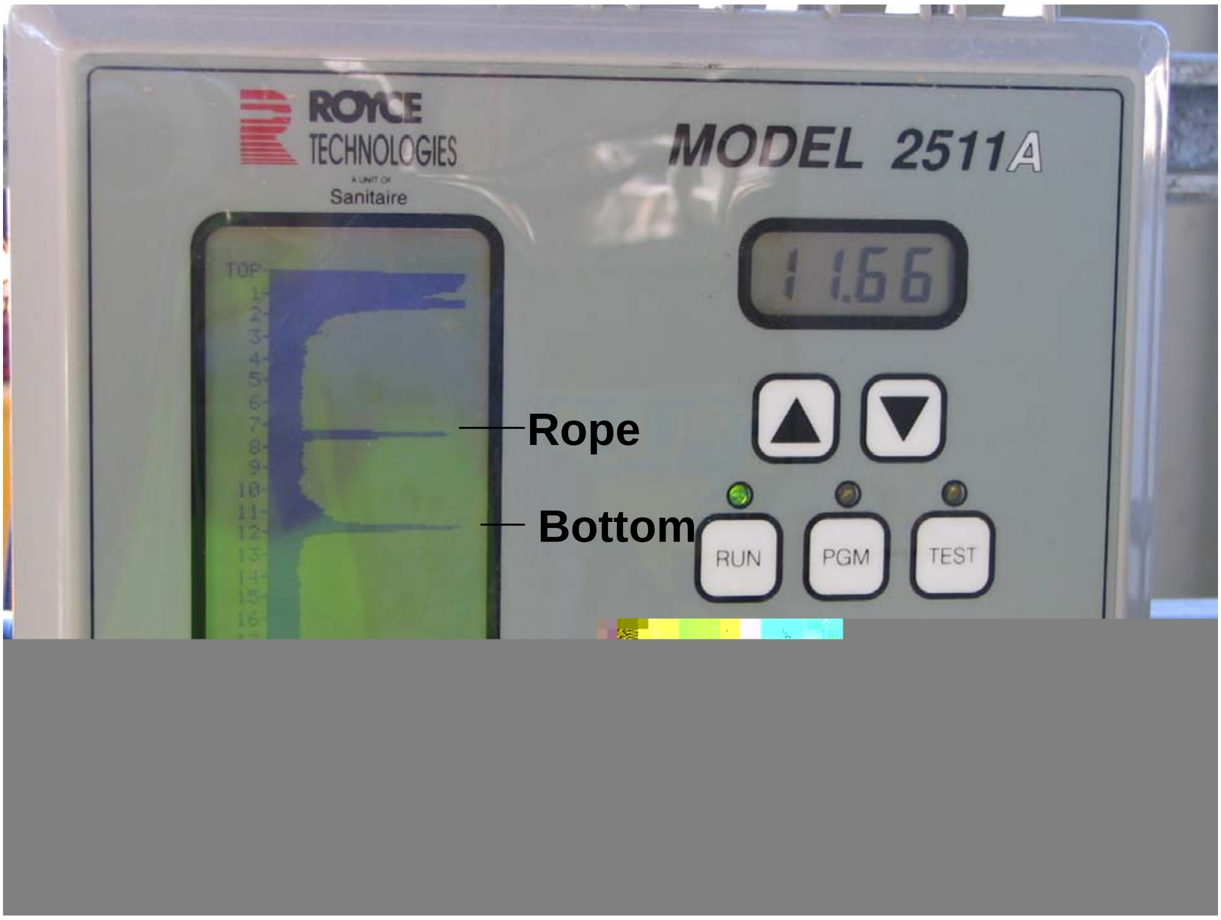

Figure 5. Face plate of Interface level analyzer showing signal for rope and bottom of pond.

The measurement sequence is as follows (refer also to Figure 6).

- As the dredge swing approaches the limit, the rope passes under the ILA,
- The ILA sonar detects the rope as it passes into the sonar beam,
- When the rope is detected under the ILA, the GPS information and the ladder geometry is used to calculate the bearing angle of the rope and its position in plan view,
- By inference, this then provides an estimate of the position of the rope anchors,
- Once the rope anchor orientation is known, the rope angle can be continuously calculated and plotted on the display (refer Figure 3 and Figure 7) using the GPS position as the dredge swings towards the other limit,
- If the rope anchor is moved or is hung up on the face the new position is automatically calculated the next time the rope sweeps beneath the ILA.

Figure 7 shows the graphical alarm indicator and Figure 3 shows the rope position displayed with depth and face position data.

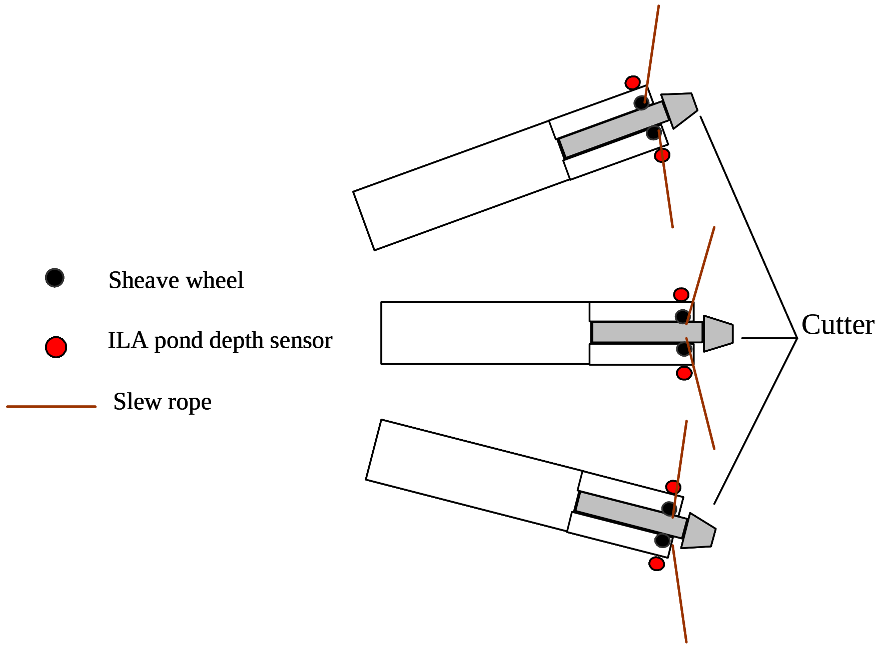

Figure 6. Plan view of dredge at different points in cycle swing.

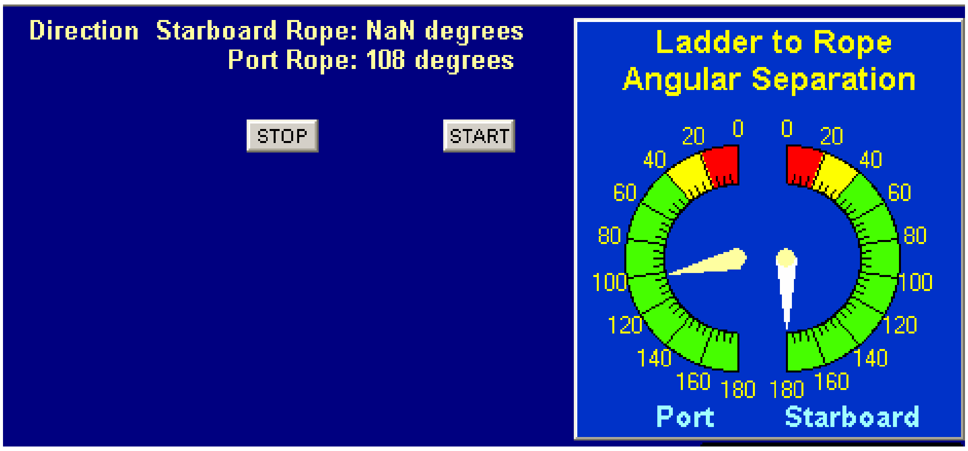

Figure 7. Section of SCADA display showing rope angle indication with alarms.

Data recorded to date indicates normal dredging parameters are defined by:

1. Ladder angle approximately 40° below horizontal.
2. Swing span of approximately 70°.
3. Maximum swing rate 0.5° per second.
4. Minimum swing rate 0.13° per second.

Using this data, the rope depth of the rope when immediately under the ILA sonar probe is calculated at approximately 10m. At this depth the “sonar beam” from the ILA is 2m in diameter which equates to 41° of rope swing (refer Figure 8). Therefore at the minimum swing rate, the 7.5 second scan period of the ILA will achieve 42 scans as the rope passes under the sonar probe. At the maximum swing rate the ILA will achieve 12 scans. The scan information is associated with GPS data and continually averaged to allow the position of the rope/anchor to be calculated. If required, the ILA can be repositioned to a lower depth and/or a position from the sheave wheel to achieve different measurement sensitivities.

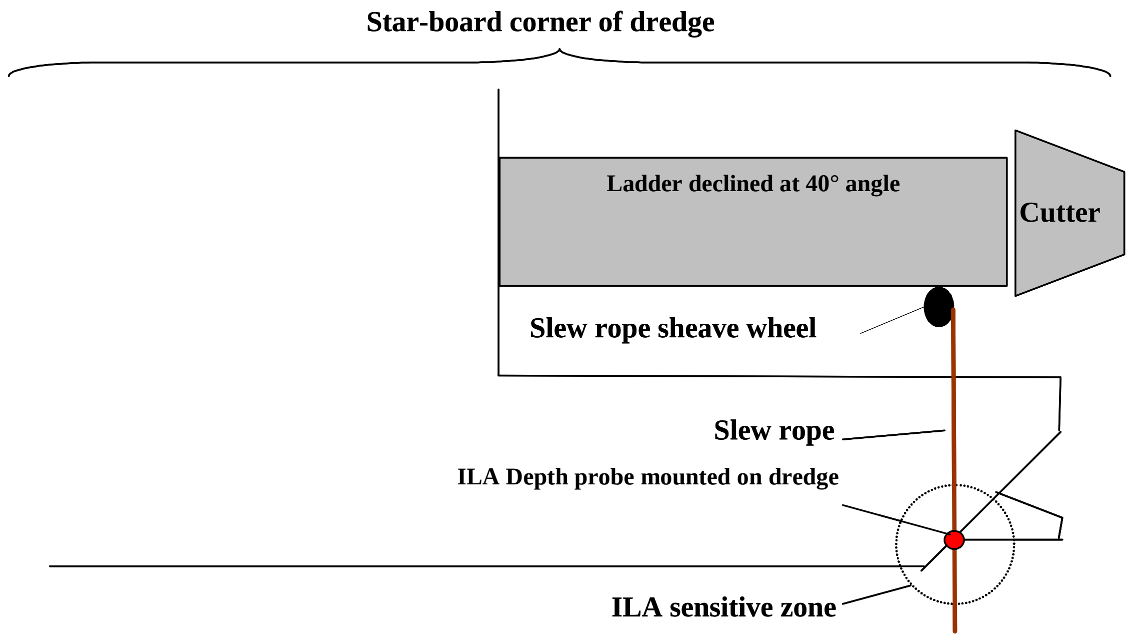

Figure 8. Schematic plan view of components for rope position calculation (cutter lowered).

Spud Position Measurement

Before selection of the scanning laser, other options to measure spud position were reviewed. A range of traditional sensors applied to various parts of the spud mechanisms were considered including proximity sensors, rotary encoders, odometers, ultrasonic sensors and single-point distance measuring lasers. Non-contact solutions were preferred and scanning lasers were considered to be the best approach. During operation it was found that the laser required cleaning once per week to remove a build up of oil (the cleaning operation to wipe the laser window with a cloth).

Figure 9 illustrates the concept of using scanning lasers. Each laser is mounted forward of the spud so that it scans vertically along the full length of the exposed area above the dredge deck. Also, if the spud leans to port or starboard with respect to the deck it no longer lies in the plane of the laser scan and the shape of the line of intersection becomes elliptical instead of straight. This curvature can be detected by processing the laser data in the monitoring software to identify whether the spud is tilting laterally. Therefore this single instrument with processed data can simultaneously measure the spud height, horizontal position, angle of lean fore/aft and, indicate whether the spud is leaning significantly to the side (this may be useful to detect if the spud is being unduly stressed). Figure 10 shows the real time animated display of spud position in addition to face proximity and pond depth.

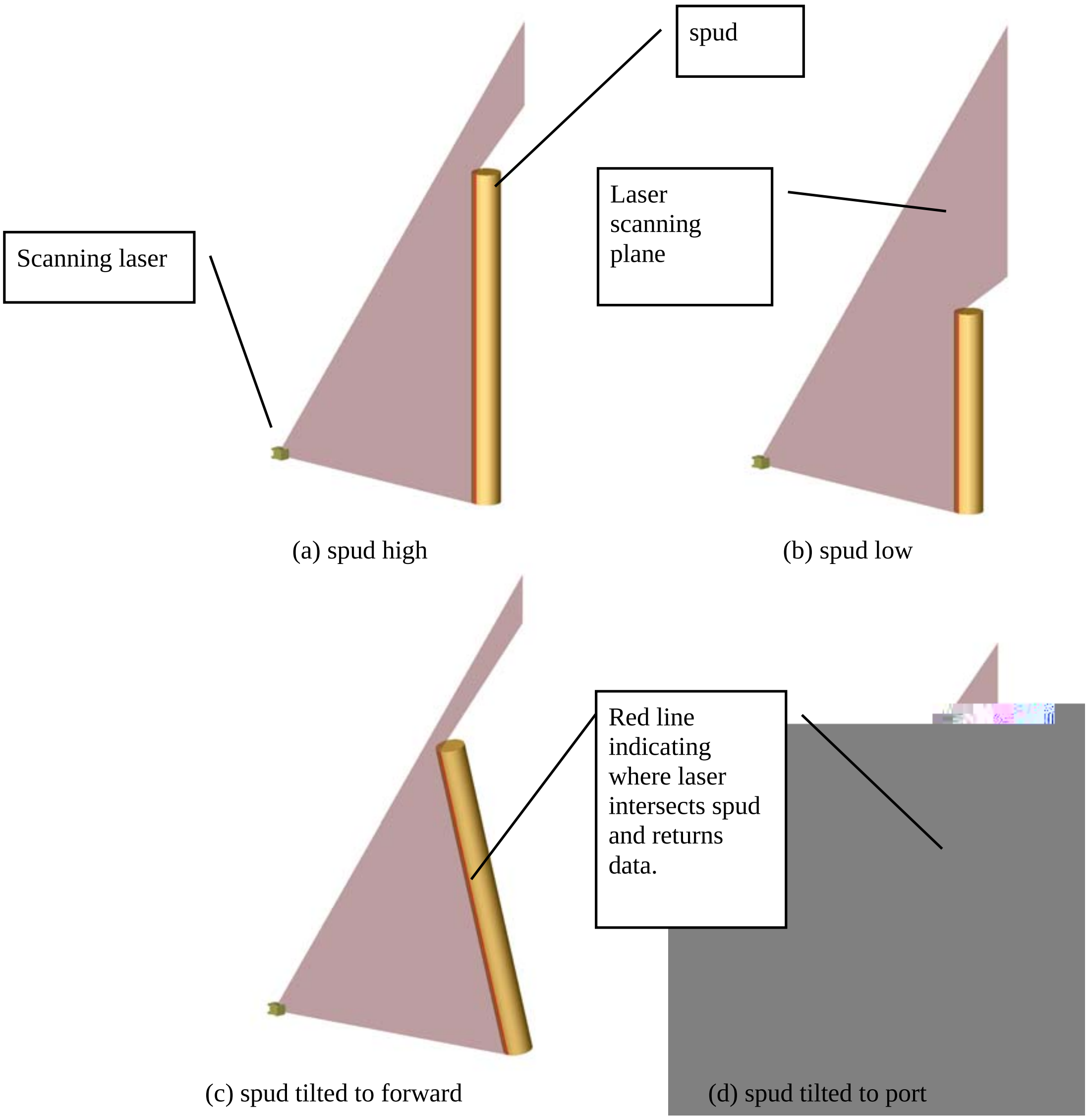

Figure 9. Schematic of scanning laser to measure spud position in four scenarios.

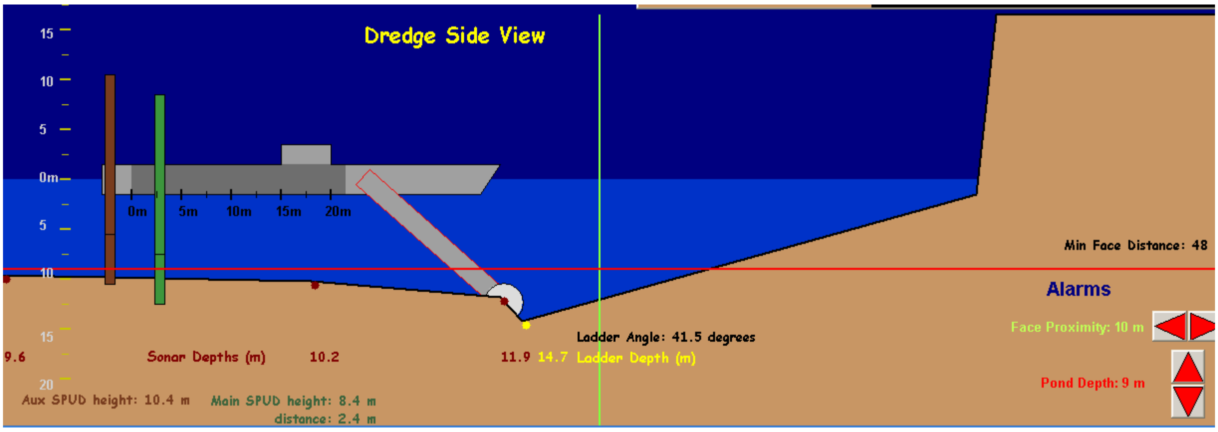

Figure10. Real time animated graphic of spud position, ladder position, pond depth and face proximity.

Face Position Detection

One scanning laser was mounted at the bow of the dredge and aimed toward the face with the scanning plane horizontal. The nominal range of the laser is 80m, but this can vary depending on the reflectivity of the sand. Face position is determined by interpreting the signal from the laser. The scanning laser measures the distance to an object at 1° intervals over a 180° arc.

For much of the time, all or some of the face will be out of range of the laser. This is not problematic, since the device is only required to return data at relatively close range and to warn the operator if the dredge is too close according to an adjustable alarm threshold.

A face profile and face proximity animation (with alarms) is displayed on the screen. Figure 3 shows the face profile scan which is incorporated in the pond depth profile display. Those areas that are out of range are plotted in pink/violet and are plotted at a nominal 80m range. Figure 10 shows another part of the display screen with the dredge in elevation showing the face proximity alarm. The displays are updated in "real-time".

Vibration Pitch and Roll

Vibration is directly measured by an accelerometer mounted in the dredge cabin. The signal is acquired, analysed and reported as a real time graph (refer Figure 11). Pitch and roll are measure by a dedicated pitch and roll transducer with data acquired and displayed as a real time "analogue gauge" type display with alarming (refer Figure 12).

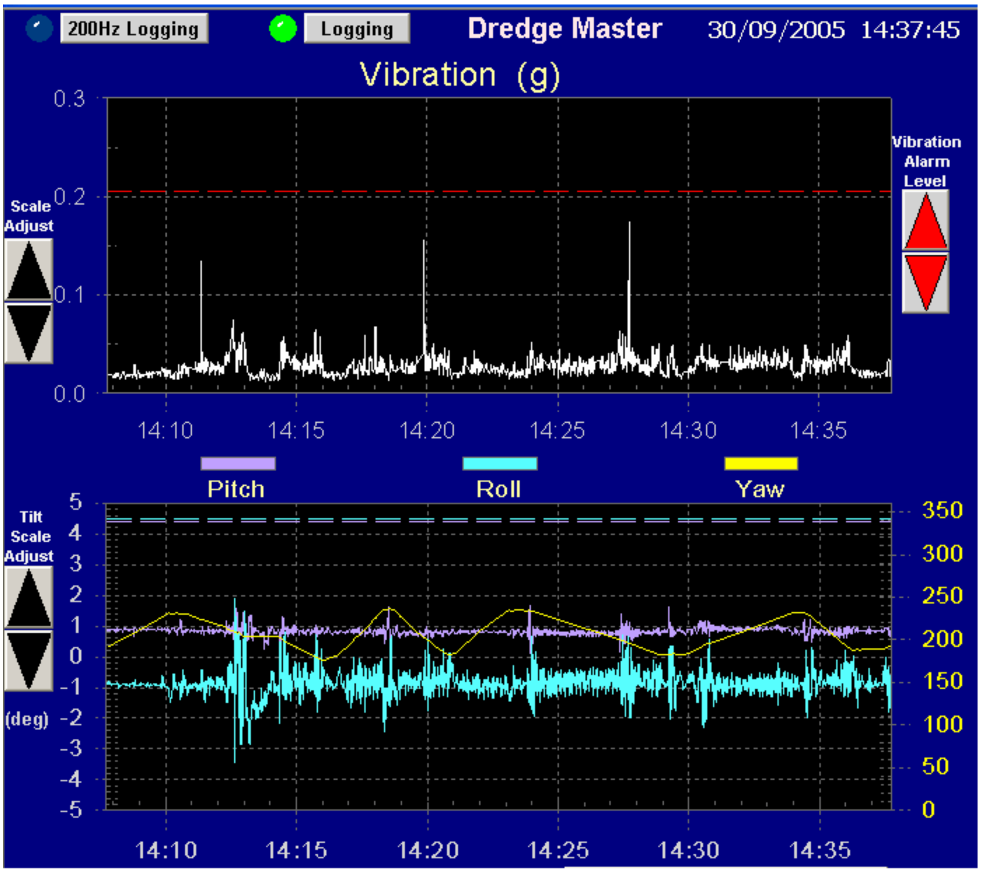

Figure 11. Section of the display showing real time plots of pitch, roll and vibration.

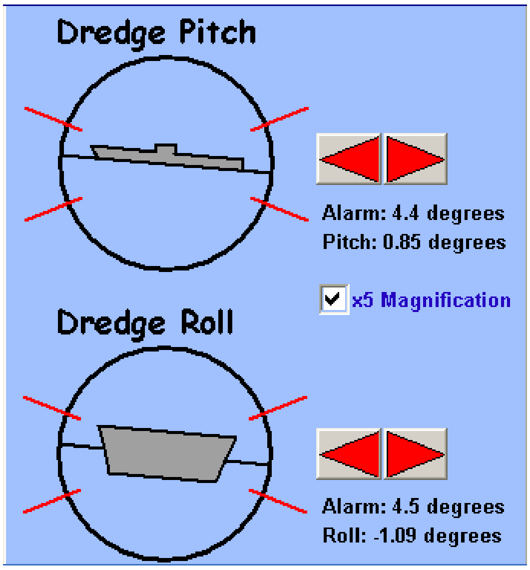

Figure 12. Screen animation of pitch and roll with alarms.

Video and Audio

A high resolution digital camera was installed to monitor the face and a lower resolution camera installed to monitor the main spud. Dredge audio information was detected using a microphone attached to the dredge structure.

The major problem encountered with the digital video cameras was the inability of the cameras to adjust to significantly varying and uneven lighting conditions. At night, the brightly lit areas of the dredge also caused interference. For example a bright area of the face often resulted in a blurred image and night vision was very poor. It is recommended to trial a more sophisticated camera with the ability to compensate for non-uniform illumination. For night time face measurement a dedicated night vision camera should be trialled.

DATA COMMUNICATIONS AND COMPUTER HARDWARE

Computers were installed in the dredge and in the concentrator with all communications between computers and instrumentation via a standard TCPIP network. The communications between the dredge and concentrator was an 802.11g wireless link at 2.4GHz as shown in Figure 13 (this link being transparent to the user).

Office grade (industrial grade equipment is significantly more expensive) equipment was used in the trial. This equipment is readily available and used routinely in network installations.

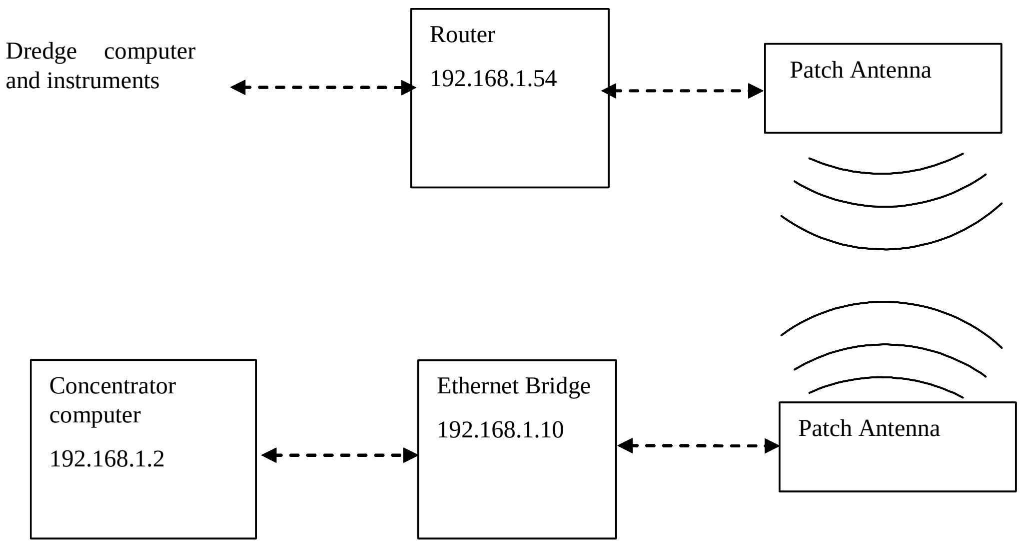

Figure 13. Schematic of dredge/concentrator communications system.

The communications network operated without failure. It should be noted that no torrential rain fell during trial period. As part of future work on the system the equipment will be upgraded to industrial grade with the communications between the dredge and the concentrator using a redundant “self healing” communications link using 2 x optical fibres installed on the float line (that connects the dredge and the concentrator) and a wireless link. This equipment is readily available and the upgrade will be transparent to the system users.

CONCLUSIONS

The project was completed successfully and the final conclusion is that all of the technical sensory requirements for remote control can be solved with products that are currently available. The monitoring system provided some information not previously available, which should also assist with manual operation.

Sonar was demonstrated to successfully measure pond depth. The sonar devices provide the pond depth and also a graphical display of the sonar intensity scan. Pond depth information, sonar plots and alarms are displayed on the computer screen near the operator.

A method to determine the position of the slew ropes has been deduced and demonstrated to provide an accurate measurement. It uses the bow mounted sonar sensors, in conjunction with GPS data. When the dredge approaches the limit of the side-to-side slew, one rope passes under the bow sonar and it is detected. At that time, the GPS heading is recorded and the location of the rope is calculated using the known geometry of the dredge and cutter. Similarly the position of the other rope can be determined as the dredge swings to the other slew limit. From then on, the system can track the location of the cutter and ropes to alarm if a collision is iminent. The system can accommodate changes in the anchor position because it automatically updates each time the dredge swings to the limit of the slew. No manual inputs are required if the anchor positions change.

A non-contact method to simultaneously measure the depth (height above deck) and location of the spuds using scanning lasers was successfully demonstrated. One laser, mounted to scan vertically is used for each spud. The main spud is tracked as it moves along the slot. The system also measures the angle of lean in the fore-aft direction and can provide an indication of whether the spud is leaning significantly in the port-starboard direction. Spud positions are displayed on the computer screen near the operator.

A scanning laser, mounted horizontally at the bow of the dredge, was used to measure the proximity of the face up to a maximum distance of 80 metres. This laser has limited range, is not a mapping tool and is intended only to operate when the dredge is close (e.g. 30m to 40m). The scan of the face is displayed to the operator via the computer screen, with alarms.

Vibration, pitch and roll measurement has been trialled successfully. Vibration signals appear to show a relationship to cutting hardness and other cutter events.

Two video cameras and an audio recording system were installed on the dredge. Audio monitoring was successful and provided a useful indication of dredge operating condition. Video systems worked well only when lighting conditions were homogeneous. Bright regions on the face caused blurring of image and night time vision was poor. It is concluded the cameras that were trialled are suitable for monitoring from a fixed distance with adequate lighting. Consequently cameras more suitable for night operation with the ability to compensate for non-uniform illumination would be required.

An 802.11g wireless link between the dredge and the concentrator was installed and tested. The system used patch antennas and no failures were experienced. It should be noted that no torrential rain fell during the trial.

REFERENCES

Hardgrave,C, Cunningham J, and Gipps. I (2003). “Remote control of a sand mining dredge – feasibility report” CSIRO Brisbane Australia. Report No. 1147c

Cunningham, J, Gipps, I, “Practical & Strategic Technology Choices for Advanced Mining”. (Keynote address) In Proceedings of the 12th International Symposium on Mine Planning and Equipment Selection, Pgs 19-27, Kalgoorlie, WA, 2003.

E. Schulte, H. Grebe, R. Handschuh, J. Panthel, B. Wenzlawski, W. Schwarz, M.A. Atmanand, C.R. Deepak, R. Jeyamani, M.A. Shajahan and M. Ravindran (2001). “Instrumentation and Control System of a Sand Mining System for Shallow Water” *Proceedings Fourth ISOP Ocean Mining Symposium, 2001* Szczecin, Poland, 108-115

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of staff at the CSIRO, Consolidated Rutile Limited, J&P Richardsons, Geocomp Systems and Yokogawa Austalasia.

The authors would like to thank the Dredge Operators of the Yarraman Mine for assistance in commissioning the systems and helpful discussions on operation of the mining dredges.