Integrated Dredging Automation

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ABSTRACT

Most mining dredges are adapted from canal/harbour dredges. Their automation and control systems are generally not designed for integrated mining operations. Consequently they have a number of limitations. This paper describes a new dredge control concept which paves the way for improved efficiency and increased production.

INTRODUCTION

Although there are significant difference between the objectives of mining and harbour/canal dredging, most of the mining dredges are still based on modifications of conventional harbour/canal dredges. The only difference being that mining dredges have anchors located on-shore. Dredging using conventional methods impose a number of limitations on production performance.

In 1997, BHP Titanium Minerals recognised the need to develop a better, integrated dredging control technique using Hatch's technology in mining automation. In particular the control allows the dredging trajectory to be tailored to suit the desired mining trajectory and mine plan. Consequently, for mining requiring bench dredging, efficiency and throughput is improved. This is achieved by:

- designing an integrated coordinated winch-manoeuvring system which improves dredge production availability by minimising unproductive downtime due to spud and anchor relocations;
- an integrated approach in designing the mining trajectory which improves dredging performance, particularly near the corner edges;
- the new control technology works for both shallow and deep operations eliminating the need for adjusting pond levels;
- maximising overall production rate by using advanced control techniques to maximise dredge slewing and cutting speed while minimising cutter trip due to overload;
- improving the overall production efficiency by using an integrated automation approach which caters for mine path tracking, machine collision protection, coordinated throughput control to maximise mineral recovery; and
- having an anchor relocation practice which optimises the overall production throughput by minimising the frequency of moving anchors while maintaining the available manoeuvring forces.

In 1998, Hatch successfully developed and applied such an integrated dredging system known as virtual spud dredging. This technology paves the way for improved efficiency and increased production. In order to understand the background which led the development of this new technology, it is useful to first understand typical dredging methods and their associated problems.

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REVIEW OF COMMON DREDGE MINING METHODS

Spud dredging

The most common form of dredge mining is spud dredging. Spud dredges used for canal dredging applications have been adopted in mining by simply replacing the underwater anchors with on-shore anchors. Most of the automation and control systems for these dredges are based on canal dredging application. Consequently, the control systems are often poorly integrated with the rest of the mining and mineral processing plant.

The dredging trajectory is constrained by the spud arcs. The dredge is slewed clockwise (CW) or anticlockwise (CCW) (refer Figure 1) about working spud as the pivot point by using two sideline winches. At the end of each slew, the cutter is advanced by extending the spud carriage backwards. Typically, the carriage is capable of extending up to 7 - 15 m. Once the carriage is fully extended, an auxiliary spud is dropped to hold the dredge while the main spud is raised. In a sequence called spud walking, the carriage is then retracted (brought forward), the main spud dropped and the auxiliary spud raised so that mining can continue. This manoeuvring method leads to the following drawbacks:

- Since the working spud is the main means of providing the reaction force for the cutter, during a spud walk, it is not possible to continue mining while the working spud is up. This translates to a potential loss of production time of five to 30 minutes for each spud moves.
- In addition, the length of the ladder (which limits the width of the arc to typically around 75 m) limits the mine width for each spud (as shown in Figure 1). Hence, for a dredge path width greater than 75 m, it is necessary to have multiple spud centrelines. There is a further loss of mining time of 0.5 to one hour every time there is a need to change centreline (the spud movement sequence required for moving between centrelines is known as crabbing).

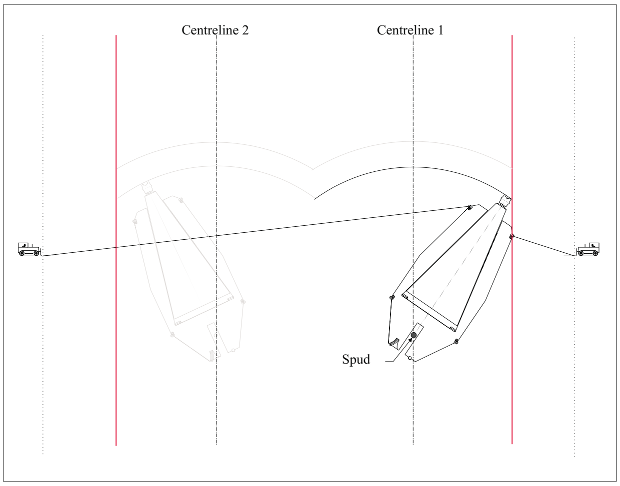

FIG 1 - Spud dredging.

- Another disadvantage of spud dredging is that the mining-arcs are not concentric because the centre of the arc remains the same while the radius of the arc changes. Hence, unless the slewing speed is controlled to compensate for this effect, the effective cutting rate across the face will be inconsistent. Note that this effect is most prominent immediately after a spud walk because there is a difference in the radii of arcs equal to the carriage extension length.

The maximum mining depth for a spud dredge is 22 m. This is because it is impractical for a dredge to carry a spud with a sufficiently large diameter required for operation deeper than 22 m. Hence, it is necessary to adjust pond level wherever the deposit is deeper than 22 m.

Xmas-tree dredging

For dredging depths greater than 22 m, it is necessary to operate solely on lines and winches. One popular method is based on the same concept as spud dredging. Instead of a spud, a swivel ring on the dredge is held in place using lines attached to a set of three to four anchors (as show in Figure 2). This type of dredge is often referred to as a Xmas-tree dredge and operates essentially the same as a spud dredge. Consequently it inherits the same limitations as the spud dredge. Instead of the need to move the spud, there is a need to move the Xmas-tree anchors. Since it is much more complex to move the Xmas-tree anchors in comparison to walking and crabbing a spud dredge, a Xmas-tree dredge suffers from much larger production downtime than a spud dredge.

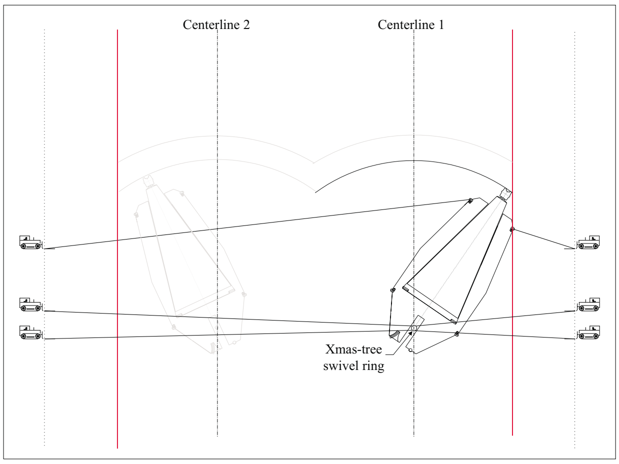

FIG 2 - Xmas-tree dredging.

INTEGRATED DREDGING AUTOMATION

In order to develop a solution, a control hazard and operability study was conducted involving a team of operational and maintenance personnel to better understand the business and process objectives; operational and maintenance requirements and constraints. A mathematical model was then developed using Simulink (a simulation package by Mathworks) to study the various aspect of dredging. This culminated in the formulation of an integrated approach of dredging.

Optimising dredge configuration

The mathematical model was used to study the dynamic force interactions between the manoeuvring winches under various dredge manoeuvring control configurations, control strategies and mining trajectories. After an extensive study, it was determined that by using six winches (two headlines and four sidelines – refer Figure 3), it is possible develop a system which would allow a flexible mining trajectory.

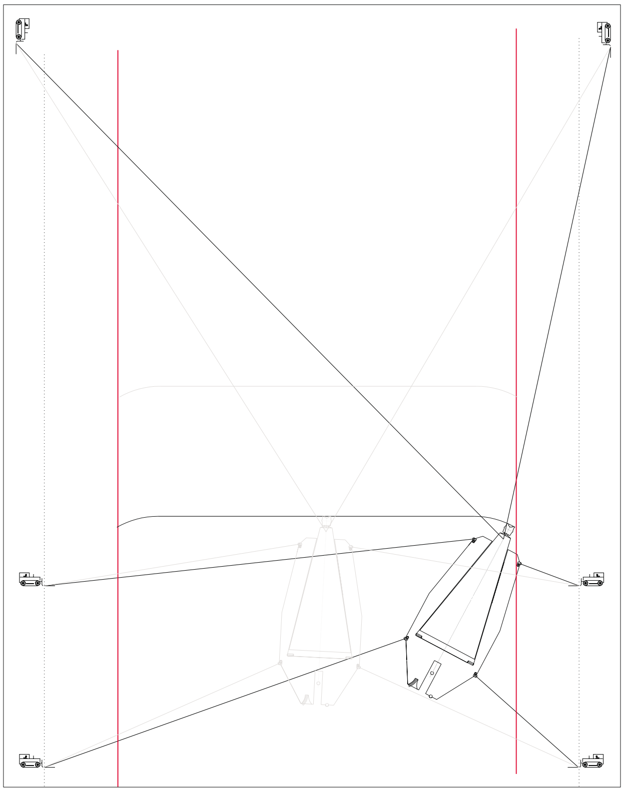

FIG 3 - Virtual spud dredging.

Integrated trajectories designed to suit the mine plan and dredge profile

As highlighted in the last sections, there are a number drawbacks in the traditional dredging methods which can be attributed to the fixed nature of the trajectory. Hence, in order to avoid these drawbacks, it is necessary to have a dredge manoeuvring method that will accommodate a flexible cutting trajectory which would allow continuous mining across wide mine face. This requirement rules out the use of any fixed anchored device such as spud or locked anchor held in place by lines. In fact, it requires a virtual constantly moving 'spud/anchor', hence the term virtual spud dredging.

The cutting trajectory consists of a straight line and two symmetrical arcs on either side. It is necessary to have the concave arc near either side of the bank to avoid any structure (either above or below the waterline) of the dredge colliding with the bank. By coordinated control of six manoeuvring winches, the dredge can be made to slew along a predetermined trajectory. At each of corner, again by coordinated control of the winches, the cutter can be made to advance forward by the desired bite of cut. After the advance, the dredge slews back along a new trajectory parallel to the last trajectory. Consequently, the bite of cut is always consistent. This translates to consistent cutting rate, hence improved productivity.

The angle of the corner arcs is designed to provide the required clearance to suit the dredge and cutter profile. The curvature and radius of the arc is designed to maximise the turning moment that can be generated by the manoeuvring winches. Figure 4 shows the forces acting on the dredge by the six manoeuvring winches. These forces can be expressed as resultant forces in the X, Y components and rotating moment. Note that the effective manoeuvring force and moments are highly dependent on the angles of the manoeuvring winch lines. Furthermore, the force and moment contribution from each of the winches are highly interactive. Hence it is important to have a coordinated control of the winches to maximise the effective manoeuvring forces and moments.

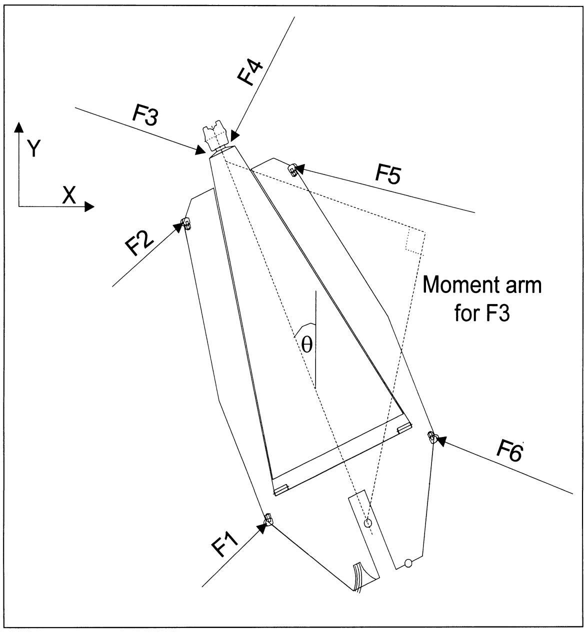

FIG 4 - Dredge winch forces.

Continuous mining across the mine face

This control algorithm allows continuous dredging across widths greater than 200 m eliminating the downtime due to spud changes. The only downtime incurred is when it is necessary to relocate the headline anchors (Note that sideline anchors can be moved on-the-fly while the dredge is slewing away from the anchors). By optimising the anchor position and relocation rules, it is possible to continuously mine forward for distances greater than 40 m without significant deterioration of dredging performance. This translates to 40 × 200 m^2 of continuous dredging. In comparison, for a spud/Xmas-tree dredge with a maximum carriage extension of 7 m and mining width of 67 m, it would require three mining centrelines change and six spud/ Xmas-tree advances in each centrelines. Assuming each of these spud/Xmas-tree advances takes quarter of an hour and each centreline changes takes half an hour, this is equivalent to a total downtime time of six hours per every 40 m forward. If the dredging is carried out in benches then this total downtime needs to be further multiplied by the number of benches. Note also that unlike the spud or Xmas-tree dredge where the maximum continuous dredging width is related to the length of the ladder, there is no such requirement associated with a virtual spud dredge.

Beside the flexible cutting trajectory, since the system is fully controlled using lines and winches, it is possible to have full control over the cutter heading. This capability is particularly useful when the cutter is a dual bucket wheel cutter. Using a negative heading offset, it is possible to minimise the backward reaction forces which tends to wobble the cutter and cause the cutter to fall back from the face (refer Figure 6).

Coordinated control to maximise effective cutting forces

The six manoeuvring winches is a highly interactive system. In order to maximise the available manoeuvring forces, a unique multivariable control was developed for controlling the six manoeuvring winches. Figure 5 shows a block diagram of the control algorithm. The key sensors for the manoeuvring control are the global position system (GPS) and a gyro. The GPS provides the spatial position of the dredge while the gyro provides the heading of the dredge. The position information is used by the trajectory controller to generate the required velocity components for slew (x), forward (y) and rotation (θ) axes to make the cutter track the required cutting trajectory. These velocity components are then transformed using a multivariable algorithm to the six winch speeds to physically move the dredge.

Anchor relocation optimised to minimise unproductive downtime

The available manoeuvring forces from each of the winches are highly dependent on the anchor positions (as shown in Figure 4 – the effective forces and moments are functions of the angle the lines with respective to the dredge position). There is a trade-off between frequency of moving an anchor (to maximise the effective available manoeuvring forces) and lost time/reduced production rate incurred during the anchor moves. Using the model, Hatch has developed an algorithm for determine the optimum rules for anchor relocation which minimises the frequency of anchor moves with little impact on the available manoeuvring forces.

Advanced predictive slew speed control

One of the biggest challenges of the dredge operator is to know when to increase the slewing rate while cutting through softer material and when to slow down the slewing rate through harder material to avoid cutter trip. Consequently, a conservative operator may be content to operate the dredge at a lower slew speed to avoid tripping the cutter, whereas an over-optimistic operator tends to operate the dredge at a higher slew speed to achieve higher instantaneous cutting rate; however, if there is hard material in the path, the cutter may trip resulting in a lower overall average cutting rate. Hence the dredge performance tends to vary depending on the skills of the operator. To overcome this problem, Hatch developed a predictive self-learning algorithm for automatic slew speed control. The algorithm uses the previous cutter load values to predict the cutter load ahead and calculate the required slew speed limit to slow the dredge before it reaches the hard material so as to avoid the cutter from tripping. The same algorithm will also automatically lift the slew speed limit if it deemed that there is softer material ahead; allowing the dredge to slew at its maximum speed.

Integrated approach to automation and control

In the previous sections, the discussions have been focused on dredge automation and control. However, in order to reap the full benefit, there should be an integrated approach for addressing the automation and control needs for the dredge and the entire process plant. For example:

- **Machine anti-collision management** within the mining pond – coordinated control of mobile machines (eg dredge to dredge, dredge to concentrator, dredge to pipeline, etc) allowing the machines to work safely and closer; minimising the unnecessary downtime due to inter-machines interference.
- **Mine tracking and management** – automatic recording and tracking of the mine profile and cutting trajectory;

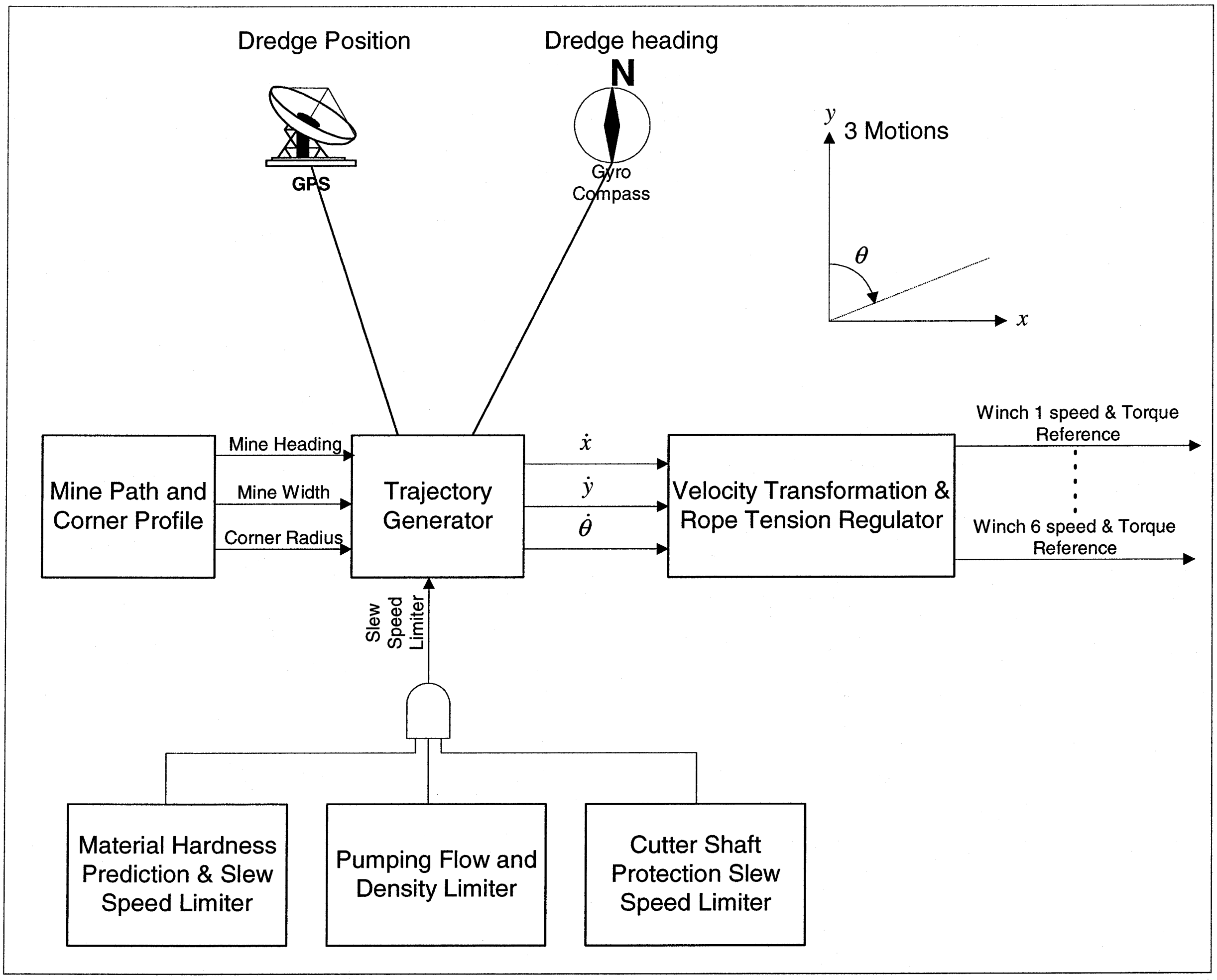

FIG 5 - Virtual spud dredging control block diagram.

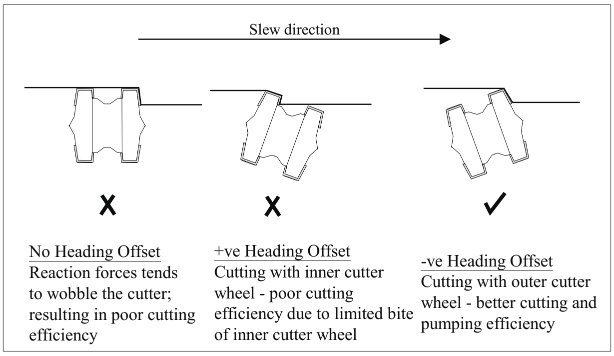

FIG 6 - Using heading offset with dual bucket wheel cutter.

facilitating automatic machine relocation, mine data reconciliation and mine plan optimisation with respect to mineral grades/ composition.

- **Coordinated process control strategy** – Using feed-forward to minimise disturbance propagation and maximise mineral recovery. For example, using coordinated control of the concentrator surge bin level, dredge and concentrator throughput. This ensures a consistent density and flow through the gravitational separation circuits in the concentrator to maximise mineral recovery efficiency.
- **High level of automation and effective operator interface** – minimise the production variability due to operator; minimise the skill level required; provides simple key performance indicators to allow the operator to evaluate his/her operating strategies.

ACHIEVEMENTS

This integrated virtual spud dredging method has been successfully applied to a 3800 tonne mineral sand mining dredge (with a nameplate rating of 3500 tph) for BHP Titanium Minerals in Western Australia in 1998. It resulted in greater than 50 per cent improvement in the overall production rate. Figure 7 compares the average production rates (expressed in percentage of nameplate rating) before and after the installation of virtual spud dredging method. Note that Bench 3 used to be a spud mining bench while Bench 4 - 9 were single headline benches. Each bench is 5 m deep, hence Bench 9 has a depth of 45 m. It is interesting to note from Figure 7 that with virtual spud dredging, even though the width of Bench 9 is only 30 per cent that of Bench 3, the Bench 9 performance is still comparable to Bench 3. This is because the corner trajectory of virtual spud dredging has been tailored to suit the dredge profile resulting in higher corner dredging efficiencies than the traditional headline or spud/Xmas-tree dredges.

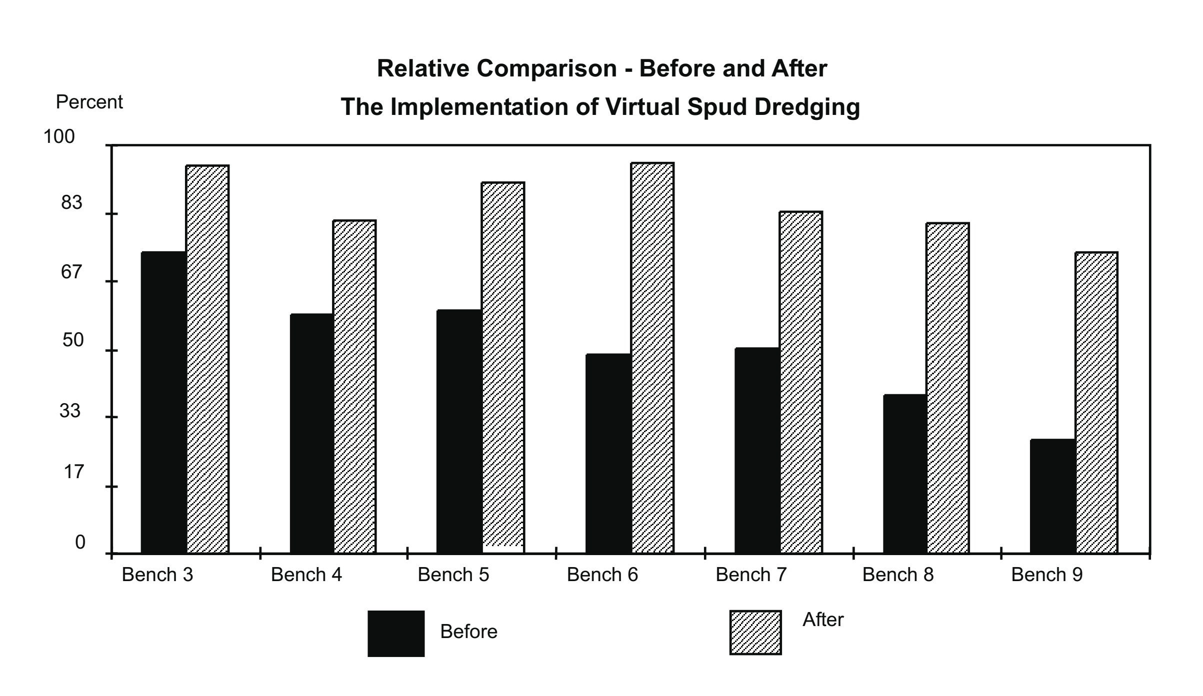

FIG 7 - Before and after comparison.

CONCLUSION

In summary, the integrated solution, virtual spud dredging offers the following advantages:

- Downtime saving of six to ten hours per bench (every 40 m advance) due to elimination of the need for spud advance and centreline changes. Using a virtual spud concept, it is possible to continuously dredge an area greater than 40 × 200 m^2 without any downtime due to anchor moves.
- Using an embedded on-line prediction algorithm for material hardness, the technique delivers optimal cutting rate and dredge slewing speed.
- Using a multivariable control technique to minimise interactions from the manoeuvring winches, the technique delivers maximum available cutting forces and avoids slack rope conditions; further improving the dredge efficiency, and reducing the frequency of broken cables.
- Fully flexible manouvering trajectory tailored to suit the profile of the dredge and dredging path; improving the corner dredging efficiency and minimising fall-back from the face.
- High level of automation – automatic dredging operation with integrated anti-collision, mine path management, coordinated dredging, pumping and processing control to maximise the mineral recovery rate.

Note that although the technologies described in this paper were original developed as an integral part of virtual spud dredging, some of the control techniques can also be applied to improve the performance of conventional dredges. For example, the predictive slew speed control, integrated mine path automation, coordinated dredging and processing control, etc can be used with conventional dredging methods to improve the dredging efficiency. In addition, the and trajectory tracking control technique is a generic technique suitable for application for any floating structure such as concentrator and sublay stacker.

ACKNOWLEDGEMENT

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Mathworks, Simulink – a mathematical simulation package for modelling dynamic systems, www.mathworks.com