APPLICATIONS OF ARTIFICIAL INTELLIGENCE ON THE DREDGE CONTROLS OF A HOPPER DREDGER

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ABSTRACT

Increasingly advanced dredging technology is being used to allow higher efficiency and greater precision dredging operations for projects with more difficult soil conditions and site constraints. This is being accomplished by applying sophisticated designs, unique dredging components and integrated systems. . The use of Artificial Intelligence (AI) aided systems enable even more efficient and sustainable use of the innovative dredging equipment in these circumstances. Current improvement is based progressively more on the application of AI to remove the more difficult tasks from the dredge operator. Through the course of monitoring results of modern means like dredge simulators it was learned that multi-tasking can be handled very well by AI. Especially in conjunction with the ever more complicated dredge jobs, due to graduating accountability requirements and also due to higher environmental standards.

In a modern dredge simulator for hopper dredgers, all related dredging processes including sensors, actuators and the dynamic relationship between the processes are simulated to obtain a realistic virtual dredge operation. The virtual dredge can be controlled using pre-installed real-time conditions while also implementing AI to perform preliminary tests. Use of the latest state of computer technology, central monitoring and data logging allows a three dimensional virtual view of the outside world. This virtual view includes not only what is normally seen from the control room or bridge, but if required an underwater view.

In this paper the latest state of the art software and the possibilities in the use of the controls is discussed and supported by actual testing data such as the “ECO Pump Controller” the “Automatic Visor Controller” for the hopper draghead and the “Trail Speed Controller” for propulsion. The emphasis of the paper is on functioning of these controllers and how this improves the dredging production and fuel consumption for efficient and sustainable use of modern equipment.

Keywords: efficient dredging, artificial intelligence, advanced controllers, hopper dredger

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INTRODUCTION

The science and engineering of fabricating intelligent machines has a long history in the dredging Industry. In the formative years of the 1970's the first electronic measurements and automation of some functions emerged. First forms of automation were the now common functions like Automatic Light Mixture Overboard, a function to decide on the value of the measured density of the dredged material or this was pumped in the hopper or directly dumped overboard. And also keeping the draghead on a certain maximum depth by measuring and limiting the paid out length of the winchwires of the dragarm. Later on in the 1980's this was followed by ACOE Hopperdredgers like the Wheeler and Essayons with automation of nearly all separate dredging functions by separate computers, although a "Master Dredge Computer" suggested integration. In the 1990's the Integrated Bridge emerged on the new dredgers built for the Belgian company DEME with her hopperdredge Antigoon, followed by JDN and others. This development of integration has progressed over the last 10 years with the "One man bridge" concept, where all dredge processes were integrated in one PC/PLC SCADA (Supervisory Control And Data Acquisition) platform together with a DP/DT (Dynamic Positioning / Dynamic Tracking) system. The DP/DT is a development originating from the offshore industry, focusing on the DP function, but re-designed and re-focused for the dredging industry to the DT function, as exemplified by the function to dredge trenches for pipelines by multiple passes over the same dredging track. The result is the combination of the automation of the dredging process and the nautical process.

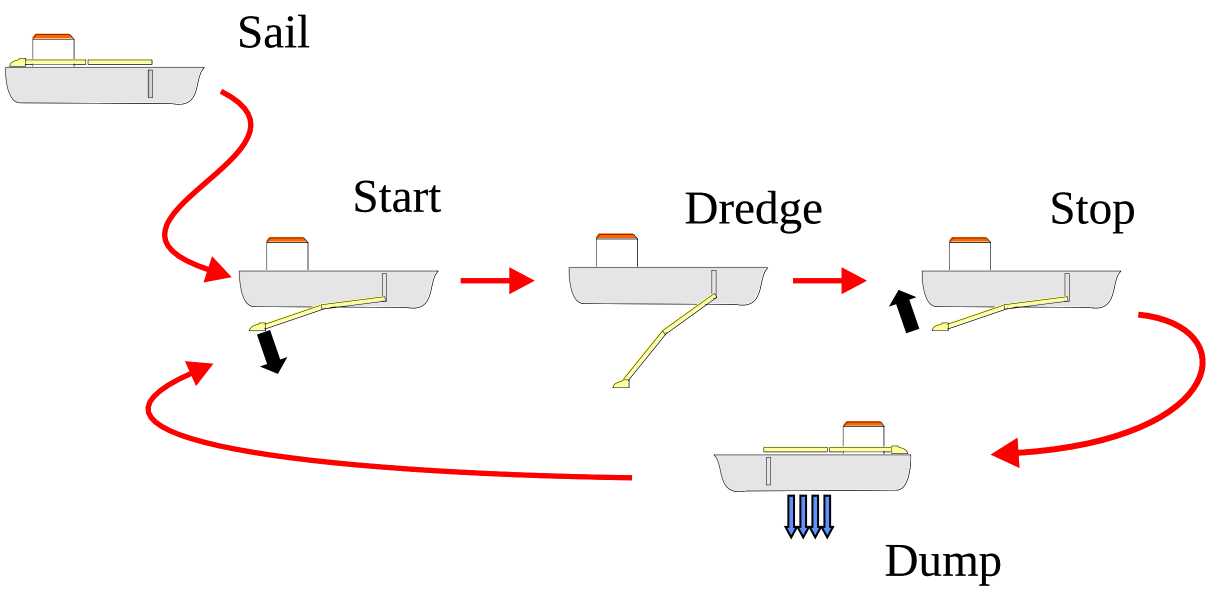

Figure 1. Dredging cycle of a hopperdredge.

The whole dredging cycle of a hopperdredger (Figure 1.) can be pre-programmed and executed without human interference. The leftover necessary crew on the ship's bridge, one man, is focused on mandatory nautical duties only. Their assistant, a computer system handling around a 1000 I/O's (Input & Outputs) and a host of processes is handling the dredging mission. However several experiences have shown, due to the complex dredging process, a well-trained human can still easily outperform the computer on several parts of the process. Especially non-repetitive tasks. The final conclusion for this development is still under development and possible further study clearly points to a superior human behavior and intelligence.

ARTIFICIAL INTELLIGENCE (AI)

The discovery toward the latter stages of hardware integration pointed toward the fact that further improvements would need to arise from further investigation in the dredging process and practical Human Machine Interface (HMI) behavior. Therefore this the field of science was examined, as well as other technical developments outside the limited dredge world, such as the Military, Processing industry and Shipping in general. A new path to efficient dredging was now clearly established.

Path

In the 1950's, far away from dredging in every aspect, the term "Artificial Intelligence" was coined by an American computer scientist and cognitive scientist: John McCarthy. This held the promise that a central property of humans, intelligence—the essence of *Homo sapiens*—could be sufficiently well described to the extent that it could be simulated by a machine. This was a remarkable statement at the time but without a direct application. This was definitely not the case in the 1950's with the limited computer capacity available. However this opened up the thinking that the dredging process, as executed by humans could be modeled into software and connected to a huge $ 200 million robot dredger.

Dredging Simulators

Also important was the development of Dredging Simulators now in use by several dredging companies. This has been utilized primarily for 3 major activities: Operational training of dredge crew on hopper dredgers, cutter dredgers and excavators; cost estimation/research of dredging projects with those dredging machines and for development purposes to improve the machines and dredging methods. The experience with the simulators rewarded the users and builders with a magnificent playground for relative inexpensive tests on any kind of idea about influencing the productivity and operational costs of the dredgers. A good example for this type of practical solution is the graphical view of the overflow loss estimator (Figure 2.) to determine with an acceptable accuracy the amount of overflow loss.

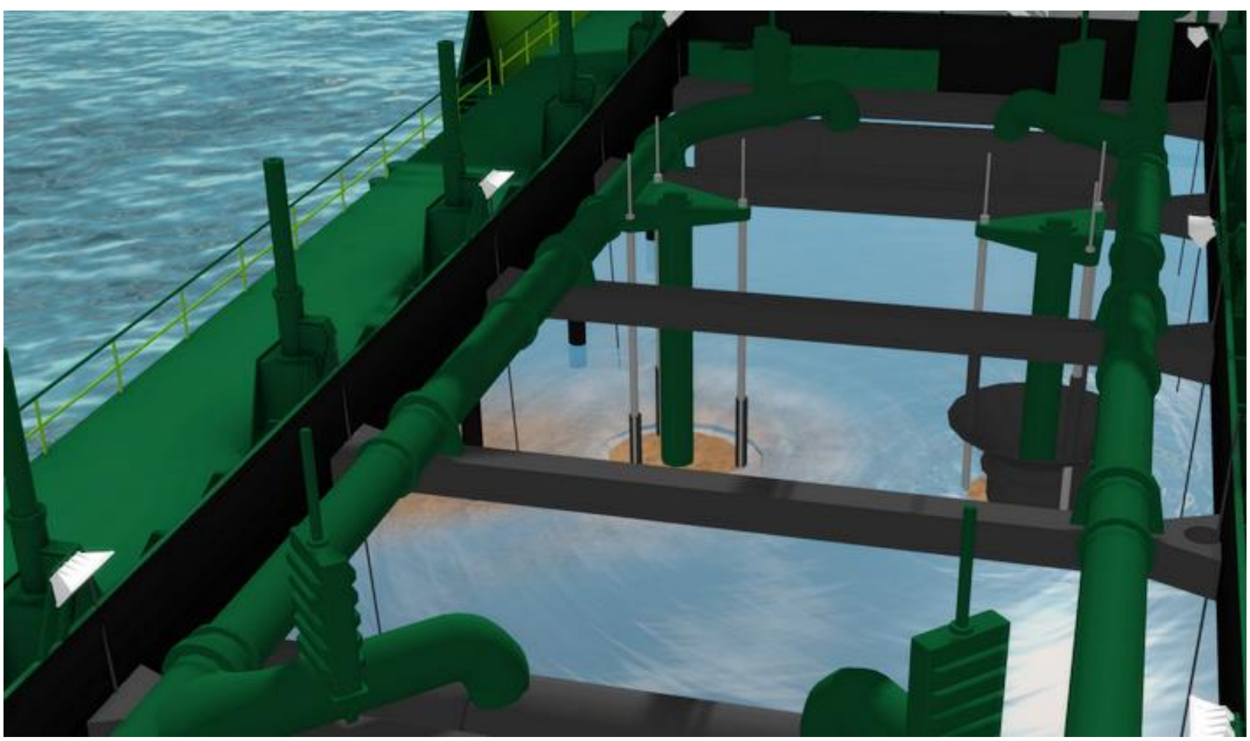

Figure 2. Resolving the overflow estimator.

AI-SYSTEM

Years of significant effort have been expended by IHC Systems to develop a self-learning dredging control system for efficiently controlling the dredging process, named the AI-system. As the name already suggests the AI-system uses artificial intelligence comprising a combination of measurements, mathematical models and algorithms to predict the optimal set points for a given situation. As circumstances change during the dredging process, such as the soil characteristics, dredging depth or draught, the AI-system actively modifies the set points to obtain permanent optimization of the process.

Figure 3. shows an overview of the AI-system showing the most relevant parts. The main part of the necessary inputs for the AI-system is measured and interfaced via Programmable Logic Controllers (PLC's). Among others, these are common measurements like mixture velocity, mixture density, dredge pump speeds, speed over ground etc. Other inputs are calculated by monitoring systems such as the Suction Tube Position Monitor (STPM) and the Draught and Loading Monitor (DLM), such as the tons of dry solids, suction tube positions and angles. The Human Machine Interface (HMI) of the AI-system is provided by SCADA viewers. Here the dredge operator can select the desired primary goal (i.e. the overall control objective of the AI-system), such as maximizing the production cycle. For more detailed information on the algorithms used in the AI system see references (J. Osnabrugge and P.M. van den Bergh, 2013) and (Braaksma, J. and J. Osnabrugge, 2007).

With all these inputs the AI-system predicts the optimal set points for the controllers, such as the Trail Speed Controller (TSC), the Eco Pump Controller (EPC) and the Automatic Visor Controller (AVC) . The TSC is used to maintain a constant and optimal trail speed during dredging and hence a constant excavation height for a stable production-rate. This is done by controlling the pitches of the Controllable Pitch Propeller (CPP's). The AVC controls the visor position to obtain optimal ratio of mixture flow and density that maximizes the excavation production. And the EPC controls the pump speed to increase the pump efficiency by preventing excessive cavitation of the dredge pump. These three controllers will be discussed in more detail in the next paragraphs.

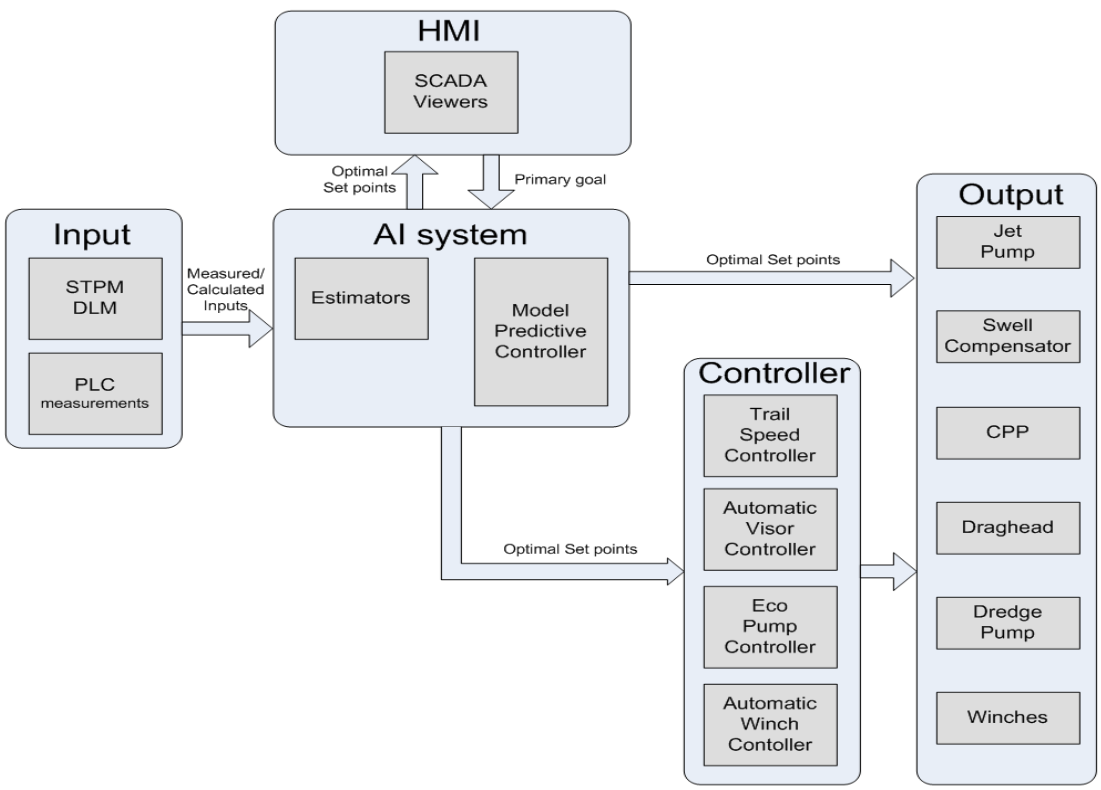

Figure 3. Overview of the AI-system

TRAIL SPEED CONTROLLER

The trail speed controller (TSC) is used as automation to maintain a constant trail speed during dredging. Therefore, the ship navigator only needs to focus on navigating and monitoring the dredging process. The second advantage is that the excavation height will be constant for a constant production-rate and smooth suction process. A very important aspect in this process is the dredge force caused by the drag head, such as the cutting force, with her pull on the side of the ship. This dredging force may become so large that 100% of the available propulsion power is necessary when dredging, whereas only 5 to 10 % is required for maintaining a ship speed of 2 to 3 knots without dredging. Dredging can lead to an increase of power up to tenfold. For a good performance of the TSC it is of vital importance to know these dredging forces. The dredging force mainly depends on the soil type, permeability and dredging depth. These parameters are typically not known during the dredging process. Moreover, these properties vary from place to place. Unfortunately, as a consequence of the hostile dredging environment these forces are difficult to measure and the expensive mechanical force measurement sensors need to be replaced regularly. Therefore sophisticated estimation techniques to estimate the dredging force are developed, see reference (Braaksma, J. and J. Osnabrugge, 2009) for more detailed information. Figure 4. is showing a schematic overview of the control implementation.

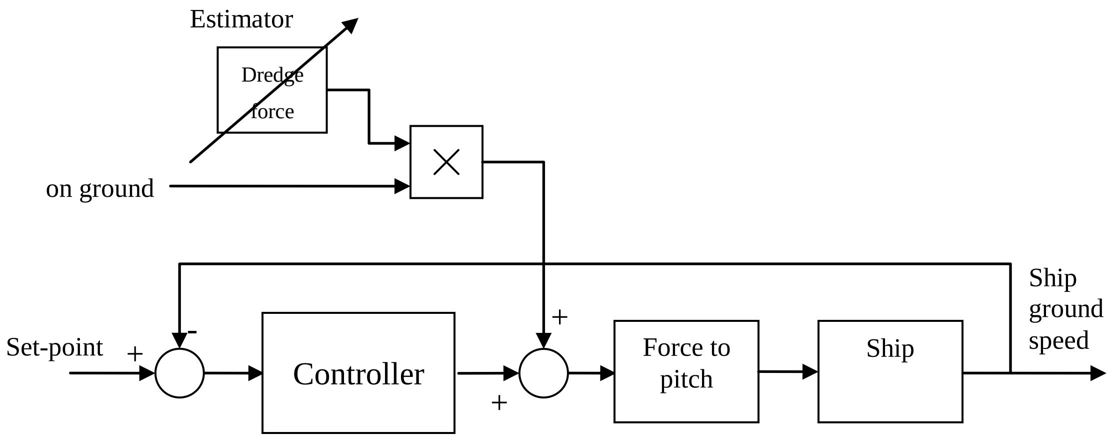

Figure 4. Schematic overview of the Trail Speed Controller.

The controller structure is a classical combination of feedback and feed-forward control. The figure below shows the TSC in action. The upper part shows the actual trail speed in black and the setpoint in red. The lower part shows the CPP pitch of port side in red and starboard side in black.

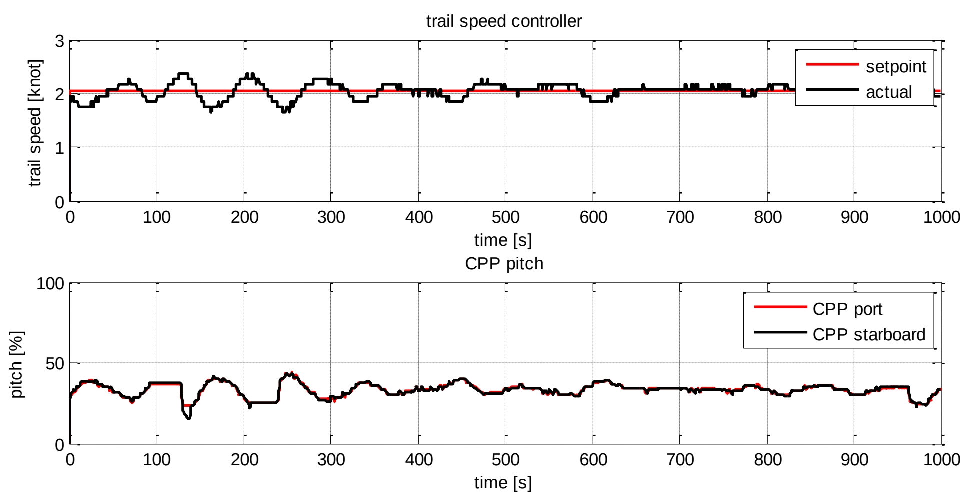

Figure 5. TSC in action

ECO PUMP CONTROLLER

In general a dredger is a floating vessel to dredge and transport the dredged material to a different location. In most cases the use of a pumping system is the most economical way of doing this, either by a cutter dredger or a hopper dredger. This makes the dredge pump process one of the most important parts of the total dredging process, also because of energy consumption and wear and tear issues. So there is a general interest to have a dredge pump operating in the most economical way with a good eye to all factors involved. For example, when the dredge pump is cavitating (especially for inboard dredge pumps) the pump efficiency is reduced significantly, below indicated by the ellipse in figure 6.

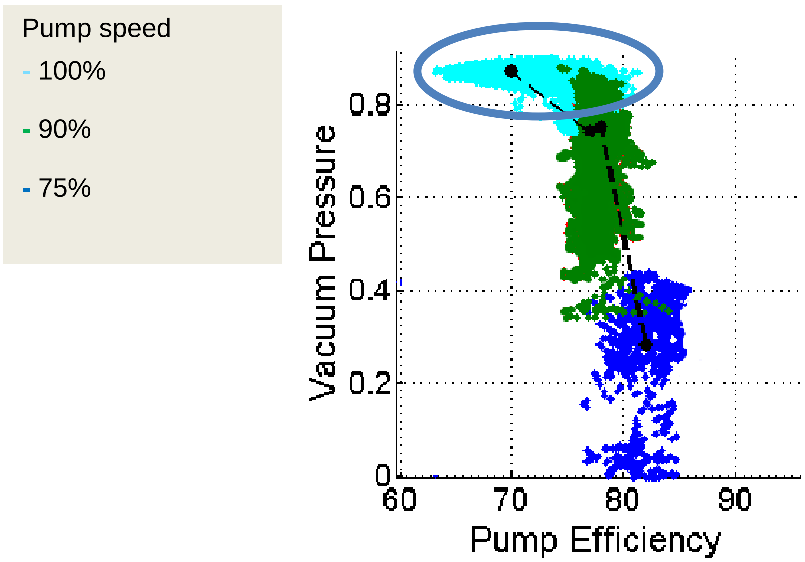

Figure 6. Reduced pump efficiency.

By reducing the pump speed in this situation until it is just not cavitating (or only a little) it will increase the efficiency and reduce the fuel consumption of the dredge pump while maintaining the same dredging production. The Eco Pump Controller (EPC) determines when the pump is cavitating. This is determined by directly calculating the efficiency or, in case of no power or torque measurement, by comparing the calculated theoretical pump head with the measured actual pump head. If cavitation occurs, the efficiency drops and the actual pump head becomes smaller than the theoretical pump head. The EPC then, by its self-learning (i.e. AI), dynamically finds an optimal pump speed to obtain high values for both the pump efficiency and the dredging production.
Figure 7. shows an extreme example of the impact of cavitation on the pump efficiency where the cavitating pump is given in blue and the non-cavitating pump in red. The graph shows a significant increase in the average pump efficiency for the non-cavitating pump, 78% versus 56% for the cavitating pump.

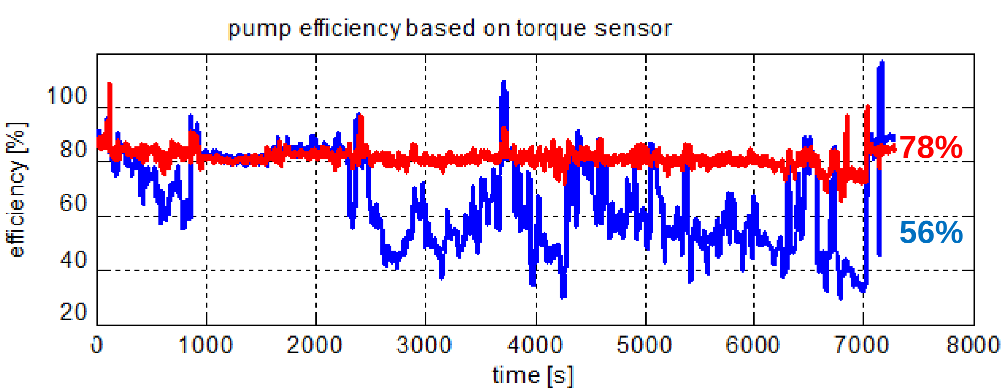

Figure 7. Efficiency of cavitating pump (blue) versus non-cavitating pump (red)

AUTOMATIC VISOR CONTROLLER

The goal of the automatic visor controller (AVC) is to provide an optimal working point for the dredging mixture flow. This is primarily enabling the possibility for process optimization of the ideal combination of flow and density of the dredging mixture. In collaboration with the Trail Speed Controller and Eco Pump Controller the AVC converges on the maximum dredging production, as indicated by the figure below. The figure shows the maximum production as a function of the mixture flow when the vacuum of the dredge pump is the limiting factor. The optimal mixture velocity work point changes during the loading of the hopper dredger due to increasing vessel draft and variations in the dredging depth and soil characteristics. It is the goal of the AI-system (with the controllers) to adapt and maintain maximum production rates during the whole dredging cycle. Secondarily the controller provides a stable and robust operation, also under the presence of disturbances like sand dunes, with limited to no intervention needed of the operator.

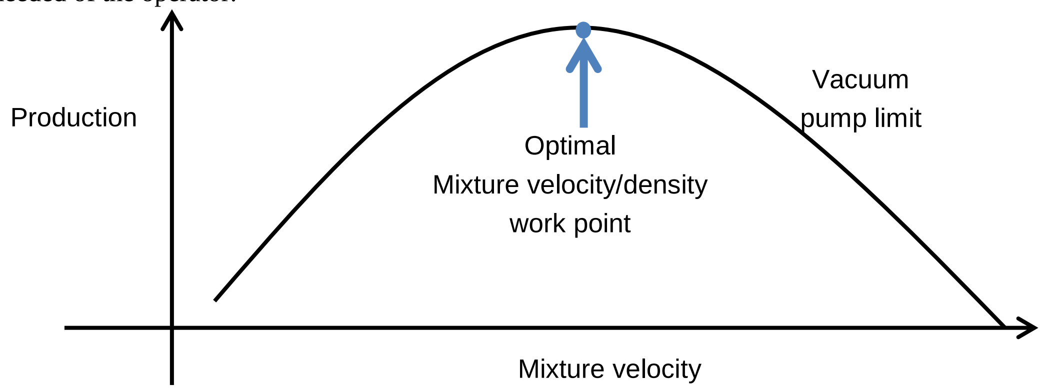

Figure 8. Optimal working point

Compensation for extreme circumstances

In the almost unpredictable draghead operating environments there are several disturbances strongly affecting dredge production. As shown below (Figure 9.) the positive effect of the AVC is visible on the encounter of several high spots and sand dunes.

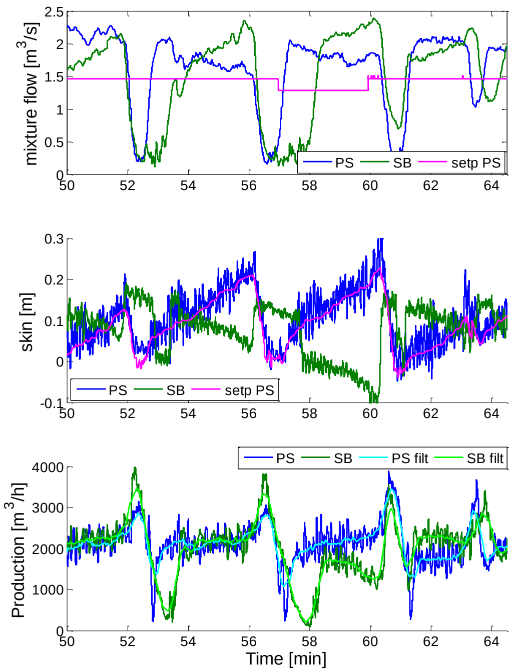

Figure 9. Very uneven sea bottom.

A comparison between a controller operated portside draghead and a manually operated starboard side draghead is given in figure 9. The upper graph shows the dredging mixture flow. The middle graph is incorporating the controller signal, indicating that the setpoint is quite stable followed by the visor, indicated by the blue line of actual removed surface. The pink line represents the desired surface. More surface removal is closely connected with a higher density in the draghead and for this the dredged mixture of water and material. Between 52 and 62 on the time scale it can be observed that the AI influenced visor controller has better forward looking/reaction time capability than human behavior. Every time the draghead is encountering a high spot production is severely affected and also quickly corrected by the controller.

RESULTS

Although all kind of theoretic thinking and models based on previous experience are recommended and this confirmation can be good indicators, it is nevertheless very necessary to remember "the proof of the pudding is in the eating". This a realistic and expensive playground within the Netherlands and research must eventually provide tangible results. The coincidence of building 3 sister ships, medium size hopper dredgers, for the Dredging Cooperation of India (DCI) was a blessing in disguise to test the previously described controllers in every aspect necessary.

Figure 10. DCI Dredge XXI

This was especially apparent on the newly built Dredge XXI (figure 10.) several tests were conducted during the sea trials to prove that the theoretical and simulated results could be realized in practice with very little to no difference in predicted results. Below (Figure 11) two pictures of the SCADA system are given showing the performance of the controllers.The left picture shows the dredging process with the EPC and AVC controllers switched off and the right picture shows the dredging process with the controllers switched on.

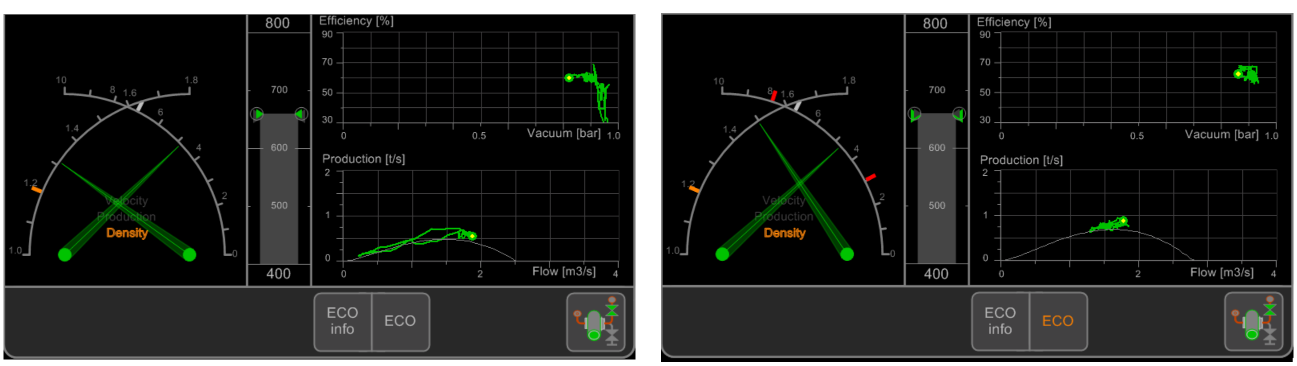

Figure 11. Dredging process with controllers enabled (right) and disabled (left)

The right upper part of the picture shows the measured pump efficiency as a function of the pump vacuum. The right lower part shows the production as a function of the mixture flow. Here the maximum production curve for the actual dredging situation is plotted in grey. For both parts the actual measured data is plotted as a yellow dot and the history data points of the last minute are plotted in green. The differences in the left and right pictures clearly show the positive effect of the controllers on both the pump efficiency and the production rates. The experiments showed a remarkable reduction in the total loading time of 15% and a reduction of the total fuel consumption of 16% with the controllers used.

CONCLUSIONS

It has become abundantly clear that the use of a combination of TSC, EPC & AVC is a powerful improvement package for a hopper dredger. This is most evidently expressed in fuel savings and a lower cycle time due to faster loading. The use of AI in dredging is a relatively recent phenomena with a remarkablly high potential to produce positive effects for the further reduction of the stress on the environment by better fuel efficiency and lowering the price per dredged cubic meter.

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CITATION

William Camden's ***“Remaines of a Greater Worke Concerning Britaine”*** 1605 (earliest printed):
"All the proof of a pudding is in the eating."