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Conference Paper · May 2017

DOI: 10.7148/2017-0276

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AN INTELLIGENT WINCH PROTOTYPING TOOL

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KEYWORDS

Virtual prototyping; Product optimisation; Computer-automated design; Maritime winch design; Genetic algorithm; Artificial intelligence.

ABSTRACT

In this paper we present a recently developed intelligent winch prototyping tool for optimising the design of maritime winches, continuing our recent line of work using artificial intelligence for intelligent computer-automated design of offshore cranes. The tool consists of three main components: (i) a winch calculator for determining key performance indicators for a given winch design; (ii) a genetic algorithm that interrogates the winch calculator to optimise a chosen set of design parameters; and (iii) a web graphical user interface connected with (i) and (ii) such that winch designers can use it to manually design new winches or optimise the design by the click of a button. We demonstrate the feasibility of our work by a case study in which we improve the torque profiles of a default winch design by means of optimisation. Extending our generic and modular software framework for intelligent product optimisation, the winch calculator can easily be interfaced to external product optimisation clients by means of the HTTP and WebSocket protocols and a standardised JSON data format. In an accompanying paper submitted concurrently to this conference, we present one such client developed in Matlab that incorporates a variety of intelligent algorithms for the optimisation of maritime winch design.

INTRODUCTION

NTNU in Ålesund is located on the west coast of Norway in the heart of the Global Centre of Expertise (GCE) Blue Maritime Cluster.[1] This industrial cluster is a world leader in design, construction, equipment and operation of advanced special vessels for the global ocean industry, with an annual turnover of about 62 billion NOK (GCE Blue Maritime Cluster, 2016). In close cooperation with the maritime industry, NTNU in Ålesund offers courses on 3D modelling, visualisation and VP, training of maritime personnel in advanced simulators, and takes part in research projects. Together with two companies in the maritime cluster, ICD Software AS[2] (provider of industrial control systems software) and Seaonics AS[3] (designer and manufacturer of offshore equipment), the Software and Intelligent Control Engineering (SoftICE) Laboratory[4] has received funding from the Research Council of Norway and its Programme for Regional R&D and Innovation (VRI) for two independent but related research projects for using artificial intelligence (AI) for intelligent computer-automated design (CautoD) of offshore cranes and winches, respectively. Our main focus is on the development of a generic and modular software framework for intelligent CautoD of maritime products, exemplified by offshore cranes and winches. We have previously presented the software framework with respect to the design of cranes (Bye, Osen, Pedersen, Hameed and Schaathun, 2016) and how various intelligent algorithms can be applied to optimise the design (Hameed, Bye, Osen, Pedersen and Schaathun, 2016; Hameed, Bye and Osen, 2016*a*,*b*).

In this paper, we extend this framework with the inclusion of new product calculator for maritime winches that together with a GA optimisation module and a web GUI constitute what we refer to as a winch prototyping tool (WPT). Submitted concurrently in an accompanying paper, we present a Matlab winch optimisation client (MWOC) that we use to test a number of algorithms within this same framework (Hameed et al., 2017). (Hameed, Bye, Pedersen and Osen, 2017). Whilst we have achieved the goals of the specific two research projects mentioned above, we wish to emphasise that our work easily can be extended to other products and CautoD methodologies.

In the following, we begin with a background overview of virtual prototyping (VP) in general and CautoD in

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[1] `http://www.bluemaritimecluster.no`

[2] `http://www.icdsoftware.no`

[3] `http://www.seaonics.com`

[4] `http://blog.hials.no/softice`

particular, VP of maritime winches, and the motivation for our work. Next, we outline the method we have used, including details about the software architecture of our product optimisation system and its main components, and the new intelligent WPT. Finally, we present a case study where we use the WPT to optimise a given winch design and discuss our work and potential future directions.

BACKGROUND

Virtual Prototyping (VP)

VP may be defined as the computer-aided construction of digital product models, usually virtual prototypes or digital mockups, and realistic graphical simulations for the purpose of design and functionality analyses in the early stages of the product development process (Pratt, 1995). Common VP methodologies include computer-aided design (CAD), realistic virtual environments (VEs), VR, and CautoD, with modelling, simulation, and visualisation as key underlying themes. In our work, the main focus is on applying AI methods such as genetic algorithms (GAs), simulated annealing (SA), particle swarm optimisation (PSO), and grey wolf optimisation (GWO) for CautoD in order to automate and optimise the design phase of product development.

Computer-Automated Design (CautoD)

CautoD traces back at least to the 1960s, when Kamentsky and Liu (1963) created a computer programme for determining suitable logic circuits satisfying certain hardware constraints while at the same time evaluating the ability of the logics to perform character recognition. Since then, there have been many contributions of CautoD, particularly in the field of structural engineering (see Hare et al., 2013, for a survey).

The general paradigm of CautoD is that of *optimisation*, where one formulates the design problem as the optimisation of an objective function. The objective function is either a cost function that must be minimised, or a fitness function that must be maximised. Parameterising the design, the goal is to find suitable values for the design parameters such that the objective function is optimised.

Whilst some optimisation problems can be formulated such that analytical or exact solutions can be found, more complex optimisation problems, including non-deterministic polynomial time (NP) problems, may require heuristic or intelligent methods from the field of AI, such as machine learning and evolutionary computation, to find satisfactory solutions (see Zhang et al., 2011, for a survey).

Virtual Prototyping of Maritime Winch Systems

Figure 1 shows a winch system in the Seaonics Big Drum Trawlwinch series, which is one of several kinds of maritime winch systems offered by Seaonics AS. In addition to trawling, maritime winches are used for anchor handling, mooring, towing, and more. The winch may at first sight appear insignificant and be conceived as a taken-for-granted piece of machinery, however, winches are

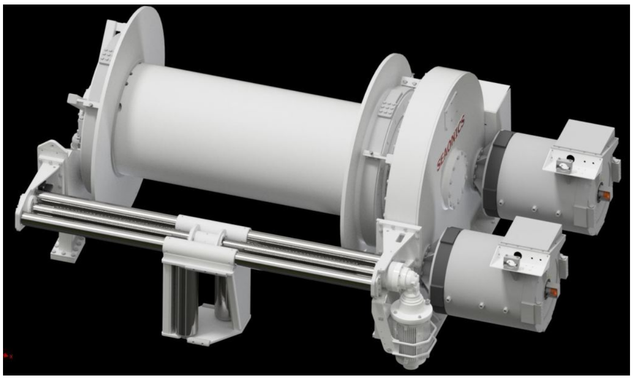


Figure 1: Seaonics Big Drum Trawlwinch PM, designed for trawling on deep water and rough bottoms, in arctic conditions. The winch is delivered with permanent magnet (PM) or conventional AC motors for both demersal and pelagic trawling. Image courtesy of Seaonics AS.

indispensable for many tasks, including the precise monitoring of various operating conditions (e.g., cable payout length, speed, and tension), active motion compensation, integrated cable cleaning systems, remote control, and as a computer interface (Pearlman et al., 2017). Thus, maritime winch systems are typically complex, come in many flavours, and consist of many different parts and components. With the advent of new technologies, major improvements in the drive systems, cable handling, safety and reliability are possible, particularly in motor and hydraulic controls (Pearlman et al., 2017). Examples of recent relevant research include model-based control designs for offshore hydraulic winch systems (Skjong and Pedersen, 2016), the influence of fishing grounds on trawler winch design (e.g., see Carral et al., 2015, for a review), winch design interventions for safety and entanglement hazard prevention (Lincoln et al., 2016), analysis of trawl winches barrels deformations (Solovyov and Cherniavsky, 2013), and high performance winch and synthetic rope systems for workboats, tug boats, and commercial marine applications (Griffin, 2004), to mention some.

In the work we present here, we focus on winches with two kinds of motors, namely electric and hydraulic. Together with the drum and the wire, these four components and their properties yield a number of design parameters that must be appropriately chosen by the designer to achieve a winch design with desired measures of performance, or key performance indicators (KPIs). As noted in a review by Pearlman et al. (2017), many of these parameters are dependent on each other and the winch designer must apply an iterative process to obtain a satisfactory design.

In this paper, we are mainly concerned with torque performance but emphasise the many other concerns must be taken into account by the winch designer, including adhering to laws, regulations, and the use of design codes such as the standards provided by classification socities like DNV GL, Lloyd’s Register Group Limited, and the American Bureau of Shipping.

Motivation

Designing an optimal winch requires deep knowledge about its intended application. For example, an optimal winch for trawling will not be optimal for heave-compensated cranes, since heave compensation will operate in a sinusoidal mode around a working area whereas trawling will require high capacity for bringing the catch on-board in a continuous operation. Also, within any one application there are usually many conflicting requirements. For instance, for trawling it is important to set the net quickly, which requires high wire velocity and a winch drum with a large inner diameter. However, when the net is full of fish, one needs high torque, which requires lower wire velocity and a smaller drum diameter.

Moreover, the design process traditionally has involved rather complicated spreadsheets that are difficult to use and maintain and have very limited visualisation features. In addition, in order to improve the versatility of the winches and enhance their performance, it has become popular to design hybrid winches that employ both electrical and hydraulic motors, combining the advantages of both kinds of motors. The merit of hybrid winches comes at a cost though, as the design process become even more complex, and even with a fully functional spreadsheet, the most difficult part remains, namely finding the optimal parameters. Due to the large number of parameters, the task of improving the design through trial and error is very time consuming and difficult. Hence, it is a difficult task to engineer a winch with desired specifications due to the large number of possibly conflicting design parameters and the lack of suitable optimisation tools for problems that may be NP-hard in nature.

In the next sections we present our WPT that has support for hybrid winches and with built-in support for "automagic" parameter optimisation. Unlike many other automatic parameter optimisation tools, this tool also support selection from predefined components, such as a catalogue of commercially available motors. Hence, designers are free to limit parameters to an interval or to a predefined set of components. Another rather unique feature is that designers can limit the scope of the component library. For example, the designers may choose to let predefined component sets such as pairs of motors and gears be lumped together as bigger units, or they may choose to have the software search for motors and gears independently of each other.

METHOD

Product Optimisation System

The diagram in Figure 2 shows a high-level overview of the software architecture of our product optimisation system. The system employs a server-client software architecture. The main component of the server is a product calculator, e.g., for offshore cranes or winches, that contains a number of different product design parameters, of which many are interdependent through electrical, hydraulic, and mechanical interactions in a highly complex, and often nonlinear, manner. Different parameter values constitute different designs of the same product. When new parameter values are set, the product calculator calculates a number of KPIs. The goal of the product designer is to determine the parameter values that yields a product design with desirable KPIs. Using a client, the product designer can manually set the parameter values in the product calculator via two different communication interfaces: the Hypertext Transfer Protocol (HTTP) or the WebSocket (WS) protocol. In return, the client can obtain the values of the KPIs, as well as other measures of interest, calculated by the product calculator. These bidirectional messages are transferred as JavaScript Object Notation (JSON), which is a lightweight human-readable data-interchange format.

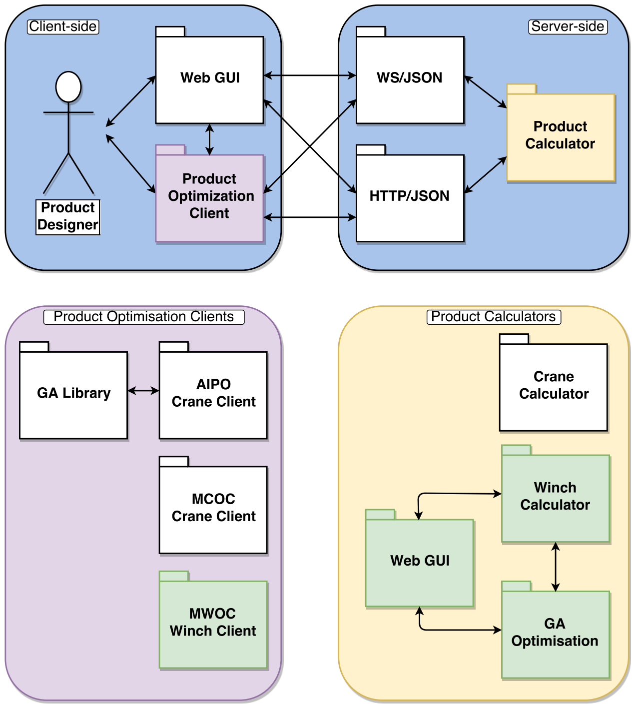


Figure 2: Software architecture for intelligent CautoD of offshore cranes, winches, or other products. Green boxes indicate work not presented previously.

Determining a suitable product design by manual trial-and-error is a tedious task for the product designer. Instead, one can opt to use a product optimisation client (POC) that automates this process. In addition, it may be beneficial to use a graphical user interface (GUI) both for interacting with optimisation software and with the server-side product calculator.

The design of this software framework is generic and modular. On the server side, we can develop new product calculators as long as they conform to the HTTP/JSON or WS/JSON communication interfaces and message formats that we have defined. Likewise, on the client side, users can develop GUIs and POCs for different products as needed, again as long as they conform to said communication interfaces and message formats.

Recently, we have experimented with various client solutions and developed both a GUI and several POCs for optimisation of offshore cranes, including the Artificial Intelligence for Product Optimisation (AIPO) client written in Haskell that uses a GA for the optimisation (Bye et al., 2016), as well as the Matlab Crane Optimisation Client (MCOC) that uses several evolutionary algorithms for the optimisation, including the GA, SA, PSO, and GWO algorithms (Hameed, Bye, Osen, Pedersen and Schaathun, 2016; Hameed, Bye and Osen, 2016*a*,*b*).

In the following sections, we present our new intelligent winch prototyping tool, or WPT. The interested reader may also wish to refer to our accompanying paper, in which we present a Matlab winch optimisation client implemented with several intelligent algorithms, the MWOC, and test it within this same framework (Hameed et al., 2017).

Intelligent Winch Prototyping Tool (WPT)

Implementing all the necessary design parameters in a winch calculator based on detailed models of the physics involved, we are able to calculate the theoretical physical properties for a given winch design as defined by the chosen set of parameter values. The aim of the winch designer is choose the parameter values that result in a winch design with desirable properties, usually expressed as KPIs, while simultaneously meeting requirements by laws, regulations, codes and standards. Our industrial partner, Seaonics AS, has identified a subset of the most important design parameters that the winch designer is free to experiment with. Via a web GUI (see below), the designer can set and manually tune these design parameters, or use a GA to optimise the design based on some desired optimisation criteria (see Figure 3). Seaonics AS has tested the WPT and the accuracy of the tool has been verified against other existing tools such as spreadsheets currently in use in the industry.

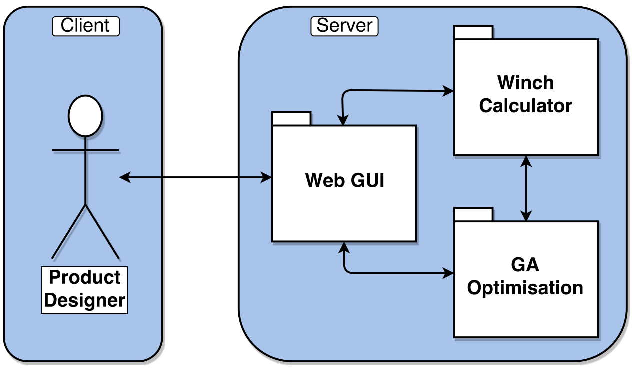


Figure 3: Winch prototyping tool (WPT).

Web Graphical User Interface (GUI)

To simplify practical use of the winch calculator, we have implemented a web GUI (see Figure 4). The GUI has two main panes: one for user input (left-hand pane) that allows the user to select one of three tabs: *Specify*, *View*, and *Optimize*; and one for displaying a graph of key torque characteristics (right-hand pane).

Under the Specify tab, the user can enter values for the winch design parameters, and observe how newly entered values will update the graphical key torque characteristics in the right-hand pane. Parameters are grouped together and categorised as belonging to one of four major components of the winch, namely the drum, the electrical motor, the hydraulic motor, or the wire. Under the View tab, the user can set the resolution (number of data points) of the graph; the total number of winch layers; and the current layer to be observed in the graph. The user can also generate a file in portable document format (PDF) that contains a plot for all the winch layers. Under the Optimize tab, the user can use a GA to optimise a winch design based on a user-defined objective function. To do so, the user must (i) set a number of settings for the GA (see Table 1); (ii) define a suitable objective function (more details in following sections); and (iii) set the allowable ranges (constraints) for each design parameter (optimisation variable) to be optimised.

The right-hand pane shows graphically the S1 continuous duty cycle[5] torque (red), the maximum torque (green), and the required torque (blue), as functions of the wire velocity, for a given set of winch specifications and for the particular winch layer defined under the Specify and View tabs, respectively. When a parameter value changes, or after an optimisation has been run, the plots are automatically updated to reflect the effect on the three torque profiles determined by the winch calculator.

The Genetic Algorithm (GA)

The GA (Holland, 1975) is an intelligent algorithm inspired by natural evolution and principles such as inheritance, mutation, selection, and crossover. GAs are well suited for hard optimisation problems (e.g., where solutions are difficult or impossible to obtain in polynomial time) and can also conveniently handle constraints. Since its popularisation in the 1980s, the GA has continued to be a very popular optimisation tool across many different disciplines (e.g., see Haupt and Haupt, 2004). Indeed, in addition to our work on design of offshore cranes and winches, the authors and colleagues have themselves used GAs for a number of diverse real-world optimisation problems, including a general optimisation and machine learning framework for pedagogical and industrial use (Hatledal et al., 2014), boids swarm models (Alaliyat et al., 2014), and dynamic resource allocation with maritime application (DRAMA) (e.g., Bye, 2012; Bye and Schaathun, 2014, 2015).

We assume that the reader is somewhat familiar with GA and refer to a previous paper (Bye et al., 2015) and relevant literature (e.g., see Haupt and Haupt, 2004) for pseudocode and more details. Table 1 shows a summary of some basic GA parameters with typical values that must be set in the web GUI before the GA is run. For the particular objective function we use here, we must also set a *resolution* parameter N_r (see next section).

[5]One of eight duty cycle classifications (S1–S8) provided by the International Electrotechnical Commission in the IEC 60034-1 standard.

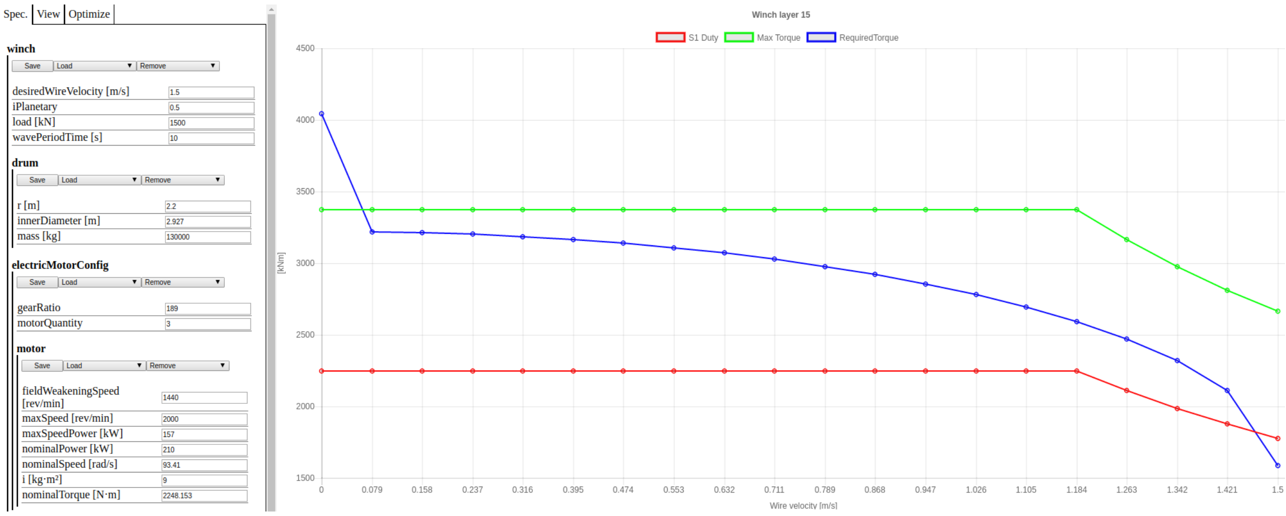


Figure 4: Web GUI for winch prototyping tool (WPT).

parameter	typical
candidates, N_c	100
parents, N_p	50
elites, N_e	10
mutations, N_m	10
generations, N_g	500
resolution, N_r	20

Table 1: GA parameters with typical values.

CASE STUDY

As a simple case study, the main KPI that Seaonics AS is interested in consists of the three torque profiles that result from a given winch design, namely the S1 continuous duty cycle torque T_{S1}, the maximum torque T_{max}, and the required torque T_{req}, which are all functions of the wire velocity v, which has a resolution of N_r sample points between zero and the maximum wire velocity v_{max} (see Figure 4). The S1 torque is the maximum continuous duty cycle with constant load that the electric motors can safely operate under. The maximum torque is an upper threshold at which the electric motors can safely operate under but only for shorter periods of time. The required torque is the minimum torque required for safe operation for a given constant load.

The torque profiles are also dependent on the winch layer of interest. The number of winch layers, as well as the winch layer to be inspected, can be set in the View tab in the web GUI. Since the torque requirements of the winch increase with winch layers, we conservatively optimise the design parameters for the outermost winch layer. In this paper, the winch is designed with 15 layers and we optimise with respect to layer 15. Notably, however, our GA is able to take all layers into consideration if needed.

Design Parameters

Seaonics AS has provided us with 28 design parameters that can used for optimisation of winch design (see Table 2).[6] As indicated, these parameters can further be divided into five subsets as being *general*, or related to the *drum*, the *electric motors* or *hydraulic motors*, or the *wire*. Choosing the default values for each parameter results in a winch with the same torque profiles as depicted previously in Figure 4. This default design acts as a baseline winch that was designed by a human operator at Seaonics and hereafter will be subject to optimisation and comparison.

For optimisation, we first need to decide which parameters to include as optimisation variables. Keeping the four general parameters such as the wave period and load constant at their default values makes sense, since these parameters relate to the kind of operating scenario for which we need to determine optimised solutions, and the GA should not be allowed to modify these. The 24 remaining parameters relating to the drum, motors, and wire may all have an influence on the main KPI we are interested in, namely the torque profiles. However, for illustration purposes, we limit ourselves to only five parameters that intuitively should strongly influence the torque profiles, namely the inner diameter of the drum, and the gear ratios and quantities of the electric and hydraulic motors (shown in bold in Table 2).

Whilst our GA easily can optimise over the entire set of parameters, one should ideally have a more realistic library of components with fixed parameters, and the GA should optimise the composition of several components put together rather than individual parameters. Our GA has been implemented to be able to perform such component-wise optimisation, however, Seaonics AS has not yet been able to provide us with a useful library of components and we therefore perform optimisation over the set of parameters mentioned above instead. Conceptually, this approach is no different from component-wise optimisation.

Finally, for each design parameter to be optimised, we need to add constraints, that is, minimum and maximum values. Table 2 summarises the parameter settings, includ-

[6] Due to space considerations, we only provide an explanation for selected relevant parameters.

ing default, minimum, maximum, and optimised parameter values.

Objective Function

As mentioned previously, the main KPI that we are concerned with here relates to the torque profiles of T_{req}, T_{max}, and T_{S1} as shown in Figure 4. Because the torque required to rotate the drum and the inertia of the drum and wire increase with the lever arm (the perpendicular distance from the axis of rotation to the line of action of the force), we focus on the worst case when most of the wire is on the drum, in this case winch layer 15.

In order to define a suitable objective function we need to establish what the torque profiles of T_{req}, T_{max}, and T_{S1} should look like. As per information provided by Seaonics AS, a set of guidelines could for instance be given by the following:

- T_{req} should be lower than T_{max} for all wire velocities v_k, except for standstill where $v_0 = 0$, where it could be allowed to be higher.
- T_{req} should be lower than T_{S1} at wire velocities used for continuous operation, that is, typically from half the maximum wire velocity v_{max} and higher.
- conversely, T_{req} should preferably lie between T_{max} and T_{S1} for wire velocities *not* used for continuous operation, that is, typically from half the maximum wire velocity v_{max} and lower.

The rationale for this is that we do not want to use bigger and more expensive motors than necessary, which could lead to T_{req} being below T_{S1} for all velocities, including low velocities not suitable for continuous operation. This rationale is motivated not only by cost, but also by weight and performance, since bigger motors will have higher mass and inertia. Hence, the possibility of operating above the nominal S1 duty rating for the motors should be utilised. Operating above the S1 duty cycle is only possible for shorter periods of time due to heat accumulation in the motors. Consequently, after a short period of operating above S1, the motors must be allowed to operate below S1 in order to cool down.

It is important to understand that the guidelines above are merely an example of suitable guidelines for a specific application. Say, if the winch would be used in constant tension mode, then either T_{req} must be lower than T_{S1} at zero wire velocity to avoid overheating and failure, or other heat-preventing precautions must be taken, such as additional cooling by installing more fans or by installing water cooling.

Based on the above guidelines we have devised the following objective function, which is in fact a cost function:

$$f_{\text{cost}} = \sum_{k=1}^{N_{\text{r}}} a \cdot \text{R}_k + (1-a) \cdot \text{S}_k \tag{1}$$

where

$$\text{R}_k = \begin{cases} \delta\text{R}_k^2 \text{ for } \delta\text{R}_k > 0 \\ 0 \text{ otherwise} \end{cases} \tag{2}$$

$$\text{S}_k = \delta\text{S}_k^2 \tag{3}$$

$$\delta\text{R}_k = T_{\text{req}}(v_k) - T_{\text{max}}(v_k) \tag{4}$$

$$\delta\text{S}_k = T_{\text{req}}(v_k) - T_{\text{S1}}(v_k) \tag{5}$$

$$a = 0.5 \tag{6}$$

and v_k is the kth sample of the wire velocity. That is, this cost function is a weighted sum of the squared difference between T_{req} and T_{max} for only those velocities v_k where T_{req} is higher than T_{max}, and the squared difference between T_{req} and T_{S1}. The effect of the first term is that an intolerable torque T_{req} higher than T_{max} is punished severely. For the second term, the smallest cost of zero at any wire velocity is achieved for T_{req} equal to T_{S1}, whilst T_{req} being either higher or lower than T_{S1} is punished severely, and more so the bigger the difference, due to squaring. Because T_{req} will typically have a falling torque profile, due to higher torque requirements at lower velocities, the intention of the second term is to obtain a profile for T_{req} that is higher than T_{S1} for low velocities and lower than T_{S1} for high velocities. The two terms can be weighted relative to each other by the weighting factor a, here set to $a = 0.5$.

Results

Figure 5 shows the default torque profiles for T_{max} (red), T_{req} (blue), and T_{S1} (green) for winch layers 1, 5, 10, and 15 before optimisation, and for $T_{\text{req,GA}}$ (black) after GA optimisation (T_{max} and T_{S1} remain unchanged).

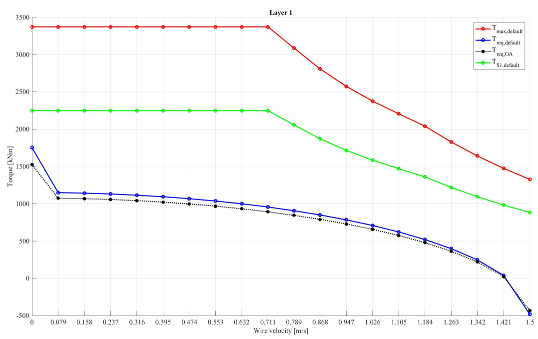
For winch layers 1 and 5, there is not much difference between T_{req} and $T_{\text{req,GA}}$, whereas for winch layers 10 and 15 there is a big improvement in reduced required torque from GA optimisation resulting in $T_{\text{req,GA}}$. Comparing with the guidelines we used to define the objective function, we observe that all three requirements for the worst case of layer 15 are satisfied.

The optimised values for the five design parameters that were chosen as optimisation variables are provided in boldface in Table 2. After optimisation, the size of the inner diameter of the drum has increased from its default value of 2.927 m to 2.97 m, which is close to the parameter maximum constraint of 2.99 m. The number of electric motors has increased from 3 to 4, whereas the number of hydraulic motors is unchanged at 4. Finally the gear ratio of the electric motors has increased from their default value of 189 to 199.8, which is very close to the parameter maximum constraint of 200. The gear ratio of the hydraulic motors has increased slightly from their default value of 159.16 to 167.90, which is close to the middle of the constrained parameter ranged from 150 to 190.

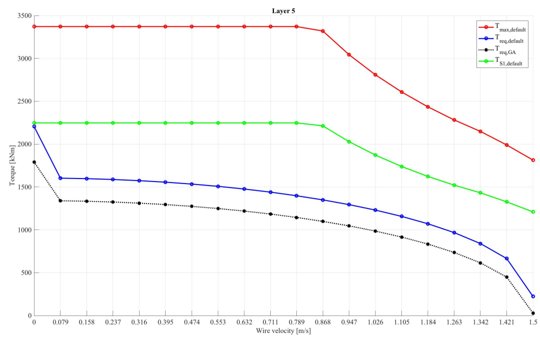
It is not surprising that having an extra electric motor with a better gear ratio reduces the required torque, however, it is less intuitive that the gear ratio of the hydraulic motor seems less important (it was not driven towards its

subset	number	name	units	default	min	max	optimised
general	1	wavePeriodTime	s	10	-	-	10
	2	load	kN	1500	-	-	1500
	3	iPlanetary	-	0.50	-	-	0.50
	4	desiredWireVelocity	m/s	1.50	-	-	1.50
drum	5	r	m	2.20	-	-	2.20
	6	**innerDiameter**	**m**	**2.927**	**2.70**	**2.99**	**2.97**
	7	mass	kg	130000	-	-	130000
electric motor	**8**	**gearRatio**	**-**	**189.0**	**170.0**	**200.0**	**199.8**
	9	**motorQuantity**	**-**	**3**	**1**	**5**	**4**
	10	fieldWeakeningSpeed	rev/min	1440	-	-	1440
	11	maxSpeed	rev/min	2000	-	-	2000
	12	maxSpeedPower	kW	157.0	-	-	157.0
	13	nominalPower	kW	210	-	-	210
	14	nominalSpeed	rad/s	93.410	-	-	93.410
	15	i	kg·m^2	9.00	-	-	9.00
	16	nominalTorque	N·m	2248.15	-	-	2248.15
hydraulic motor	**17**	**gearRatio**	**-**	**159.16**	**150.00**	**190.00**	**167.90**
	18	**motorQuantity**	**-**	**4**	**1**	**5**	**4**
	19	friction	-	0.950	-	-	0.950
	20	staticEfficiency	-	0.789	-	-	0.789
	21	dynamicEfficiency	-	0.916	-	-	0.916
	22	maxSpeed	rev/min	1600	-	-	1600
	23	displ	cm^3	1000	-	-	1000
	24	pressureDrop	bar	280	-	-	280
	25	i	kg·m^2	0.550	-	-	0.550
	26	nominalTorque	N·m	4457.71	-	-	4457.71
wire	27	diameter	mm	77.0	-	-	77.0
	28	diameterReductionFactor	-	0.866	-	-	0.866

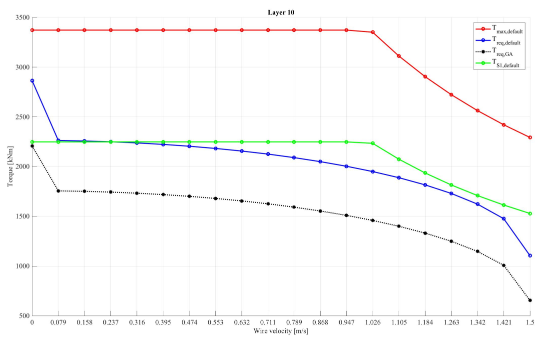
Table 2: Default and optimised (bold) winch design.



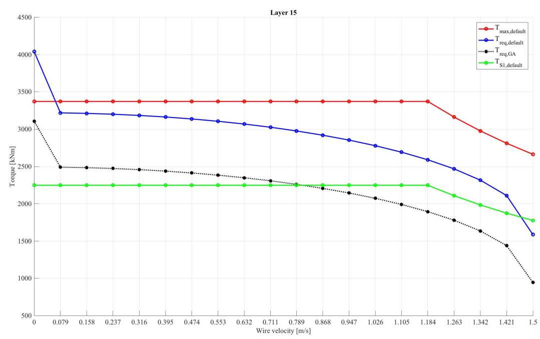
(a) layer 1



(b) layer 5



(c) layer 10



(d) layer 15

Figure 5: Default torque profiles for $T_{\max}$ (red), T_{req} (blue), and T_{S1} (green) for winch layers 1, 5, 10, and 15 before optimisation, and for $T_{\mathrm{req,GA}}$ (black) after GA optimisation ($T_{\max}$ and T_{S1} remain unchanged).

maximum value constraint like its electric counterpart). This may be because the hydraulic motors have a higher nominal torque and are not suffering from field weakening at higher speeds such as electric motors. Due to different speeds and gear ratios on hydraulic and electric motors, one kind of motor might be operating below maximum whilst the other kind is at maximum, and this might explain why the gear ratio for the hydraulic motors is not driven to its maximum by the GA as for the electric motors. That the inner diameter of the drum is nearly maxed out from a default value of 2.927 to a value of 2.97, with the maximum parameter constraint being 2.99, is counter-intuitive when considering torque alone. However, we suspect that it has been increased to ensure that the default speed requirements of the motors are satisfied, as the wire velocity increases with the diameter of the drum for the same rotational speed.

The results show that the GA indeed is capable of improving a default unsatisfactory design to yield an optimised design that satisfies the design guidelines we set out previously.

DISCUSSION

In this paper, we have expanded our software framework from earlier work on design optimisation of offshore cranes to also include maritime winches by means of a WPT. All our work, previous and current, have been performed in cooperation with two industrial partners, ICD Software AS and Seaonics AS, to ensure correctness and relevance of our projects. We have successfully tested the WPT on a design optimisation problem of reducing the required torque for a winch in a desired manner described previously by letting a GA determine suitable values for a subset of five design parameters. Choosing a suitable objective function and which design parameters to optimise is dependent on the kind of operation the winch is intended for, physical limitations such as available components (e.g., motors) and weight, size, and cost requirements, to name a few.

Implementation Details

The WPT differs from our previous work in that the optimisation module and the web GUI is also implemented on the server-side, thus offering a complete solution to end-users with no need for a local installation, but more importantly, removing communication overhead between a client-side POC and the server-side product calculator. Nevertheless, simultaneously, we have ensured that the WPT is compatible within the client-server architecture of our framework, which means it is still possible to implement winch optimisation clients in any language of choice (e.g., Matlab Hameed et al., 2017) that can connect to the winch calculator through the HTTP/JSON and WS/JSON interfaces. Nevertheless, we note the benefit of letting the software modules for the POC and the product calculator co-exist on the same server to avoid communication overhead.

Furthermore, we have implemented optional authentication for the WS communication interface and for the server-side WPT, requiring users to be registered and enter a password for access. This feature can useful for licensing of software, e.g., on a time-limited basis, and other models of commercialisation that our industrial partners want to proceed with.

Finally, we wish to re-iterate that our software framework is highly modular and generic, as we have demonstrated here and in our earlier work.

Web GUI and Future Work

In our earlier work on crane design optimisation (Bye et al., 2016), the POC using a GA was not accessible via a web GUI, which raised the bar significantly for usage by a product designer without programming experience and/or AI knowledge. In the WPT we present here, we have incorporated application of a GA by means of a simple user interface where a winch designer can perform winch optimisation by the press of a button. The web GUI also offers some useful defaults for GA settings and parameter values and boundaries that the designer can modify as needed.

For the future, we would like to implement some improvements to the web GUI. First, as short electronic manual outlining the basics of GAs as well as the effect of the GA settings should be provided, possibly integrated in the web GUI (e.g., by mouseovers and/or a separate webpage). Second, the manual should also include notes on how to design useful objective functions, and the web GUI should store a library of such functions, with explanations, for different optimisation purposes. Third, Seaonics AS should provide a library of real-world components with pre-defined sets of parameters that the GA should combine in an optimal manner. Fourth, the web GUI should allow for import and export of optimisation parameters to allow for batch processing and analysis in the design process. Finally, the auto-generated report tool, which currently exports plots of the torque profiles of all the winch layers could be expanded to contain more information and quantitative data.

ACKNOWLEDGEMENTS

The SoftICE lab at NTNU in Ålesund wishes to thank ICD Software AS for their contribution in the software development process, and Seaonics AS for providing documentation and insight into the design and manufacturing process of offshore cranes. We are also grateful for the support provided by Regionalt Forskningsfond (RFF) Midt-Norge and the Research Council of Norway through the VRI research projects *Artificial Intelligence for Crane Design (Kunstig intelligens for krandesign (KIK))*, grant no. 241238, and *Artificial Intelligence for Winch Design (Kunstig intelligens for vinsjdesign (KIV))*, grant no. 249171.

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