Empirical Prediction of Resistance of Fast Catamarans

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Problem

In the early design stage, often before the hull lines are designed, there is a need for a quick resistance calculation method which require little input. The current empirical resistance prediction method used by SINTEF Ocean, called CatRES, is based on the model trials carried out at the MARINTEK towing facility up to 1997 [1]. However, the method have become outdated and gives conservative performance prediction for new catamaran designs. SINTEF Ocean desires to update the current method, and the author has chosen to do this using Artificial Neural Networks (ANN).

Objectives and Scope

The objective of this master thesis is to develop and validate an improved empirical resistance prediction method for fast catamarans. The method shall be implemented in a computer tool suitable for implementation in a larger software system. Theory concerning resistance of catamarans and machine learning with emphasis on artificial neural networks is presented, before an in depth parameter study of neural network training in Matlab is carried out. Lastly an optimal model is developed and validated against resistance data from SINTEF Ocean and University of Southampton.

Catamaran Resistance

Resistance coefficients for a model scale catamaran is expressed in Equation 1 [2, equation 9.1]. Interaction between the hulls is an important factor, which is taken into account by the factors: γ and β in the expression below. Residual resistance can be calculated from model trials as:

$$C_{Rm} = C_{Tm} + \left[C_{Fm}(1 + k \cdot \beta) + C_{AAm} + C_{BDm}\right] \quad (1)$$

C_{Rm} is the difference between measured resistance C_{Tm} and the calculated viscous resistance inside the brackets, often called C_{ITTC} when calculated using ITTC standards [3].

Available Model Data

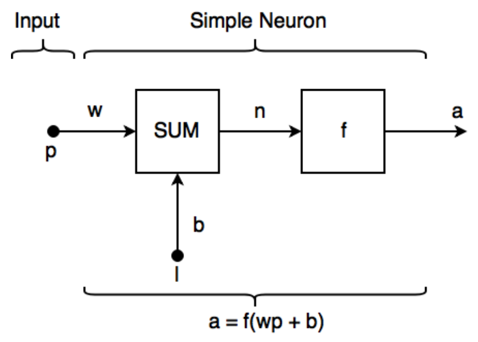
Model data has been given by SINTEF Ocean, both the data set used to develop CatRES (1082 samples), and new model tests carried out up til now (1231). Additionally, resistance data from University of Southampton is included for verification [4]. Data ranges are presented below.

Parameter		Southampton	SINTEF Ocean
Fn	Range: Mean:	[0.2000-1.0000] 0.6227	[0.0920-1.5540] 0.711
Lwl/Bwl	Range: Mean:	[7.0000-15.1000] 10.8982	[0-14.8310] 5.6870
B/T	Range: Mean:	[1.5000-2.5000] 2.0042	[1.1538-12.0650] 2.4368
$L/\nabla^{1/3}$	Range: Mean:	[6.2700-9.5000] 8.3035	[5.3100-10.8400]
$S/\nabla^{2/3}$	Range: Mean:	[6.6648-8.4609] 7.7378	[7.8200-12.4000] 10.5021
Sb/S	Range: Mean:	Not Available Not Available	[0-0.0216] 0.00764
$s2/Lwl$	Range: Mean:	[0.2000-0.5000] 0.3606	[0-0.3782] 0.2067
$Cr \cdot 10^3$	Range: Mean:	[1.1210-15.4170] 3.7914	[0.1210-18.3810] 2.5404
Samples:		719	2313

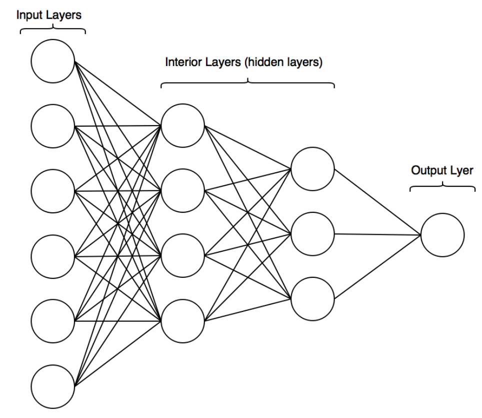
Artificial Neural Networks

Artificial neural networks are inspired by the animal brain. Multiple neurons put together in complicated and advanced structures, are able to learn and execute advanced tasks. Each neuron receives an input p which is multiplied by a weight w and added a bias b. In the next step the transfer function f sends a signal a further into the network. This can be mathematically expressed as:

$$a = f(wp + b) \quad (2)$$



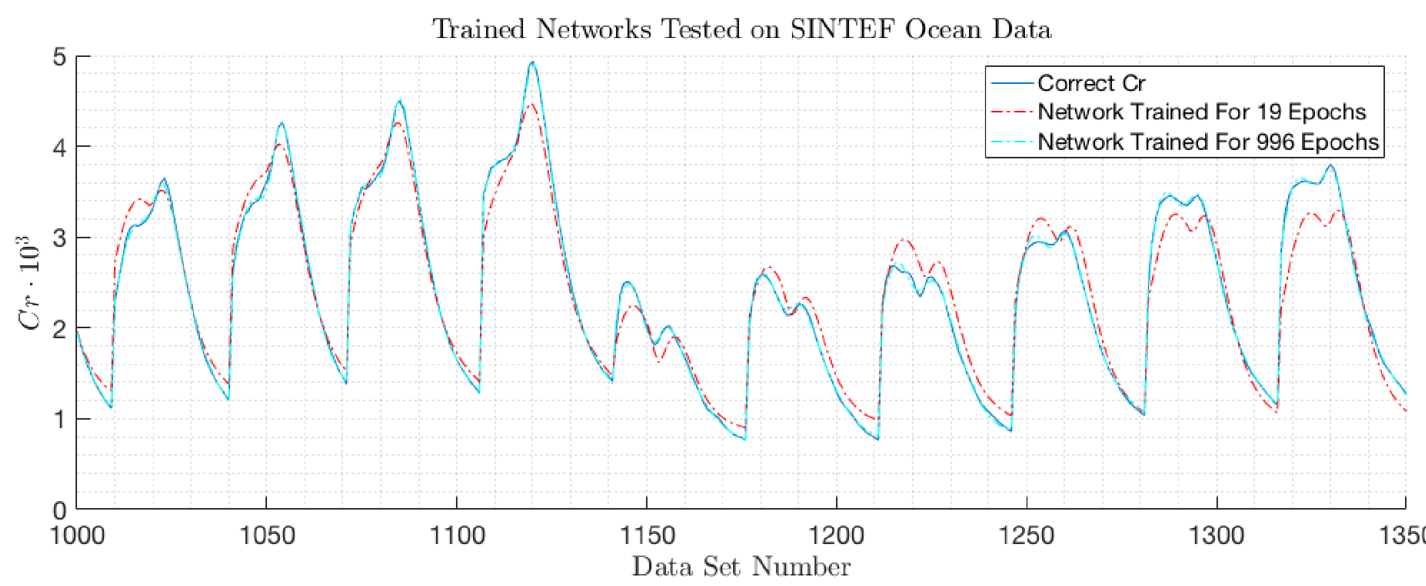
By assembling neurons, such as the one presented in the figure to the left, together in multiple layers advanced structures, such as the ones presented to the right can be created. Through network training, the weights w and biases b from Equation 2 are varied for each neuron, and a best combination is found. By extensive training an optimal network with a high degree of generalisation of the problem is found.



Results

Multiple neural networks was trained on the data presented in Section Available Model Data. A parameter set with dimensionless parameters: Fn, B/T, $L/\nabla^{1/3}$, $S/\nabla^{2/3}$, $s2/Lwl$ and Sb/S gave the best performance. The network has six input layers, four hidden layers and one output layer. After finding the optimal network for the SINTEF Ocean data, the network was tested for verification purposes against the Southampton data. The performance was poor, leading to high mean squared error (MSE) between the predicted and the correct residual resistance coefficients. The network was trained again with fewer epochs to enhance performance. Performance and generalisation ability of both networks can be seen in the Table and Figure below.

Node Distribution	Training Epochs	MSE
[10-11-11-10]	19	0.1125
[10-11-11-10]	996	0.0037



Conclusion

The neural networks designed and trained in this thesis, shows good performance and generalisation ability, to the task of predicting residual resistance coefficients for high speed displacement catamarans. Because available model data is of ferries in the range of 40-95 meters, with parameters as presented before, the validity range of the model is limited. The neural network does however predict reasonable results for out of validity range data as well. Out of the two proposed neural networks, the one trained for 996 epochs yield the best performance with a MSE of 0.0037, while the one trained for 19 epochs produces a MSE of 0.1125 when tested on the SINTEF Ocean data. Throughout this thesis neural networks have proved to give a good estimation of the residual resistance coefficient with some estimation error. The proposed model seems suitable for estimating Cr in the early stage of the design process.

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References

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