An isogeometric digital twin for "Gunnerus"

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Problem

In Computer Aided Design (CAD) it is common to use the function "trimming". This makes the surface invisible in the model but the mathematical description does not change. This causes problem for the Isogeometric analysis (IGA) because it works with the mathematical description of the model. The in-house research code can handle simple trimmed patches but not multiple patches which are trimmed, what should be extended.

Introduction

The development of a new product or structure contains of two main steps. First the modelling and then the analysis. Modelling is the step, where the design etc. is set up and is performed with help of CAD. The analysis proofs if this model is working and handle the load, which is applied with tools of Computer Aided Engineering CAE for example Finite Element Analysis. These two approaches are based on two different base functions which are connecting the nodal points. In CAD these base functions are higher polynomial degree (non-rational B-Splines NURBS) and in FEA, base functions are linear polynomials (Lagrange polynom). That results into a conflict that the model from CAD can not be used for FEA and the model has to be convert. This process is called meshing and can obtain up to 80% analysis time. This is why Huges et al. [1] introduces IGA in 2005. IGA can use the same model from CAD to perform a structural analysis because they use the same basis functions.
A problem for IGA is the trimming function in CAD. Trimming makes surface invisible in CAD but the mathematical description is still the same and IGA works only with this mathematical description. S. Schønfeldt [2] solved this issue for the existing in-house research code.
Now the idea is to combine IGA with a digital twin. A digital twin is a digital representation of a physical structure. In this thesis it will be the digital twin of NTNU's research vessel "Gunnerus". With the digital twin the research code can be tested on a complex structure with multiple trimmed patches, which was not performed yet. As well it can be shown that IGA will increase the efficiency of the workflow of a digital twin in respect to structural analysis.

References

[1] Thomas JR Hughes, John A Cottrell, and Yuri Bazilevs, "Isogeometric analysis: CAD, finite elements, NURBS, exact geometry and mesh refinement", Computer methods in applied mechanics and engineering 194, 39-41 (2005), pp. 4135–4195.

[2] Sofie Schønfeldt-Borchgrevink, Isogeometric analysis with trimmed geometries applied to ship hulls (NTNU, 2018)

[3] Fredrik Skoglund, Pictures of gunnerus, https://www.ntnu.edu/oceans/gunnerus/pictures

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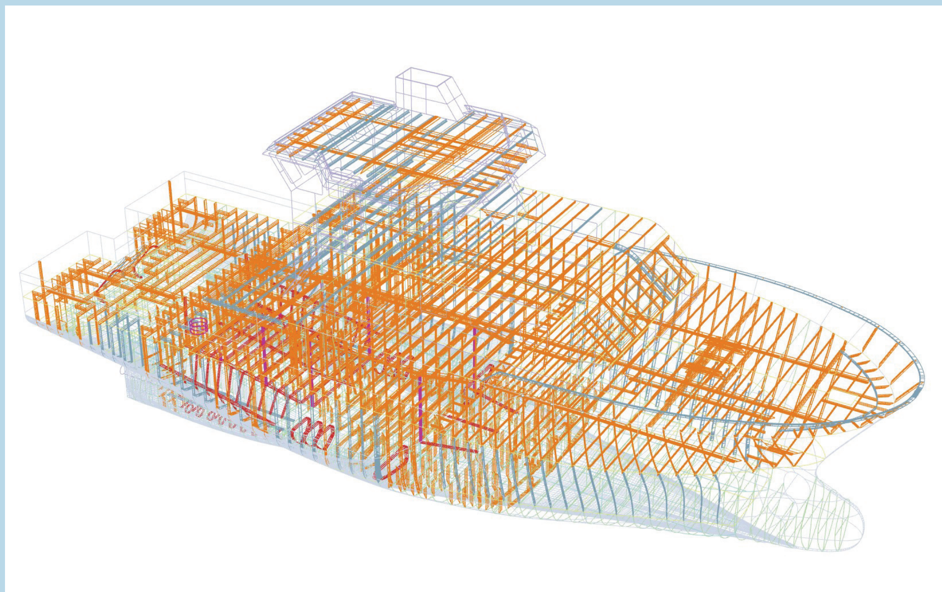
Digital twin of "Gunnerus"

The existing in-house research code for IGA can calculate simple trimmed geometries of maximum one patch. Now, the idea is to extend the existing code to a more complex structure. These complex structure will be "Gunnerus". Last summer students from NTNU built up a Digital Twin, which contains among other models, a structural model of "Gunnerus". The structural model is an exact represent of the physical one and based on shell elements, which does not contain thicknesses of all the elements. Although the whole model is made out of 11888 patches.
These two issues make it complex and time consuming to model the whole ship. For every patch the thickness has to be defined by handle. The same applies to the patch coupling, which is why only small parts of "Gunnerus" are investigated.

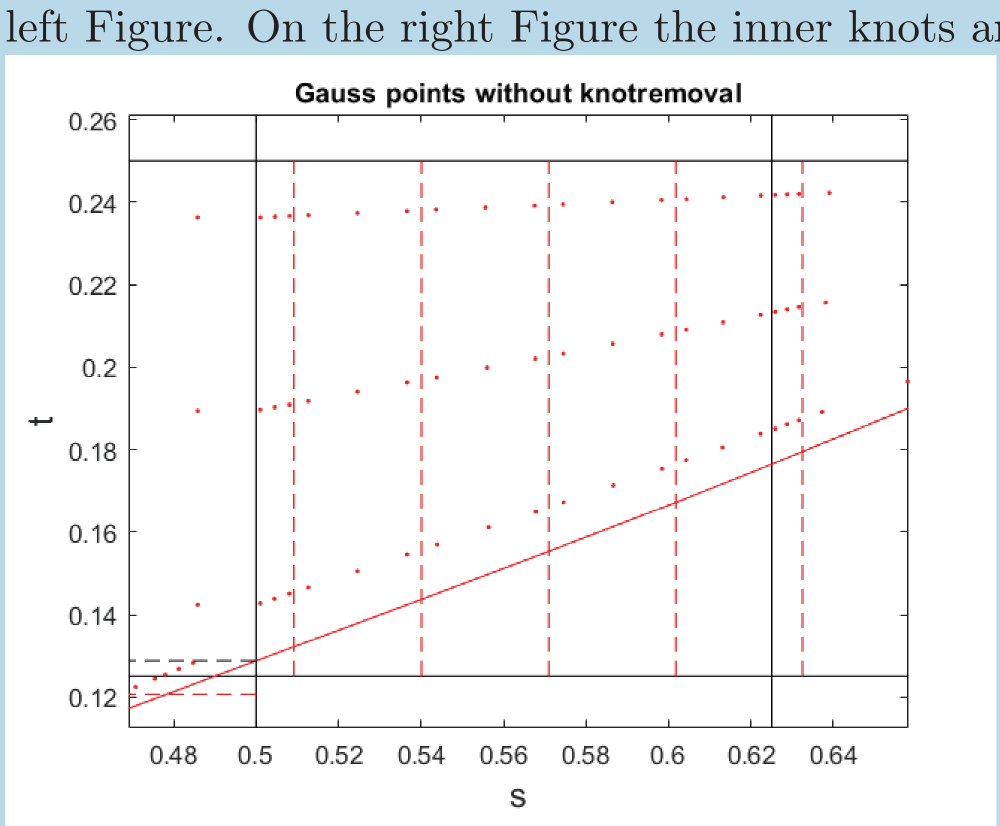
"Gunnerus" [3]



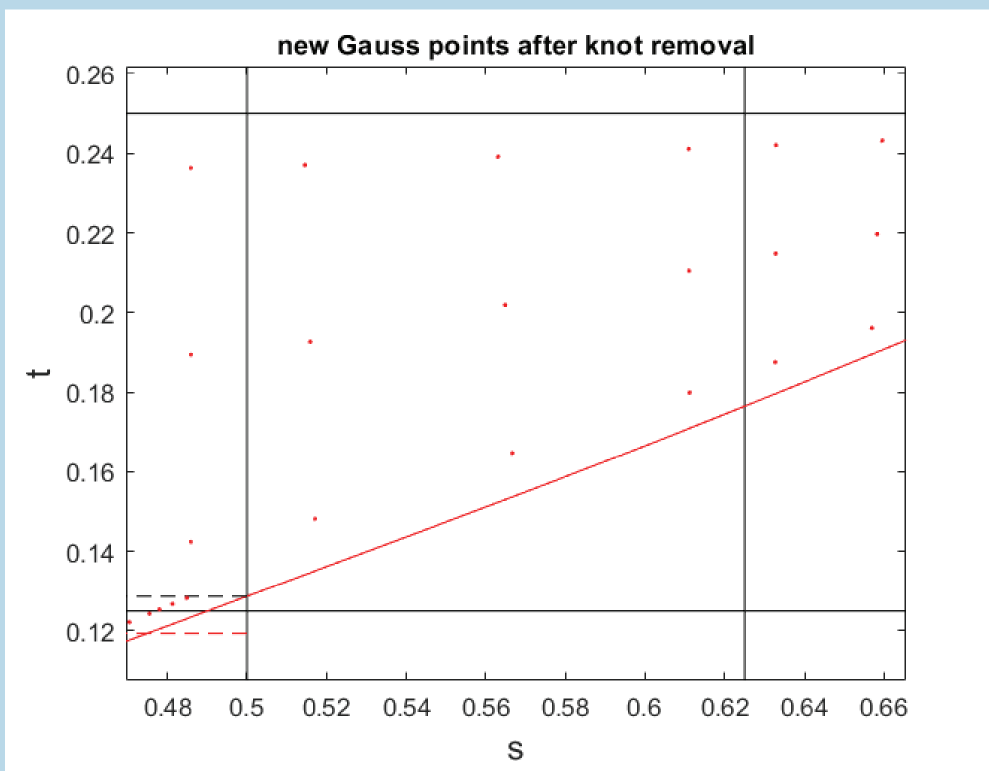
structural model of "Gunnerus"

Modelling

As mentioned before, the in-house research code needs to be modified for multiple patches with trimmed patches. First the existing IGES-function was extended. It can read different patches untrimmed and trimmed and gives out the control points, knot vectors, polynomial degree and information of each trimming curve.
Later a problem with the stiffness matrix showed up. For fine meshes or polynomials with higher order the stiffness matrix gets singular or badly scaled. This problem is related to "flying nodes". "Flying nodes" are control points of an element, which are far away from the geometry, because the stiffness of that element is quiet small in comparison to other elements. To avoid this problem, small trimmed elements under a specific area ratio between trimmed area and element area are excluded from the stiffness matrix and added to the supports.
Another point to improve IGA is not to have to much integration/Gauss points. A trimming curve is described by a knot vector, which have at least a knot at the beginning and at the end of the curve and inner knots if they are required to describe the trimming curve. Every knot divides the trimming curve into sections and for each section the Gausspoints are computed, which is why at every beginning and ending of an element knots are added. The adding of knots do not change the shape of the trimming curve but yields to unnecessary Gausspoints because the element could be divided into sub elements (s. Figure below). Removing knots can change the shape of a trimming curve, which is why the process requires a tolerance, how much the shape is allowed to vary. In the figures below the results of knot removal are shown.
The two pictures show the Gausspoints for one element, which has ion the lower side a trimming curve. The trimming curve has inner knots, the position is marked with the red dashed line in the left Figure. On the right Figure the inner knots are removed and the element has less Gausspoints.



original trimmed curves with inner knots



trimmed curves with removed inner knots