RETHINKING STCW EDUCATION TO COPE WITH INCREASED AUTONOMY AND AUTONOMOUS SHIPPING

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Keywords: STCW, Autonomous, Education, Control Systems.

Abstract. This paper presents the results of an observational study on education within Marine Cybernetics, carried out at Norwegian University of Science and Technology, (NTNU), Trondheim Norway, in the spring 2018. The observational environment chosen at NTNU is within education for the design of Marine Cybernetics. With growing autonomy and automation within the shipping industry, understanding the design principles can become even more important for a ship's crew than it is already today. The vital components of the education for design of control systems is identified and analyzed for comparison with an education for STCW compliance. Based on this a number of recommendations have been drawn up for coping with increased autonomy and automation in shipping in STCW education.

1 INTRODUCTION

The increasing complexity of systems onboard ships and within systems, which the students at maritime academies are educated in, with a view to operating and maintaining them, requires a somewhat different kind of approach for teaching system interrelations and system governance. This is considered traditionally necessary for marine engineers in automation, and for master mariners partly in navigation and partly in ships technology. The path towards autonomy in the overall governance of the system especially calls for an analysis of the implied competencies that are to be expected by the operators and maintenance engineers, and a comparative analysis with an up to date teaching strategy in order to generate valid advice on how the teaching strategy of tomorrow should be structured in order to cope with the challenges. In order to obtain knowledge of the implied competencies, the teaching environment for the designers of these systems is thought to be a valuable source for predicting design strategies for future systems. For marine systems, one of the world's top most leading universities within system interrelations and system governance is the Norwegian University of Science and Technology (NTNU), where this area of research has been given the overall framework of cybernetics. This paper presents an analysis of the teaching environment in marine cybernetics at NTNU and performs a comparative analysis of the perceived teaching competencies in relation to the Svendborg International Maritime Academy, (SIMAC). SIMAC educates marine engineers and master mariners according to the STCW convention and Danish legislation. Based on that analysis of differences, valid advice is generated for future a teaching strategy in system interrelations and system governance for the different studies at SIMAC. The methodology involves observations of lectures and group work, interviews with identified key persons, interaction with the study environment and meta-cognitive analysis of course evaluations.

2 GENERAL DIFFERENCES BETWEEN UNIVERSITIES AND MARITIME ACADEMIES

The general differences between university education and STCW training at maritime academies can be summed up as consisting of the different emphases laid down on mastering general competencies within mathematics, physics and chemistry. Where the universities put much effort into raising the students' general competencies to a very high level before venturing into more specialised knowledge areas, the general approach in STCW training and the overall approach at SIMAC is to teach general competencies alongside specialised knowledge. Many pros and cons can be raised for both approaches. One of the main advantages of the university approach is the students' ability to use linear algebra and especially the matrix calculus. This gives the university students' an ability to generate highly reliable lumped sum mathematical models within a wide variety of scientific fields, including the technical areas covered by the STCW training. Within STCW training, the student is also educated to use mathematics in modelling physical systems but seldom in the framework of matrix calculus. University education within the field of engineering is mainly focused on the design aspects of systems and structures, whereas STCW education is mainly focused on operation and maintenance. This difference in focus calls for some differences in teaching approaches and also for differences in study programs: a university education in engineering leads to a highly specialised focus area within just one of the many fields of expertise that a master mariner and a marine engineer has to cope with in every day operations on board a ship. Presently, this leads to a structure in STCW education in which master mariners and marine engineers are taught subjects equivalent to fields of engineering in ships design, mechanical structures, production engineering, energy systems, environmental systems, electrical designs, electronics, computer science and earth science. Obviously, a master mariner or marine engineer cannot reach the same level of expertise in each of these areas as a university educated engineer, simply due to time constraints on the length of education. A university education to master's level takes, in general, 5 years. That is equivalent to the length of the study programs in Denmark for master mariners and marine engineers. To sum up: the SCTW education should lead to generalist competencies in ship engineering with a focus on operation and maintenance of all structures and shipboard systems.

2.1 Structure in education at NTNU

At NTNU the first 3 years of study revolves around general subjects within physics, chemistry, mathematics and engineering. Some introduction is also given to more specific fields of application. For a student of maritime engineering this includes courses in hydrodynamics and ship technology. One of the study lines is specialized in Marine Cybernetics. For these students there is also a mandatory course on linear control theory included in the first 3 years. After the first 3 years, the students transfer into specialized courses. There are a number of courses in Marine Cybernetics in the last 2 years of study. First an introduction course on marine control systems dealing with linear control theory in marine applications, a course on control and architecture of electrical power plants, a course in non-linear control theory and marine applications, a course on guidance, navigation and control, an "Expert in Teams" course, where teams are formed across study lines to elaborate and design ideas, a 15 ECTS specialization project, where the student gets the chance to deep-dive into a field of interest and finally a 30 ECTS master project, where the student can expand the knowledge and field of interest. Throughout the study program, the students collaborate across fields of specializations and on several occasions, there are organized competitions between cross-disciplinary teams, which is perceived among the students to be highly motivating.

2.2 Structure in education at SIMAC

At SIMAC the first 3 semesters are used for gaining vocational training and practices within the fields of mechanics, electrics and seamanship. The actual contents and length of the training and practice varies for the three study lines taught at SIMAC. Common for all of the study lines is, that it is vocational training and very little use of mathematical, physical and chemistry theory is included in the education at this point. After the first three semesters, the students have introductory courses on applied science within their study lines. These courses use mathematics, physics and chemistry on a varying level of difficulty, ranging from expert level to introductory level. Common in the approach and setting of teaching level is the requirement for operation and maintenance of the available systems on board ships. For control systems, the teaching is diversified and a common level is not reached among the study lines. For the marine engineers a rather deep level is reached within control systems architecture, control strategies and linear single-input-single-output (SISO) control theory, but they have no teaching of multi-input-multi-output (MIMO) systems, non-linear control theory or even the systems architecture around modern navigational systems. For the master mariner a rather deep level is reached within control theory directly related to the control of the ships path, but only a superficial introduction is given to systems architecture and control theory in general. They are to a large extend educated to be the system governor of the ship control systems. In automated ship control systems, the system governor is automatic.

2.3 Gap Analysis between NTNU and SIMAC

The most predominant gap between the education for design at NTNU and the education for operation and maintenance at SIMAC is the difference in mathematical levels. Looking deeper into this difference and the perceived need for operation and maintenance of marine control systems shows the gap to consist of the different levels in the understanding of matrix calculus. The only other significant gap identified is the teaching of systems architecture of navigational systems, but this teaching does not need to make use of extensive mathematical formulations.

3 HOW TO STRUCTURE EDUCATION IN MARINE CONTROL SYSTEMS FOR STCW PURPOSE

It was found through the comparative gap analysis in section 2, that matrix calculus yields an important fundamental knowledge level for the understanding and design of control systems. The application of mathematical modelling and simulation software expands these competencies further and access to physical systems for experiments and analysis makes it possible to reach a specialist level for systems design. Taking this level for the designers of autonomous and automated systems and transferring it to STCW education is not straightforward though. The students will for the most part lack the needed mathematical skills, but that can be coped with to a certain degree by increasing the emphasis laid down on mastering matrix calculus in the teaching.

3.1 Matrix Calculus versus other approaches in multivariate calculus

In the real world, physical properties very seldom depend on only one variable. As a seafarer, one has very often to consider a variety of variables that all influence the system under consideration, whether it is the operation of the main engine, the travelling path of the vessel or the loading condition of the hull. All of these areas are increasingly modelled and supervised by autonomous systems [1], which, in their essence, are designed with the use of multivariate calculus. In general, multivariate calculus can be thought of as a system of interrelated variables for which, equations can be formulated. Solving these equations simultaneously yields the state of the system. One way of writing this is given in equation 1 for three independent variables, {x, y, z}, where {a, b, c, d} represent arbitrary known constants.

$$ax = b\ ;\ y = cx;\ z = dx \tag{1}$$

Solving this equation in a recursive manner for each variable is a straightforward task, which should be manageable by any high school graduate and quite similar to the way STCW training handles mathematical descriptions of physical systems. Writing the same equation in a matrix calculus format as given in equation 2 may seem at first glance to be making the problem more cumbersome.

$$[x,y,z]^T = [b/a,0,0;0,cb/a,0;0,0,db/a]\,[1,1,1]^T \tag{2}$$

However, this framework of writing the mathematical formulation of the physical system yields a tremendous simplification of systems with multiple variables and complex dependencies, which can be solved by using mathematical software. Even more importantly, the majority of all discrete control systems in the marine environment are written by use of matrix calculus.

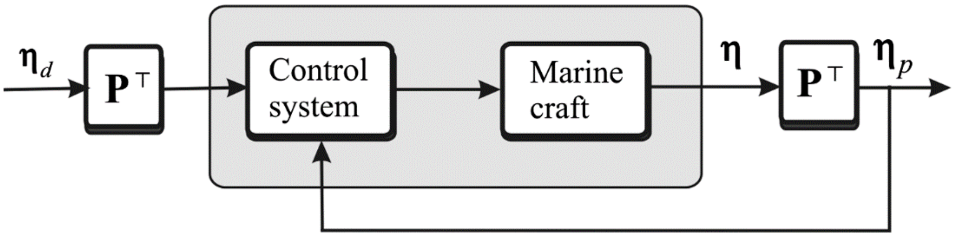

Figure 1: Transformation of desired position and measured position in a feedback control system using vessel parallel coordinates, [3].

An example of a modelled control system for a ship in transit between two desired positions is shown in figure 1, [3]. The desired position matrix, $\boldsymbol{\eta}_d$ is given as input to a transformation matrix **P,** changing the coordinate system of reference before being used in the control system. The measured position matrix, $\boldsymbol{\eta}$ is also transformed by the transformation matrix, **P**, to the feedback signal, $\boldsymbol{\eta}_p$, before being fed to the control system. The control system calculates the needed corrections based on the comparison of the transposed $\boldsymbol{\eta}_d$ and $\boldsymbol{\eta}_p$ and send these corrections to the actuators of the ship. The actuators can be rudders, propellers, thrusters, stabilizing fins, ballast systems etc. basically anything that can control the ships position and motion in the 6 degrees of freedom as visualized by figure 2, [3].

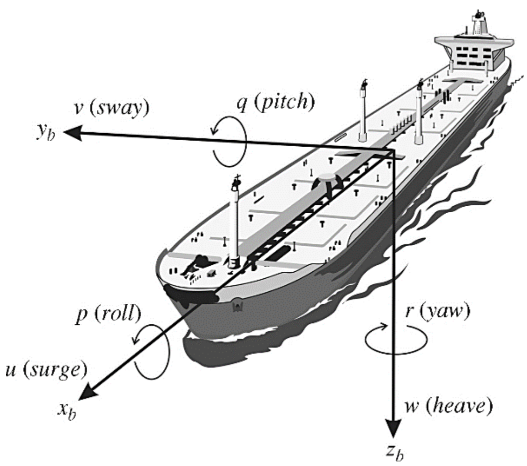

Figure 2: Definitions of the 6 degrees of freedom of movement on a marine vessel, [3].

For non-autonomous systems, the actuators are split into separated control systems and the physical interaction between them has to be understood by the operator and maintenance engineer, who makes changes into the systems. In autonomous systems and semi-autonomous systems like dynamical positioning systems, the actuators are coupled together in one control system, which makes the demand for understanding the physical properties and underlying systems architecture of the control system even more important for the operators and maintenance engineers.

An important feature of multivariate calculus is the stability in the system of equations and thereby the stability in the physical system that the system of equations models. Often in control systems, this stability is ensured by choice of suitable constants for the equations [2]. Often these constants are laid out for the operator to adjust during operation, similar to the settings in the autopilot. Very often the systems is designed in a way, where choices can be made of variables that makes the system unstable, which ultimately can result in total failure of the system. Thus, in order to activate the understanding and competent interaction with control systems a good command is needed of matrix calculus and a general understanding of the design structure of control systems for all operators and especially for maintenance engineers.

4 DISCUSSION

Taking the command of matrix calculus as a prerequisite for teaching in control systems enables a number of interactive ways for structuring the learning process. It makes it possible for the students to build their own control systems, operate ready-built models and gain valuable insights in the design structure of control systems by a comprehensive and meta-cognitive learning process, where the individual student gains the competence to analyze any system based on its appearance and responses to interaction. In STCW education this is not an option due to time constraints and the limited number of subjects that can benefit from the use of matrix calculus. It is however needed in order to understand the systems architecture of discrete control systems, so there should be some form of inclusion of matrix calculus. As for physical systems interaction, it is not so important exactly how the physical system is structured as long as it gives a reliable representation for the subject matter, e.g. a small ship model can easily give the sufficient learning of the physical system interaction in order to design, operate and analyze ship motion control. At NTNU the majority of learning is accomplished using simulators and only a very limited use of model-scale ships is utilized. In STCW education a lot of practice is included on full-scale operating ships, which could include more learning objectives of control systems in order to reach the needed level of expertise.

The STCW education of today, as it is structured at SIMAC, is in many ways teaching the students to operate in teams, but only rarely in cross-disciplinary teams, which could be a huge beneficial learning method.

5 CONCLUSION

Based on the study it can be concluded that, in order to cope with increased autonomy and autonomous shipping, the teaching of matrix calculus should be included in STCW education at introduction level for both master mariners and marine engineers. It was also found that utilizing cross-disciplinary teams can lead to a huge beneficial learning environment, especially when combined with competitions.

6 RECOMMENDATIONS

Based on these conclusions, it is recommended that the teaching of matrix calculus be included in the master mariner and marine engineer study program. It is recommended that this teaching subject is taught together with an introduction to ship control systems architecture and the control theory related to navigation and ship guidance. It is highly recommended that this teaching should be undertaken with a structure that allows the interaction of master mariners and marine engineers. It is recommended that this is a one-semester course situated towards the end of the study programs for master mariners and marine engineers and with an approximate size of 5 ECTS points. Within the course work, there should be included hands-on work by the students on navigational and control systems, in either hardware or a simulated environment. To increase motivation and strengthen the cross-disciplinary teamwork, the course could beneficially include a competition among the teams and perhaps against other STCW institutions.

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