From lenses and mirrors to advanced cameras and image processing, the new optronic system for the Royal Swedish submarines

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Abstract: The classic picture of a submariner at the periscope is not valid anymore! In the future, the commanding officer or the officer of the watch will be looking on a large screen display and give orders to a specialist that operates the optronic sensor and also performance the post processing after a Quick Lock Around is accomplished. In this paper the road from the decision to replace the periscope with an optronic sensor to the first tests on board the first Swedish submarine is described. The different steps and phases are evaluated and discussed; the concept phases, the procurement and evaluation phase, the integration phase and the test and evaluation phases. The focus will be from an end-user perspective and with the objective to implement a new system, which will affect both the tactics and also how to operate the submarine, with manageable risks. Therefore, it is of outmost importance that the crew is comfortable with the new systems as early as possible, preferably before the first sea trail starts. Therefore, an optronic sensor are procured and installed on the Submarine Land Based Training Site in Karlskrona, where the submarine crews have conducted extensively education and training. Also, the way ahead for the A26 submarine will be described and discussed in the paper.

1 Objectives

The objective of this paper is to describe the transaction from traditional periscope to optronics. This transaction not only includes technical challenges but, to a great extent, the user perspective on how to best utilize this new technology to optimize the acquisition of visual information. This includes safety as well as tactical accessibility. This paper describes underlying decisions, challenges with new technology and factors that have played a major role in the process from requirements to verification and validation.

2 Introduction

Sweden shall have four operational submarines, all of them equipped with an optronic system instead of a traditional, hull penetrating periscope. Project A26 decided this many years ago and after an analysis looking at pros and cons from a user and a cost perspective, Gotland Midlife Upgrade (MLU GTD) program made the same decision. The first optronic System (OMS) is now installed and conducting its verification and validation period at sea. A complete system, including a POD installed on the roof and with minor adaptions for land installation, has already been delivered to the Navy, enabling the submarine crew to get the training required before starting sea trials.

3 The Challenge

To introduce an optronic system on submarines is nothing new, it has been done by several countries in the past. There are also combinations of analog (periscope) and digital (optronic system) technology implemented on submarines. What makes the A26 and MLU GTD unique is the design with only one optical mast.

Historically Swedish submarines have been equipped with only one periscope and no demands for change have been made by the end user. However, there are great challenges in fulfilling the performance of the periscope regarding safety and as a tactical sensor due to the fact that the eye is such a unique and fantastic sensor. A lot of work have therefore been done regarding safe functionality and accessibility in order to achieve a better combined functionality for visual gathering information then a periscope.

During the work, the aim has been to manage the optronics as a new system and not as a periscope, although the periscope's functions within the CS must be fulfilled. The periscope's advantages, such as the eye's dynamics and spatial perception, has to be handled within the system solution using multiple sensors, enhanced image processing and an optimized HMI. To achieve this, the work was conducted in close collaboration between all involved parties. The system had to fulfil requirements regarding submarine safety at Periscope Depth (PD) and be one of the main sensors within the submarines Combat

System (CS) enabling the submarine to accomplish its assigned task without endangering the safety for the submarine and its crew.

4 Coordinated acquisition

In order to illustrate the advantages and disadvantages of a common system for both submarine projects, an analysis was conducted looking at it from two different angles; a user perspective and a cost perspective. Section 4.1 and 4.2 illustrates a summary of the report that served as an input in the decision to choose optronics not only for A26, but also for MLU GTD. Because the main focus of this paper is on the user perspective, the summary of the cost perspective will be short.

4.1 User perspective

Today the submarine flotilla doesn´t have a dedicated crew for each submarine. Instead a crew is named with a number (Crew nbr X – CO XX) and it´s CO. This means that a crew today rotates more frequently between the submarines then in the past.

Although the systems on-board are quite similar, there are differences that needs to be considered. From a user perspective there are a number of areas that needs to be considered such as equivalent HMI (same basic structure), utilization of experiences, test and evaluation, common databases, sensor and sensor performance, training and education, maintenance and system integration.

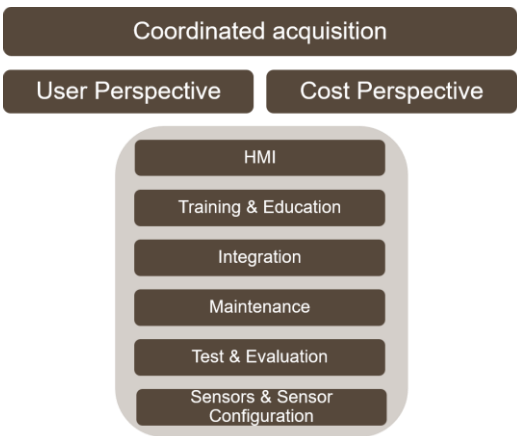

Figure 1: Coordinated Acquisition Evaluation

HMI: A joint procurement guarantees great similarities for the HMI. Lessons Learned from MLU GTD can be utilized. Similarities between the submarines primarily guarantees safety when depositing or changing personnel between the different submarine classes by lowering the risk of errors and will optimize the utilization of the system.

Training & Education: Training and education can be divided in training and education itself and its facilities. Coordinated training will probably lead to a decision that operators who were initially trained on the first system for MLU GTD will be used when delivery of the A26 approaches. This will provide the A26 project with a good start and knowledge based on both theoretical training and practical handling becomes reality. Personnel from all submarines can, with a common training, be used on all submarines when it comes to how to operate, maintain and e.g. troubleshoot the optronic system.

HMI in the training facility will be unified as well as documentation and training materials used for education irrespective of which submarine the operator is assigned on.

Integration: From an integration perspective, implementation will differ regardless of which way you choose to go. However, the principle and similarity will be greater with joint procurement to reduce the risks at infological and mechanical integration.

Maintenance: Obtaining the same spare parts will be easier for the user to administrate. You will avoid duplicated sets stored and separated in the maintenance system. Swedish Submarines can also utilize each other´s spare parts if needed during exercises far away from home base where difficulties in delivering spare parts in time can delay detachment and valuable time in the area of operation might be affected.

Another advantage of joint procurement is the user knowledge. Failures will occur and the same failures might turn up again. Lessons Learned (LL) will shorten the time from detection to managing and solve the problem. All parts of the system will be well known, maintenance cycles will be similar and the maintenance can be optimized.

Test & Evaluation: Knowledge of STW, HAT and SAT procedures are of great importance for achieving the desired end result. You will be able to update and change verification procedures from one system to the next based on gained knowledge. Personnel conducting the verification will be familiar with the system pros and cons, failures occurred from the different verification stages that might need to be tested at an earlier stage and procedures that might need less attention will make it possible to gain time for other, more important tests. All in all it's a major risk mitigation factor.

Sensors & Sensor Configuration: In general, similarities between the submarine systems benefits submarine safety, especially since the crews today change between submarines more frequently.

Increased unified tactical and practical experiences (LL) will enhance further development for the system. All personnel can fully take part and use new ideas and together they can deal with discussions with the supplier and sub suppliers (new cameras, occurred problems, integration solutions etc.). This way, modifications can, through joint procurement, be utilized and beneficial for both projects.

However, the greatest operational/user advantage is that it will be possible to change sensor head between the submarines and the submarine classes. Also, by using commonality it is possible to have different configurations optimized for different assignments and we will achieve higher flexibility.

4.2 Cost perspective

From a cost perspective, acquiring multiple systems is always preferable when looking at cost per system. Development and evolution costs, Non-recurring cost, maintenance and education can be allocated for more systems, which will result in a lower cost per system.

There might be difficulties in how to design the contract when procuring 2+2 systems for two different submarine classes and having a fifth system as an option for the LBTS, but the advantage by having all systems in one contract will probably override the disadvantages.

As a conclusion the main advantages in a coordinated acquisition are:

- Risk reduction
    - Operational Risk (system handling)
    - Technical Risk (System knowledge)
    - Test& Verification (Process knowledge)
- Lower cost per system
- Knowledge (Lessons Learned)
- Flexibility (Change POD)

The main drawback that was found was the fact that implementing an optronic system on MLU GTD will require more redesign work of the existing submarine. It will also be very difficult to change back to a periscope if the system does not work as required.

5 The Phases

As in all system procurements, a number of phases were carried out. During the procurement and evaluation phase FMV and SAAB Kockums worked in close cooperation, even though SAAB Kockums is main supplier, and responsibly for all sub-system procurements. This enabled the possibility to utilize the common knowledge within both organizations. This close cooperation continued all the way to delivery of the first system and is still ongoing since delivery of the last system for the A26 is a few years ahead of us.

5.1 Procurement and evaluation phase

Four suppliers replied on the RFQ and after the first evaluation they were reduced to three. After visiting all three remaining suppliers, looking at their system on sight, discussing the presented concept regarding key requirements, safety, HMI, integration and how to adapt their system to our needs, the three suppliers were reduced to two. The last step to decide on a final supplier, was a real challenge and one must bear in mind that the evolution of camera technology and image processing is fast and new solutions and possibilities were presented often during this phase.

Cost and technology were discussed side by side and the two remaining suppliers made a lot of efforts on how to meet our challenging requirements within an acceptable cost frame. No questions were left unanswered and all tests were conducted very thoroughly.

5.1.1 Shortwave-Infrared (SWIR) or Lowlight Level TV (LLLTV)

Live camera tests were mainly done to evaluate the performance of the new SWIR-camera and if this was a better option than an existing LLLTV-sensor.

As for the cost of the different cameras, there were no major difference. One supplier recommended SWIR, without excluding LLLTV as an alternative. SWIR tests were conducted from a boat on a lake during night, dusk and dawn. FMV paid attention to the fact that we only have one mast for visual information and that the entire visual spectra most be covered and that the time frame for discovering targets is limited. Safety when going to PD (Periscope Depth) in bad weather conditions was mentioned as a key factor. It is very important, regardless weather conditions, for the safety of the submarine to be able to discover a very weak light having the sensor just above the surface.

Figure 2: SWIR Live Camera Test

One disadvantage of the SWIR camera was the time to adjust the camera to get a good picture. We were also not entirely convinced on its ability to look through haze and fog, which was one of the main arguments for the SWIR sensor. However, this was in 2012 and the development of the SWIR sensor has probably improved a lot since then, just like the rest of visual sensors have. Concerning LLLTV, the user is used to the sensor and it is good for detecting lights, no matter how weak it is and by that increase the safety of the submarine at PD. A disadvantage for the LLLTV is that the rotation speed must be slow for this sensor in order for the sensor to work well.

However, the choice between SWIR and LLLTV was not a decisive factor for the final choice of supplier. In this case we went for proven technology, but SWIR is probably the future if you have to choose between those two sensors, the question is how far into the future? Having two optronics mast will provide you with the option of both SWIR and LLLTV, but in this case, we did not have that option.

5.1.1 HDTV and IR Live Camera Tests

The other main object was to evaluate the performance of the HDTV-camera during primarily dusk and dawn. IR and HDTV tests were conducted at several occasions, always close to the coast line, and in high intensive traffic areas and with several maritime objects to observe.

A Lux meter was used making it possible to analyse and compare recordings from different occasions. Due to sensor evolution, the suppliers often presented and tested new cameras during this period. During the tests it was obvious the e.g. sensor sensitivity in darkness increased a lot between each occasion and that the choice of camera for final delivery had to be made at a later stage in the design process regardless choice of sub supplier.

All in all, after several tests at sea, by the sea and in house aiming to find the best system for Sweden’s unique design using only one mast for visual information, the French supplier Safran were selected as preferred supplier by SAAB Kockums. In the end it was the best system covering operations day and night, dusk and dawn, including a customized HMI and managed integration in new state of the art Combat System.

5.2 Design phase

In the contract with the sub supplier it was decided that the selection of HDTV-camera should be done as late as possible without delaying the production. In this case that was at CDR. This was due to the rapid camera technology development.

5.1.1 HDTV Camera selection

Before the CDR, a live Camera test was performed outside Le Havre, providing good opportunities to detect ships, buoys and the coastline. Three different cameras were mounted on a stand and aligned in the same direction and they all had the same field of view size.

- Baseline 1; Nbr 1
- Baseline 2 Nbr 3
- Baseline 3 Nbr 2. (selected)

Figure 3: HDTV Live Camera Test

During daylight we started with studying colours and dynamics in the picture in general. Previous recordings done earlier during the day with sunlight and reflections from the sun in the water were presented. It was stated that the newer cameras had better picture dynamic regarding sun reflections in the water.

Values given below are not exact values but gives an indication on how the different cameras perform in different light conditions.

- At 80 lux, No1 began to indicate noise in the picture.
- At 60 lux Fix Pattern Noise were found.
- At 40 lux the picture showed strong noise and FPN. However, the camera still presented good colours in the picture when there was enough light.
- At 5 lux No3 indicates noticeable problem with noise.
- At around 1-2 lux noise in camera No2 appeared and at 0.8 lux the camera still had a usable picture.

Lights in different colours e.g. green and red navigation lights, both at sea an ashore, were studied in different light conditions, especially when it was dark enough only to see the bright spot. Green navigation lights generally looked good in all cameras. The cameras had some problems with the red light which appeared as a white light in the centre surrounded by a red ring.

The conclusion after the tests was that the progress of the technology is at our favour and camera No2 (Sony IMX 174) will be accepted as baseline for the project.

Since the system also includes LLLTV and IR-sensors, this HDTV will make the system “complete” and cover all foreseeable light conditions. The function for merging (fusion) the HDTV picture with IR or LLLTV will, with this new camera, provide improved functionality for detecting navigation light when the red and green light will be seen in the IR or LLLTV picture.

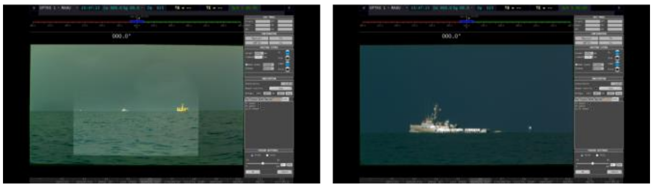

Figure 4: Image Fusion WFOV & NFOV TV/IR (50%)

5.1.2 Consoles

To get the basics correct for the different consoles that had to be constructed for the two projects, several work shops were conducted with SAAB Kockums, Safran, the end user and FMV. There were several subjects that had to be determined such as the angle of the screens, placement of joy sticks, the TID, and the keyboard. A console with movable parts were constructed to help out in the decision making. An expert in ergonomics were also consulted. Four different consoles shall in the end be developed:

- Modified Multi-Function Console (MFC) No2 MLU GTD
- New MFC No6 MLU GTD
- MFC A26
- Officer of the Watch (OOW) MFC A26

During the workshops it was found that there was a request from the end user making it possible to stand up and operate the system. The solution was a sliding system making it possible to slide the chair under the table. This has now been tested at sea and works really well. If it turns out, after a while, that the sliding solution is not needed, it is very easy to remove and use a fixed chair instead.

Figure 5: MLU GTD Modified and new Optronic Console

Another question was if the joystick for operating the sensor head should be on the left or the right hand side. To find out if there were any differences, we used a flight simulator. The result was recorded when using both left and right hand in manoeuvring the simulated aircraft. This made it possible to validate if there were any differences between the two options. The result showed that the difference between using left and right hand was negligible and that made the design of the console a little bit easier due to the fact that we could place the joysticks without considering what side it shall be.

5.1.2HMI

During the design phase several workshops were conducted. Major topics discussed were:

- HMI-layout in general making it user friendly
- Implementation of new functions
- Optimize and align the HMI with other Combat Systems

A reference group from 1.sub.flottila participated together with former Submarine CO´s now working at FMV and SK. Together with engineers from FMV, SK and Safran, a solution finally could be accomplished.

Four Operational Scenarios were used during the workshops; Surface Situational Awareness, Torpedo Guidance, Target Observation and Quick Look Direction (QLD). During the scenarios we discussed tools available supporting the operator, quick settings and shortcuts, how to optimize preparations and minor things such as colours and symbols.

Within the contract there were new features such as automatic tracking, automatic surveillance and alerts, track interval management and image fusion that was not finally developed and implemented in the system. That provided us with the opportunity to use the WS and the end-user reference group for inputs to the final development of these features.

Safety critical issues were discussed to ensure e.g. that the operator can distinguish between live and recorded images and videos and that the presented information doesn't misguide the user.

Basically we started from a well-designed HMI and no major changes were implemented. Some adaptions have been made based on WS discussions. Another outcome from the WS that was useful were inputs on how to implement the user interface/HMI for the newly developed functions.

5.1.3Redundancy

Having only one mast for optronics requires a high level of redundancy. During the design phase a Back Up Tool (BUT) was developed from the requirement that it shall be possible to use the optronic system even when the boat is ”black” i.e. powerless. The development of the BUT complemented the existing back-up making the back-up complete at all levels.

- Normal: Several modes and sensors
- Reserve: Laptop
- Emergency: BUT

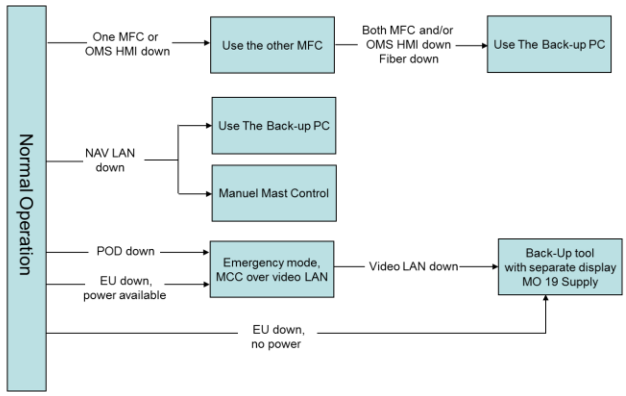

Figure 6; Overview OMS Redundancy

6 Land Based Training Site (LBTS)

Discussions regarding acquisition of a fifth system for training and education purposes started late in the acquisition process and was added as an option in the final contract. In the end it was decided from the Navy that a new Land Base Training Site based on MLU GTD configuration should be built. As far as possible, real systems should be used and they should, if possible, be bought as spare parts. This way we were able to lower the cost for spare parts since we had a whole system up and running at LBTS. Systems included in LBTS are Optronic (Live and simulated), Passive Sonar System, WECDIS, CMS/CSIS and Weapon Launch Control System (WLCS). It is all controlled and run by simulators (Naval SE simulator and Sonar Environment simulator)

The main purpose of LBTS MLU GTD is training and education for operators and, because it is mainly real systems, technicians. It is also used as a reference system, tests and verification & validation of new software.

For MLU GTD and the fact that the optronic system is a completely new system for the submarines, risk reduction was probably the main key factor for getting this project improved.

Figure 7: Mounting the OMS POD on LBTS

The ability for the user to try out different settings and functions using a real system looking out over the sea is very important. Doing this reduces the risk of fault handling and will increase the level of skills for the operator before facing new weather conditions and critical situations at sea.

7 Conclusions

Introducing a new system for visual intelligence instead of the well-known periscope requires close cooperation between several parties, elaborated requirements and several tests in different conditions. Due to the coordinated acquisition both project could benefit from several outcomes such as commonality in infrastructure, risk reduction, flexibility and training facilities.

The periscope's advantages, such as the eye's dynamics and spatial perception, have been handled with more sensors, image processing, new functionality and an optimized HMI. This has been achieved by close collaboration between FMV, end-user, main supplier and subcontractor, which resulted in a final system that responds well to set requirements and into the future.

Although the periscope and its sensor, the eye, is fantastic, there are several design features and functions implemented in the Optronic System that makes the system just as good and in some cases even better than a periscope.

In the end, the submariner shall be able to conduct all required missions in a safe and successful way. Failure is not an option.

Author/Speaker Biographies

Mr Anders Folbert has more than 20 years of submarine experience in the Swedish Navy including service on seven submarines of four different classes. Anders joined ASC and Deep Blue Tech (DBT), Australia, in 2008 as Submarine Specialist. In DBT he was lead in several different projects. Anders has since 2011 worked at FMV as Submarine Specialist & Operational Advisor Project A26 and MLU GTD. As System Manager Optronic Systems he has been involved in all phases from procurement to verification and installation of the system. 2015 he was assigned as Project Manager new Submarine Land Based Training Site.

Dr Fredrik Hellstrom is the Project Manager for Project A26/Next generation submarine at FMV. Dr Hellstrom has a background from the Royal Swedish Navy, where he served as an engineer, obtained a degree of M Sc in Naval Architecture at KTH and other different military educations. In addition to the educations mentioned, Fredrik has a PhD in fluid dynamics.

Mr Roland Dehlin is the Project Manager for Combat and Weapon Systems within Project A26/Next generation submarine at FMV, SWEDEN (Swedish Defence Materiel Administration). Roland has been working within the A26- project the past 4 years as Combat system manager, Weapon System manager and at this time in the process responsible for arrangements of the forward part of the A26 submarine.
Roland has a background from the Royal Swedish Navy (RSwN), where he served and served on several different submarine classes from early -80ies until beginning of 2002.