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Human factors challenges in unmanned ship operations – insights from other domains

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Abstract

This study presents an overview to human factors challenges that potentially concern future shore control centers for unmanned ships. Although commercial unmanned shipping does not yet exist, it is worth to consider this emerging technology domain. Without the bridge and the systems supporting the crew, the ships could be lighter and carry more cargo – this would increase revenues and fuel efficiency. Literature review of autonomous and remote operation on various fields, these being aviation, forestry, cars, subway systems, space operations, military, and cranes, and making contrast to the nautical context were applied as a method for identifying potential challenges. The most prominent issues to be considered include information overload, boredom, mishaps during changeovers and handoffs, lack of feel of the vessel, constant reorientation to new tasks, delays in control and monitoring, and the need for human understanding in local knowledge and object differentiation (e.g., in differentiating between help-seekers and pirates). Positive aspects, in turn, include lack of seasickness and physical damage to the crew in harsh weather conditions, and the possibility to functional specialization. Potential interaction and representation techniques were considered as well. Overall, our study provides insight for shore control center design. We suggest that the control centers should reflect agile command and control. This implies that the unmanned ships should be attached to global support networks and be able to reproduce information for them; video and sensor data could be transmitted directly. The shore control centers should be capable and willing to proactively communicate with the manned vessels and the authorities.

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1. Introduction

The aim of this study is to present an overview on the human factors challenges that might concern future shore control centers (SCCs) of unmanned ships. Commercial unmanned shipping does not yet exist, it is nevertheless worth to already consider this emerging technology domain. Without the bridge and the systems supporting the crew, such as sewage, electricity and air conditioning, the unmanned ships could be lighter and carry more cargo – this would increase revenues and fuel economy. Projects related to ship autonomy are progressing at least in Finland (AAWA Initiative project) and on the EU-level (MUNIN project). To the best of our knowledge, Japan, UK and Norway have on-going initiatives as well. The U.S. Navy has already developed unmanned solutions for small military boats [1].

According to Sheridan [2], in teleoperation (or remote operation) a machine is operated from a distant location from which there is no direct human sensory contact to the machine. In today's remote operation solutions, the human operator utilizes video camera feeds, sensors, and other technical means to receive information regarding the remotely operated machine and its environment. Remote operation is utilized especially in hazardous and safety-critical environments to improve the human operator's safety and the economic efficiency of the work. Remote operation may enhance the work experience in providing more pleasant and safer work environments in avoiding dirt, tremble, noise, extreme temperatures, radiation, or other issues caused by the machines or their surroundings. Indeed, a plethora of different teleoperation applications have already been developed, ranging from remote mining [3] to space operation systems [4].

In the case of nautical vessels, remote operation might imply different things depending on the vessel type. First, it has been presumed that the vessels could be unmanned and remotely monitored during trans-oceanic phases of the voyages [5]. In this scenario, the remote operator would not directly see the vessels but would monitor the vessels via a satellite connection. The U.S. Navy, in turn, has demonstrated the use of unmanned boats, as operated side-by-side with manned ships [1]. This is to say that the autonomous ships would be controlled from larger ships or ports nearby in order to protect them from the adversaries. In this paper, we will concentrate on the challenges of remote operation of ships voyaging large distances. Therefore, the monitoring would take place predominantly via satellite connections and from SCCs.

The way in which the ships would be operated is an open question. Three categories of control for autonomous ships have been distinguished by Porathe, Prison and Man [5]. First, indirect control, refers to updating the voyage plan during the voyages; this could be necessary, say, due to weather changes. Second, direct control, refers to ordering specific maneuvers, such as, giving way for officials during a rescue operation. Third, situation handling, refers to bypassing the autonomous system, that is, the rudder and thrusters would be controlled directly by a remote operator.

Porathe et al. [5] and Man, Lundh, and Porathe [6] (2014) have pioneered in studying the basic functions and possible problems of the future SCCs for unmanned ships. The method by which they have identified what the SCC should be able accomplish and what could be the possible challenges was by focus group interviews; the interviewees consisted of nautical experts and students. Overall, the found functions can be listed as follows:

1. *Monitoring voyage and updating the ship route*; this includes following the weather situation, nautical traffic and navigational warnings vis á vis ship location. The sailing and voyage of the ships would be monitored via several representations on the information that has been usually presented for the mariners at the manned ships (position, rudder angle, rate of turn, speed, and video feeds on the environments) and the ship route could be modified on the fly, if needed.
2. *Monitoring the ship health and status;* this includes consideration to various technical aspects of the ship condition, including but not limited to engine health and satellite communication signal status.
3. *Communication with other ships*; listening and responding to radio and distress channels would have to be done at the SCC.
4. *Decision making in view of all of the above*; the SCC would have to make various non-self-evident decision in considering issues such as weather, ship condition and maintenance needs, vessel traffic, business aims, and cargo; this can be seen as a challenging optimization task, while incidents and other unexpected situations could

emerge from time to time; one has even considered [7, p. 21] that the unmanned ships should be able to help other ships in accident situations.

The identified challenges, in turn, can be differentiated as follows:

1. *Limited situation awareness due to reduced sense of the ship.* Due to teleoperation there is no bodily feeling of the ship rocking and the look outside, even if communicated via camera feeds, could provide only limited understanding of the conditions [6]. This implies that the ship steering cannot easily be configured to follow the direction of incoming waves, which could be necessary in harsh conditions for safe or at least smoother ride [5].
2. *Information overload due to the plurality of ships and ship sensors.* The SCC workers could be exposed to too much information in a manner such they would no longer have the capability in understanding the situation at the sea. Two reasons for this can be identified. Firstly, the workers could be overwhelmed quite simply because they have to take care of several ships instead of just one; human errors might take place especially when focus is steered from one ship to another [5]. Secondly, since there would be limited "natural" feel of the ship, this information could be replaced with visual representation on the three dimensional orientation of the ship (based on gyroscope-derived data); this, however, could be overwhelming in view of the capabilities of the operators [6]. In other words, replacing the bodily feel of the ship with visual indications could come with the tradeoff of information overload.
3. *Communication challenges due to limited knowledge on the local conditions or language issues.* This could be a problem if the SCC would cover a large geographic area with lots of cultural and linguistic variation [5]. The SCC workers might not understand the local people, their aims, patterns of activity or even their language, which could be problematic in some situations.

Despite these existing studies, controlling and monitoring unmanned ships is a new domain for research. Therefore, it would be beneficial to consider the potential challenges and possibilities comprehensively. Given that teleoperation and remote monitoring have already been implemented in various other fields, a beneficial approach could be to consider the findings and experiences in these other domains.

2. Methods

The method applied in this study was literature review. This was done to identify relevant "human factors challenges and opportunities" in teleoperation and remote monitoring in domains that have more traditionally relied on in situ and direct (i.e., non-mediated) decision making and operation. By "human factors challenges and opportunities" we mean issues that are relevant in view of practicality, situation awareness, usability, user experience, decision making and/or societal implications, that is, technical issues that do not directly influence the preceding factors were not considered (e.g., long-term reliability or comparisons of the most optimal solutions in a technical sense). The relevant domains were first selected intuitively, and they include the following were: aviation, cars, container cranes, forest harvesters, military, space operations, and subway transit.

An internet search was conducted on these domains. The search was non-structured and intuitive, since it was quickly realized that relevant information could arise from various sources. However, scientific sources and Google Scholar were the main source; the domain name with relevant keyword in various combinations (e.g., teleoperation, drones, autonomous, etc.) was entered to search fields. The search included brief and fast look on the relevance of found articles. Then the ones with possible relevance considering unmanned shipping were taken into further consideration.

The domain study was done hand-in-hand with considering potential interaction and representation techniques. Different kinds of monitoring and process control tasks from industry and traffic were considered, along with the interfaces applied to these tasks.

We will next go through the challenges and possibilities for unmanned shipping as identified through considering the studied domains. Finally, we will also shortly discuss interaction and representation techniques in view of SCC operations.

3. Results and discussion

3.1. Aviation

Unmanned aircraft systems (UASs) have been applied for a while already, and studies concerning them seem to have implications for unmanned ships as well. Firstly, some positive aspects could be noted. These include the following:

1. *Lack of motion sickness.* Various aeromedical issues are non-existent in remote operation of aircrafts, including “barotrauma and hypoxia, acceleration, vibration, thermal stress, and those forms of spatial disorientation associated with acceleration” [8, p. 12-13]. Similarly, the problem of seasickness could be non-existent in unmanned waterborne solutions.
2. *Functional specialization.* UASs allow that expertise can be distributed to geographically dispersed specialists. A specialist team could handle uncommon situations while other operators could develop excellent skills in, say, landing of the vessel, i.e., all the expertise needn’t to be confined to the flying vessel [8]. Similar reasoning applies to unmanned ships.

Overall, as there would be no seasickness or the issue of physical damage to the crew when the ship rocks or spins heavily, unmanned ships could be less sensitive to harsh weather conditions, and additional safety could be achieved by functionally specialized teams or individual operators. However, some of the problems with UASs could apply also to unmanned ship operations. These include:

1. *Boredom.* In a study, 92% of UAS operators have reported “moderate” to “total” boredom [9].
2. *Mishaps during changeovers and handoffs.* Several mishaps with UASs have occurred during changeovers or handoffs, these having been the direct or indirect cause of the incidents [10].
3. *Lack of feel of the vehicle.* In UAS operations, the operators lack the proprioceptive cues to feel the shifts in altitude and changes in engine vibration, indication variation in speeds or engine troubles [11]. Similarly, Porathe et al. [5] have noted the lack of “ship sense” in unmanned ship operations, that is, lack bodily understanding of the ship orientation vis á vis wave and wind conditions.

“Tacit knowledge” of the feel of the ship could thus be transferred to the shore control center, this including information on engine noise and feel of the influence of weather conditions on the way in which the ship maneuvers; this might tackle the problem of boredom in addition to the problem of lack of feel of the ship, since combining the varied sources of information intelligibly might entail an element of meaningful challenge.

3.2. Cars

As a result of the increase of in-car computing systems, the nature of the driving task in cars is changing. Computers are increasingly taking care of driving-related tasks with systems such as adaptive cruise control, lane keeping, and collision avoidance. Ultimately, this type of development leads to a situation where the driver will be gradually relieved from the manual task of driving; supervision of the automation would remain as driver’s task [12]. However, the introduction of autonomous cars includes several human factors challenges as well:

1. *Behavioral adaptation.* In car driving behavioral adaption means that the drivers who often use intelligent systems have lower perceived risk and lower workload than infrequent users of the system [13]. In the nautical context, somewhat similarly, the behavioral adaptation phenomenon might imply dangerously low safety margins as the remote operators are not themselves in any physical danger. For example, if the pathways of two ships cross close to one other, the operators might rely on the system to plot the unmanned ship’s route with margins, which are technically correct (in view of sensor data), but in practice are risky.

2. *Skill degradation.* With reliance in automation and in lack of manual driving activity, skill degradation can occur [13]. The phenomenon applies to the nautical context as well. In case the automation and teleoperation fails, there would have to be a specialist team, with capability to the conventional seafaring.
3. *Need for profound local knowledge.* Related to the rally car domain, and to the remote monitoring, Wahlström et al. [14] have studied rally control centers. One of their findings was that experts with local knowledge help significantly in sending help to the correct place in the rally track; the specialists on the local areas could imaginatively figure out how the ambulances could reach correct locations, without the need to end the race. The implication of this for the SCCs is that it should have profound local knowledge in the form of seasoned experts.

3.3. Container cranes

An increasing number of container terminals are taking autonomous and remote operation systems of container handling equipment into use. More specifically, remote container crane operation has been assumed to allow increased productivity and sustainability benefits [15]. A safer work environment and better physical ergonomics can be provided with remote operation solutions. However, the challenges in this environment include:

1. *Constant reorientation to new tasks.* The remote container operators have continuously to reorient themselves to the demands of new tasks at small intervals (such as lifting a new container from trucks' chassis every 30 seconds), whereas in conventional operation the task durations were much longer [16]. Similarly, in conventional maritime operations, the main tasks, such as, docking and voyaging, last relatively long and usually take place one at a time. At SCC, when monitoring various ships, the flow of different tasks could be overwhelming.
2. *Deteriorated sense of spatial dimensions in video feed-based control.* The video image applied for remote container crane operations does not allow stereo vision (i.e., it is implemented with conventional camera technology), which was found problematic, since evaluation of distances in this environment is crucial [16]. This issue should be taken into consideration also in SCC design.

3.4. Forestry

In the future, forestry vehicles could be monitored and controlled remotely by an operator with a supervisory role. An autonomous vehicle in forest environment should entail an obstacle avoidance and route planning system that is able to detect the size of and range to all obstacles, steer around (or between) them, and then continue on the correct path again. However, in thick forest conditions some obstacles, such as bushes or small stones, should not be avoided, but simply driven over; this is much harder for the automation [17]. Similarly, the *need for comprehensive object evaluation* can be a major challenge for unmanned ships. Some objects, such as swimmers, small manned boats, or wildlife, should be avoided, while others, such as logs of wood, could be ignored. The ice condition could be difficult to assess for the computer; the SCC should evaluate whether, say, ice breaker help would be needed.

3.5. Military

Military activity entails the combination of activity in various domains, such as aviation and sea-faring. However, there are certain specific features in military operations, with potential implications also to commercial unmanned shipping.

Firstly, an issue to be learned from the military sector could be *agile command and control*, which, among other things, refers to responsiveness, flexibility, creativity, and adaptation in order to meet the needs of task. In line with this, NATO has applied the Effects Based Approach to Operations (EBAO). This includes planning actions based on the operation needs, rather than short-term military imperatives; this implies that tasks can be carried out by different actors, such as military, diplomatic, or NGO representatives, at several levels [18]. Similarly, the unmanned ships and SCCs could take part of a larger network of actors at the sea and elsewhere: the video feeds and other data sensors could be flexibly used to help the authorities during emergencies. The SCC should be flexibly attached to the operations of other maritime actors for helping them and exchanging information. There are, however, problematic aspects in remotely operated warfare, with implications to unmanned ship operations.

1. *Differentiation between adversaries and the others.* There has been discussion around the controversial claim that teleoperated military operations would produce proportionally more civilian casualties than conventional warfare [19]. Similarly, the unmanned ships should differentiate between, say, help-seekers and pirates – this would be a task for the SCC and issue to be considered in SCC design.
2. *Inhumanness.* Related to the previous argument, ethical concerns have been associated with unmanned military operations [19]. It might similarly be problematic if the unmanned ships would lack empathy and sensitivity towards their surroundings. Ships are expected to participate in rescue operations and be communicative.

3.6. Space operations

Areas beyond the atmosphere of Earth are hostile to humans, and therefore it can be beneficial to perform space operations with telerobotics. This can be challenging, since the distances are long and it takes some time for the messaging to travel in light speed. Related to this, Lester and Thronson [20] have discussed the *cognitive horizon* in telerobotics in space operations, that is, the relation between distance and latency in view of practical tasks; giving a task for a robot on the Moon would take 1.3 seconds in minimum, and seeing the robot actualizing the task (i.e., two-way latency), would take at least 2.6 seconds. Calculations of this kind and the concept of cognitive horizon have relevance for SCC operations. Immediate operation of the ships can be challenging if the communication distances are long: though the distances on Earth are less challenging than in space operations, it nevertheless takes time for the signal to travel via satellites. As derived from the Lester and Thronson study, some rules of thumb exist:

- 15,000 km (9,320 mi) distance (roughly the flight distance between, say, Helsinki and Sydney) translates to circa 50ms minimum delay, which borders the limit of delay detection for human a brain.
- 60,000 km (37,282 mi) distance (roughly one and half times the equator of Earth) translates to circa 200ms minimum delay, which is a noticeable delay.

3.7. Subway transit

Currently, there are dozens of metro lines applying unmanned train operation system. As in conventional rapid transit, the traffic situation is monitored by human operators from a stationary control room. Studies exist, which have considered the automated metro systems by exploring the current manned operations. The results with implications to unmanned ship operations are as follows:

1. *Need for human understanding on implicit intentions of others.* Karvonen et al. [21] conducted a study where the current practices of metro train drivers were investigated in order to understand what the automated system might not be able to do. One of the findings was that when the metro train arrives at a station, the driver observes the platform and intuitively notices potential troublemakers. Implication of this for the unmanned ships is that the system should be able to infer the (implicit) intentions of the other vessels; this would be a task for the SCCs.
2. *Need for direct view sharing between actors during emergency situations.* A study has explored metro control center activity during an emergency exercise [22]. The understanding about the situation from the scene of activity was transmitted to the metro control center and from there to the emergency response authorities by verbal accounts. This communication could have been more robust if the emergency response center could have directly seen the visual indications transmitted to the metro control center. Similarly, view sharing between the SCCs and authorities can be imagined; perhaps the emergency response could utilize video feed from the ships.

3.8. Interaction and representation techniques

The suitable techniques for representation and interaction on SCCs could be designed based on the tasks and on usability and user experience goals. Important goals could include *support for awareness*, *efficient communication* *and collaboration* both locally at SCCs and in remote contacts, and *feeling of presence* during remote control. Commonly utilized interaction modalities can support remote operations. *Visual modality* can be considered the fundamental way to provide both symbolic information and onboard camera feed to operators. Warnings and alerts can be presented *aurally* and *speech* is an important communication medium. Ship sense [6] and could be transmitting to remote operators via *haptic feedback*. In the following, we shortly discuss solutions, which could be applicable in the future SCCs. Existing monitoring work solutions provide applicable techniques. These include:

1. *Large shared displays.* Shared screens can help maintain shared awareness in control centers. Map style displays can show geographical information (including vessel locations and planned routes, weather reports, and forecasts). Symbolic and numeric information, such as ship location, heading, and speed, and engine operation parameters could be displayed in a somewhat similar manner as on conventional ship bridges.
2. *Cameras with live video feed.* Direct video feed is the central point in, say, remote operation of unmanned aerial vehicles. Because of the slow pace of the operation, it could be less central but at times useful in ship operations. Delays and in particular limited bandwidth are also issues to be considered.
3. *Forecast and timeline visualizations.* Scheduling and prediction support with, e.g., progress bar -type presentation of the voyage of each vessel, including past, present and planned activities, weather forecasts, and work scheduling solutions, could support overall situation awareness.
4. *Voice loops.* Voice loops are real-time auditory channels connecting physically distributed people; an operator monitors several simultaneously, and they allow to follow relevant communications without disrupting their own activities [23]. Collaboration within the SCC and with remote participants could be supported with voice loops.
5. *Hand-over and shift change support.* Monitoring operations entail critical, long time frame communication, some of it asynchronous. Shift changes form a critical discontinuity point in 24/7 monitoring. Remote operation could be separated into multiple control centers, and there may be handovers of vessels from one center to another. Semi-automatic reports and reminders can help ensure communication.

Given that unmanned shipping is a domain of the future, one may also imagine utilization of techniques that are trending, experimental, or not yet established in monitoring work. The following could be taken into consideration:

1. *Ambient displays.* When the aim is to not communicate detailed information, but to keep people aware of processes they are not focusing on, ambient displays based on audio or lighting could be utilized [24].
2. *Remotely movable cameras.* Ships are large and there are many things to look at, the issues ranging from the view at sea and environment in general to the details of engine, other machinery and cargo. Remotely movable cameras may be the only way to get decent coverage.
3. *Multimodal presentation of information.* Moving operation away from on-board necessarily removes lot of the information available locally. Some of the multimodal information available could be transmitted to SCC. These include sounds, which could be utilized for monitoring of the health of machinery, and haptic [25] (motion-based) presentations of physical movement of the ships.
4. *Flexible physical spaces.* Shared physical spaces could support communication and collaborative problem-solving. Solutions such as dynamic lighting and movable walls and furniture could improve space utilization.
5. *Audio analysis.* Spoken communication between people could be monitored and analyzed by computers for content and/or affect [26] – strong negative emotions in radio chatter, for instance, could be notified to SCC operators. Additionally, transmitted and perhaps enhanced audio from the ships, from the engine rooms in particular, could help the operators to maintain understanding on the ship conditions.

4. Conclusions

We have now reviewed some basic human factors benefits and challenges related to unmanned ship operations; potential monitoring techniques have been noted. All this provides basis for SCC design. For the purpose of brevity, this study paper does not yet report comprehensively our design ideas for addressing the challenges. We are planning to write a longer version of this paper and presentation of the ideas in other means as well.

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