# EEG Application for Human-Centered Experiments in Remote Ship Operations

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*Abstract*— **Electroencephalography (EEG) is an exceptional technique in order to study human behavior via neurocognitive processes. EEG can be utilized in different domains to study the neurocognitive processes behind human-machine interactions. Furthermore, remote ship operations are an innovative approach in the maritime industry to improve the efficiency of operations. However, in the Shore Control Center (SCC), human-machine interactions are challenging and highly important in order to implement successful remote ship operations. In this respect, human operators are key components of the SCCs; performance and efficiency of their interactions directly affect remote monitoring and remote controls. Hence, the present study introduces the EEG EPOC Flex in order to objectively investigate human interactions. The current paper focuses on operator's stress in different levels of workload within the SCC. In effect, EEG will facilitate investigating human factor issues that may affect operators' interactions in the SCC. The result of this study can help SCC designers to design an efficient environment for SCC operators.**

***Keywords-Remote operations; Ship; EEG; Human experiments***

## I. INTRODUCTION

Today, studying the underlying mechanisms of human behavior is the center of interest for many researchers in different fields, especially for automated environments and remote-controlled vessels. Thus, different types of Human Factor Engineering (HFE), Human-Computer Interaction (HCI), and affective engineering experiments have been performed [1], [2]. While the concept of remote-controlled vessels and remote ship operations are in their early stage, study the human interactions will significantly improve the functionality and value of remote ship operations. Although the autonomous vessel might be in the form of an unmanned vessel, human operators still play an important role in the unmanned systems [3] within the SCC. In this respect, operators' stress due to information overload is one of the important identified human factor issues; because one SCC operator has to deal with several vessels at the same time [3], [4]. According to the communication requirements for an unmanned vessel, remote control and remote monitoring are two important control modes within the SCC [5] where humans play a critical role to monitor and control the vessels from distant locations.

The concept of SCC relies on a manned shore-based control center which is responsible for the ship operation. In this scenario, difficult or critical remote ship operations will be conducted by the SCC [5]. However, in order to decrease the workload on the SCC operators, assure the safety, or in the case of the limited or loss of the communication between the vessel and SCC, the vessel must be able to perform the normal operation without human supervision. There are several fails to safe strategies that are programmed and updated by the SCC and the vessel can enter one of the possible strategies when SCC cannot respond [5].

According to the concept of remote ship operation and SCC, the crew will be relocated from on board the vessel to shore-based control centers, and they will perform different tasks based on the organization and control modes of the SCC. This relocation does not mean the elimination of the human factors or solving all human errors; by contrast, more questions regarding human factors and human interactions will be raised, because SCC operators have to take the full control over the vessel at any time [4]. In addition, the SCC operator is defined as an Officer of Watch (OOW), who is responsible for monitoring the vessel at any time and interevent if needed [6]. This is highlighted in the remote monitoring mode of SCC as well [5].

Thus, human operators are key components of the SCC and their performance and efficiency directly affect remote ship operations. This implies that study the human-human and human-machine interactions are highly important in order to implement remote ship operations. In this respect, Electroencephalography (EEG) is a special tool that can be utilized for quantifying human interactions and study the neurocognitive processes underlying human behavior [7]. Although there are various studies that investigate the behavioral interactions in a qualitative manner, using physiological sensors especially EEG leads to quantify human interactions. EEG records brain waves and electrical activities by using electrodes on the scalp. Electrical activities of the brain indicate that how is the communication between different neurons in the brain network through electrical impulses [8].

The current study presents the application of EEG EPOC Flex in order to objectively investigate human factor issues affecting SCC operators. According to [9], there are different types of issues that affect human interactions during the remote ship operations especially within the SCCs. For example, a high level of mental workload and a lack of direct sensory. On the other hand, the main hypothesis of the successful implementation of the Human-Machine Interface (HMI) within the SCC introduces an SCC operator as a person who has to be able to monitor and control up to six vessels at the same time [10]. In this respect, the current paper focuses on using EEG EPOC Flex for measuring the stress of SCC operators during the remote monitoring and remote ship operations in different levels of workload. The paper presents stress as a dependent variable and workload as an independent variable, which can be manipulated during an EEG experiment.

Developing this type of human-centered experiment leads to the study of human interactions in a quantitative manner, which can boost the acceptability of results. But, the development process of a human-centered experiment requires fundamental knowledge in various domains, such as psychology, physiology, engineering design, electro-physics, and neuroscience [2]. This increases the complexity of the development process, especially when the experiment is to be designed from scratch and there is no clear experiment precedes for scenarios [2]. Thus, the current paper reviews some aspects of knowledge domains in order to build an EEG human-centered experiment within the SCC. In addition, an example case comprising a high workload and low workload scenarios is presented. The example case is developed based on the wayfaring model; this model supports the early concept creation stage of designing experiments including multi-disciplines and high levels of complexity [2].

The rest of the paper is organized as follows: the definition of remote ship operations and SCC in section II. Electroencephalography (EEG) and its characteristics appear in section III; this section reviews how stress can be investigated by using brain frequencies. Wayfaring model and example case is presented in section IV. Section V discusses the objective and EEG as an explicit tool to design a human-centered experiment regarding the stress of SCC operators. Finally, section VI presents the conclusion and future works.

## II. REMOT SHIP OPERATIONS AND SCC

Today, technology is generally available to operate a vessel without on board crew, however, several developments and validations are required [5]. According to the definition of remote operation, a machine is under the continuing and direct human control from a distant location [11]. This implies that the concept of unmanned vessels will rely on an SCC, which is responsible for the operation of the vessel based on the different types of vessel and SCC control modes [5].

According to the baseline case from Maritime Unmanned Navigation through Intelligence in Networks (MUNIN), the SCC contains all on land functions, remote bridge, and engine control modules that can be utilized to take the direct control over the vessel in specific cases [12]. Furthermore, the initial voyage planning will be conducted in SCC, and all the voice communication to the vessel will be relayed to the SCC in order to handle by the SCC operators [12].

There are five main ship control modes for an onboard Autonomous Ship Controller (ASC) comprising autonomous execution, autonomous control, direct remote control, indirect remote control, and fail to safe mode [5]. According to different modes of ship control, it can be concluded that SCC will operate in various modes as well. Remote monitoring, remote operation, status investigation, ASC update, and intervention are the main SCC control modes [5]. Generally, the SCC will be in the remote monitoring mode, when all the ship status indicators are normal; in this case, no action will be taken from SCC. The ASC sends a set of ship status flags to SCC at short intervals (for example every 5 seconds). A set of ship status indicators are presented by [5] based on the hierarchical ship function decomposition [13] and the ship functional model [14]. Table I indicates ship status indicators which are critical parameters for the SCC operators in different SCC control modes.

TABLE I. SHIP INDICATORS IN SCC [5]

| **Indicator** | **Detailed description elements** |
|---|---|
| Location | Position, heading, speed, distance from planned position as well as position quality flag. |
| Weather | Wind speed/ direction, wave and swell hight/ length/ direction |
| Visibility | Visibility, radar range and culture. COLREG status of ship |
| Collision | Vectors to targets, status/heading/ speed of targets |
| Grounding | Depth measurement |
| Communication | Critical communication directly to ship, for example on VHF, GMDSS. |
| Stability | Trim, heel, draft, water tight integrity, void space, water ingress |
| Environment | Environmental performance and emission to air and sea |
| Economy | Fuel use and potential for late arrival/ off hire etc |
| Hull propulsion | Hull and equipment status, anchor, towing, ladders |
| Propulsion | Engine, auxiliaries, piping, fuel |
| Electric | Electric power systems, switch boards, emergency power |
| Safety | Fire, evacuation, extinguishing, escape |
| Cargo | Cargo status |

If one of the above indicators shows some abnormality, the SCC will enter to ASC update and investigation modes [5]. Remote ship operation mode is utilized to control the vessel manually when ASC cannot solve the problem in a certain situation. SCC will enter intervention mode when deeper interactions with onboard systems are necessary [5], [12].

## III. ELECTROENCEPHALOGRAPHY (EEG)

Electroencephalography in short EEG means recording the electric activity of the brain. Most cognitive processes happen within tens to hundreds of milliseconds, this is much faster than the blink of an eye. On the other hand, events, which trigger cognitive processes happen in time sequences

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that span hundreds of million seconds to a few seconds [8]. EEG similar to a high-speed camera has a high time resolution; hence, it can capture the physiological changes of underlying cognitive processes better than other brain imaging techniques including Positron Emission Tomography (PET) scanners and Magnetic Resonance Imaging (MRI) [8].

The brain is continually active and generates electrical activities that are significantly less than a 9v battery. EEG sensors can pick up weak signals from the surface of the scalp [8]. The international brain research has been gaining important findings regarding EEG and established theories which are well-accepted on how the EEG signals relate to attentional, affective or cognitive processing [8]. The current paper utilized the Emotiv EEG EPOC Flex containing 32 channels. Each sensor records five main brain band powers consisting Theta (4-8Hz), Alpha (8-12Hz), Low beta (12-16Hz), High beta (16-25Hz), and Gamma (25-45Hz). EEG researchers record the brain's electrical activities via sensors placed at the scalp surface; this applied first to humans by a German neurologist Hans Berger in the 1920s [8]. As the electrical signals are very small, the data is digitized and sent to an amplifier. Then, the recorded data can be displayed as a time series of voltage values [8].

American Encephalographic society (1994) has been provided the most common system in order to define and name the electrode locations/positions on the scalp. This system is called the 10-20 system such that electrodes are placed at 10% and 20% points along lines of longitude and latitude. In the 10-20 system electrode names start with one or two letters showing the general brain region or lobes where the electrode is placed [8].

Electrode's name end with a letter or a number showing the distance to the midline. Even numbers in the right hemisphere, and odd numbers in the left hemisphere. Larger numbers refer to the greater distances from the midline [8]. Electrodes placed at the midline are labeled with "z", which indicates zero distance from the midline. For instance, T7 is placed over the left temporal regions, Fp8 is placed over the right front-polar regions, and Cz is located over the midline central brain region [8].

### *A. EEG frequencies*

Brain oscillations with the 4-8 Hz frequency range are identified as theta band [15], [16]. Various studies highlight that frontal theta activities are correlated with the difficulty of mental operations; for instance, during learning, information takes up, focused attention or memory recall. In this respect, theta frequencies are more prominent when the task difficulty increase. Hence, theta is usually associated with the processes underlying working memory and mental workload [8], [17]–[19]. Workload refers to any cognitive process involving executive processes including problem-solving, working memory and analytical reasoning. Workload which is associated with the theta band power, increases in the case of a higher level of task demand and working memory load [8]. Theta frequency can be recorded from all over the cortex, this indicates that it is generated via a wide network involving central, parental, prefrontal and temporal cortices [8]. On the other hand, there is an improvement of theta waves in the case of mental stress. This implies a good correlation between EEG signals and mental stress [20], [21]. Table II indicates a summary of studies on theta and other EEG bands focusing on stress and workload.

Alpha band as a rhythmic oscillatory activity with the frequency range between 8–12 Hz was discovered by Hans Berger in 1929 [15] cited by [8]. The alpha band is generated in posterior cortical areas, comprising parietal, occipital and posterior temporal brain areas [8], however, it is more active in frontal and occipital regions of the brain [22]. Figure 1 indicates four main brain lobes and their responsibilities. In normal adults, alpha waves can be seen spontaneously during wakefulness and relaxed state [18]. The alpha band is correlated with sensory, memory, and motor functions. During the mental and physical relaxation with closed eyes, there is an increase in alpha band power. By contrast, alpha power is suppressed during mental and body activities with open eyes [8]. In other words, alpha suppression indicates that the brain is preparing to pick up information from different senses, focusing on what really matters in that specific moment, and coordinating attentional sources [8]. This implies that alpha suppression is a valid presentation of engagement and mental activities, for instance during focused attention to different types of the stimulus [23] cited by [8].

Importantly, in the case of no stress, when the brain is performing no activity alpha waves are dominant. In stressful conditions, the alpha power declines to indicate the change in the response under stress [21]. The power suppression of alpha band during the stressful situation is also highlighted by [24]. It is important to mention that in a study regarding functional roles of 10 Hz alpha band power, Magnetoencephalography (MEG) signals similar to EEG signals indicate that alpha oscillations are associated with semantic, spatial and social attention [25].

Oscillations within the range of 12-25 Hz are generally referred to as beta band activities [8], [16], [18]. Beta frequency is generated in both frontal and posterior regions of the brain. Higher beta power is generally correlated to active concentration and busy or anxious thinking [8], [32].

TABLE II. SUMMARY OF EEG STUDIES ON STRESS AND WORKLOAD

| Authors | EEG band | EEG sensors | Results |
|---|---|---|---|
| [26] | Delta, Theta, Alpha, Beta, Gamma | $F_3$,$FC_5$,$T_7$,$P_7$,$O_1$,$O_2$, $P_8$,$T_8$,$FC_6$,$F_4$,$F_8$,$AF_3$, $F_7$, $AF_4$ | The results indicate the feasibility of EEG in order to detect stress. The highest accuracy was obtained in the alpha band power. |
| [27] | Theta (fmθ) Beta | 71 EEG electrodes | Theta (fmθ) increased consistently with memory load. |
| [28] | Beta | $FC_5$, $FC_6$, $O_1$, $O_2$, | Participants in the stress group had the highest level of Beta activity. |
| [29] | Theta | The locations of 48 electrodes (out of 171) are shown in the study | In more complex mazes there are more theta oscillations. Theta oscillations are more frequent through recall trials compare with learning trials. |
| [20] | Theta, Beta, Delta, Alpha, | $FP_1$,$FP_2$, $F_3$, $F_4$,$C_3$,$C_4$,$P_3$, $P_4$,$O_1$,$O_2$, $F_7$,$F_8$,$T_3$,$T_4$, $T_5$,$T_6$,Fz,Cz, Pz, Oz | During the most complex task, delta power increased. Delta only increases when attention to internal processing is required. During the performance of a task, alpha activity was suppressed, but low theta increased. |
| [23] | Alpha | $C_4$-$A_2$,$C_3$ $A_1$,$O_2$-$A_2$,$O_1$-$A_1$ | During the visual stimulation, a decreased in Rhythmic Activity within the Alpha Band (RAAB) happened in occipital regions. During the auditory stimulation, power declined in the central regions. |
| [30] | Alpha, Beta, Theta | Fp1,AF3, F3,F7,FC5, FC1,C3,T7, CP5, CP1,P3,P7, PO3,O1, Oz,Pz,Fp2, AF4,Fz,F4, F8,FC6,FC2,Cz,C4,T8, Cp6,Cp2,P4,P8,PO4, O2 | In the field of spectral centroids, 30 out of 32 electrodes indicated increased centroid frequency during stress (without significant effect). It is argued that negative valence stimuli lead to an increase in the right frontal activities. Besides, left frontal activity indicates the EEG response to positive valence stimuli. |
| [31] | Theta, Alpha, Beta | Fp1,Fp2, FpZ(prefrontal sites) | Stressful subjects showed a higher level of EEG complexity. The group with chronic stress had higher left prefrontal power. There was a significant difference in relative power of alpha between the normal group and the stress group. |
| [19] | Theta, Alpha | 19 electrodes based on the 10-20 system (including $O_2$, $P_4$, $F_7$) | Upper Alpha is dominant during retention (increasing the memory load). Theta and upper Alpha play an important role during the retrieval. |

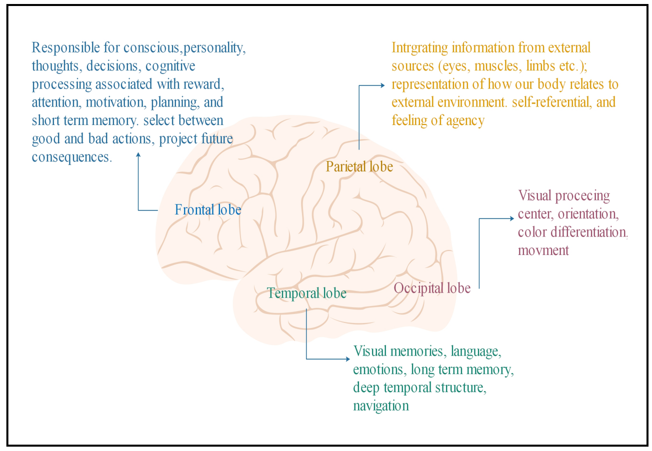


Figure 1. Brain lobes and their responsibilities

Another study indicates that there is a high beta activity at the $FC_5$ electrode during the stress situation [28]. This means that there is a meaningful correlation between beta frequencies and levels of stress.

Oscillations above 25 Hz are referred to gamma frequencies which usually found during conscious perception. Due to high contamination by muscle artifacts and small amplitude [18]. Gamma frequencies are black holes of the EEG studies. Still, it is unclear that which parts of the brain generate gamma frequencies and what these frequencies reflect. Some studies argue that the gamma band is a by-product of other neural processes, hence, they do not reflect any cognitive processing at all [8]. Notably, high gamma activity in the temporal region is associated with memory processes [18]. Furthermore, some studies report that gamma activity is connected to attention, working memory and long-term memory processes [18], [33].

## IV. HUMAN-CENTERED EXPERIMENT IN THE EXAMPLE CASE

This part presents an example of a human-centered experiment to study stress and workload within the SCC. The wayfaring approach is applied to the development of the experiment. The current example comprises two scenarios with different levels of workload. The research hypothesis is defined as follows:

$H_1$: There is a significant difference in participant's stress between high workload and low workload scenarios.

### *A. Wayfaring approch*

Wayfaring model [34], [35] can be utilized as an exploration journey instead of a planning-based approach to discover innovative ideas. The wayfaring model describes that "an optimum new solution to a problem cannot be preconceived as we do not have empirical evidence for the outcome of something that has not previously been done" [2]. In this respect, the model provides a methodology for a

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practical exploration of the problem and solution. According to [2], this methodology comprises four steps as follows:

1. Probing ideas: the exploration of opportunities, sometimes this phase includes a low-resolution prototype in order to fail early and to abductive learning.
2. Merging multidisciplinary: comprising all knowledge domains from the beginning to discover interdependencies and develop interrelated knowledge
3. Speed: make a plan based on the short iteration timeframe to maximize the iteration numbers
4. Agility: opportunistically select the next step and let the development process shape the outcome. This phase can be followed in order to achieve serendipity findings and innovation outcomes

### B. Scenario 1

This experiment uses EEG EPOC Flex to record the brain activity of a human operator while monitoring the vessel's operation in the simulation environment. The task takes 10 minutes due to limitations for using EEG EPOC Flex. The instructor room of the navigation simulators will be considered as an SCC and a ship bridge as a remote-controlled vessel. As we can see in Figure 2, the instructor room is assumed as an SCC where one operator can monitor up to six vessels (SCC remote monitoring mode). In the current scenario, an SCC operator is defined as an OOW. As mentioned before, this person is responsible for monitoring the ship and intervening if required [6]; this means sending high-level commands in specific situations. The ship bridge will be operated by simulator assistants based on the predefined route. In this scenario, SCC operators will fill in a self-report stress survey after they finish the experiment. In addition, the paper-based NASA TLX forms will be used in order to assess the workload objectively.

In scenario number 1, SCC operator will monitor one remotely operated vessel from the instructor room (based on the monitor mode of SCC), and there is a ship-ship communication between the bridge operators and SCC operators. SCC operator is responsible to send high-level commands if needed in the case of accidents, crossing other vessels or harsh weather. In addition, SCC operator has to monitor the radar data, heading, propeller revolution, rate of turn, rudder and speed of each vessel to ensure that all the vessels are in an appropriate status. Independent variable will be manipulated as follows:

- Area: Kristiansund to Trondheim (low difficulty)
- One container ship as the main vessel
- 5+ targets (traffic)
- Good visibility in daylight
- Moderated wind, calm sea-state
- No accidental situation

Figure 2. Simulator instructor room

### C. Scenario 2

Actors, environment, and components of scenario number 2 are the same as scenario number 1. The independent variable will be manipulated as follows:

- Area: Vatlestraumen (moderate difficulty)
- 5 container ships as the main vessels
- 15+ targets (traffic)
- Bad visibility, night time
- Strong wind, wavy sea
- Two accidental situation

It is notable that in this experiment physiological baseline will be performed before scenario 1.

## V. DISCUSSION

Remote monitoring and remote controls have been merged in different types of control modes of unmanned vessels and SCCs. In this respect, SCC appears as a black box comprising human, hardware, software and different types of human-machine interfaces. It is clear that by relocating crew from on board the vessel to SCC, we will face more human factor challenges such as stress and information overloading. Hence, study human interactions within the SCC leads to gain more knowledge about different aspects of remote ship operations and decoding the black box of the SCC. The current paper presented EEG as a remarkable method in order to investigate the stress of SCC operators during the different levels of workload.

Moreover, the paper presented a very simple example case based on the wayfaring approach. The wayfaring model was an appropriate model in order to develop the experiment due to a lack of clear procedures and a high level of complexity. EEG EPOC Flex was defined as a tool to record the participant's brain signals during the experiment. According to the various studies regarding the EEG signals and stress, we suggest theta and alpha frequencies as two important EEG frequencies which can be considered to study stress. During the stressful situation, the power of alpha frequencies falls down, however, the power

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of theta waves increases. In addition, EEG electrodes in the frontal region of the brain including Fp1, Fp2, FpZ (prefrontal site), $FC_5$ and $FC_6$ can be considered as effective electrodes during the stress evaluation. However, a comprehensive analysis of stress requires considering more EEG electrodes in addition to different band powers.

Developing a human-centered experiment is a challenging task, as fundamental knowledge in the different domains is required. This implies one of the main challenges in developing human-centered experiments, especially in the field of EEG. Using a simulator environment rather than a real SCC is another issue, which can affect the results of the experiment. Furthermore, the availability of participants is another limitation during the human-centered experiments. It is important to mention that in the current high workload scenario, all the independent factors (number of targets, weather, route, etc.) were manipulated aiming to make a significant change in the level of workload; thus, the effect of each factor is not clear. Future experiments can provide more details regarding the independent variable.

## VI. CONCLUSION

In this paper, we studied general aspects of remote ship operations, SCC and EEG in order to a develop human-centered experiment. EEG is presented as an exceptional tool to study stress in different levels of workload within the SCC. Moreover, an example case including high and low workload scenarios was defined by applying the wayfaring approach. The current example case focused on the monitoring mode of the SCC. In this respect, future studies can investigate stress and workload in other SCC control modes. Moreover, future studies can investigate different analysis and pre-processing techniques in order to extract the required data of stress and workload from raw EEG data.

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