# Human Reliability Estimation Using Physiological Behaviour

*Thesis to be submitted in partial fulfillment of the requirements for the degree*

*of*

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*by*


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# CERTIFICATE

This is to certify that we have examined the thesis entitled **Human Reliability Estimation Using Physiological Behaviour**, submitted by **Abhishek Topwal**(Roll Number: *21CS60R01*) a postgraduate student of **Department of Computer Science and Engineering** in partial fulfillment for the award of degree of Master of Technology in Computer Science and Engineering. We hereby accord our approval of it as a study carried out and presented in a manner required for its acceptance in partial fulfillment for the Post Graduate Degree for which it has been submitted. The thesis has fulfilled all the requirements as per the regulations of the Institute and has reached the standard needed for submission.

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**Place: Kharagpur**
**Date:**

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1. The work contained in this report is original and has been done by me under the guidance of my supervisor.
2. The work has not been submitted to any other Institute for any degree or diploma.
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**Abhishek Topwal**

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# Chapter 1

# Introduction

Human reliability refers to the likelihood of successful human performance within specified time frames and environmental conditions. Human performance can be affected by many factors such as age, state of mind, physical health, attitude, emotions, propensity for certain common mistakes, errors and cognitive biases [8]. Human reliability is an essential factor to depict the contributions of humans to the resilience of systems and to avoid possible adverse consequences of human errors or oversights. The concept of **Human Reliability Analysis (HRA)** allows us to understand the human side of a man-machine interaction in a better way. In spite of the enormous growth and development in system reliability, the overall system well-being continues to remain questioned due to unpredictable human behavior. Thus, to improve on the factor of human reliability, there is a need of improvement in understanding of human cognitive behaviour.

Human errors arise due to various factors including internal factors (such as, workload, stress, experience, etc.) and external factors (such as, training, task settings etc.). These factors determine the performance of human in the working environment and are popularly known as **Performance Shaping Factors (PSFs)**. Considering these factors, different HRA methods have established methodologies to evaluate **Human Error Probability (HEP)**. Due to complicated nature of human behaviour, it becomes difficult to predict HEP and comment about the reliability of the subject.

## 1.1 Motivation

The concept of Human Reliability Analysis (HRA) reflects an understanding that people and systems are not error-proof. Hence, human reliability estimation for a given task can help us not only to avoid human errors but to also comment about the performance of the subject. It also gives the freedom to focus on a user-centered design, as well as increases the probability to develop an error-tolerant design. Moreover, estimating reliability using quantitative measures related to utilization of physiological parameters such as EEG signals leads to a highly correlated approach with the changes in subject cognitive state. Also, additional physiological measure like heart rate can be included in analysis to extend the capabilities of quantification of cognitive states.

Traditionally, human cognitive behaviours have been analyzed using questionnaires, which are qualitative approaches and are mostly subjective. Since, human behaviour is very complex and is affected by various factors, it becomes very difficult to predict or simulate human behaviour. Moreover, methods of evaluation like questionnaires depends highly on the expert and remains specific to the context only.

Methods using physiological parameters are objective and provides a measure for quantitative performance. The widely used physiological parameters are ECG (Electrocardiogram), EOG (Electrooculogram), Heart Rate, Eye blinking, and Heart Rate Variability (HRV). Our approach for the quantitative analysis uses Electroencephalogram (EEG, the brain electrical activity) signals by extracting indices and features from EEG signals.

## 1.2 Problem Statement

Since EEG records brain activity in real time as well as it has a High temporal resolution which allows it to resolve the rapidly changing patterns of brain activity and hence the underline mental function. EEG signals provides the temporal resolution in the millisecond range. Therefore the potential of EEG can be utilized to explore certain parameters which can be incorporated into the proposed HEP evaluation model.

In complex working environment, there are certain characteristics of human nature which gets accentuated. These can be stress, limited working memory, limited attention resources, fatigue etc [8]. The human specific factors like the ones mentioned above will make the proposed approach independent to the subject as well as dynamic in nature. The barrier lies in estimating these complex parameters which are highly variable and changes w.r.t subject. By applying various machine learning and deep learning techniques on EEG signals, the level of the mentioned parameters can be estimated and used to analyze the performance of the subject. An experiment needs to designed such that it involve components to carefully invoke the parameters on different levels such that analysis on them reflects the performance of the subjects. The approach will help in developing a system containing ensemble of various classification models which can determine the level of various human PSFs and estimate the reliability of the subject.

## 1.3 Organization of the Report

The rest of the report is in the following manner:

- **Chapter 2** contains the Literature Review of similar work done related to the problem statement.
- **Chapter 3** contains the proposed approach and the description of the model used to estimate the Human Reliability.
- **Chapter 4** discusses about the components and guidelines related to the experiment.
- **Chapter 5** comprises the datasets and various Machine Learning and Deep Learning techniques used.
- **Chapter 6** explains the results of the experiment.
- **Chapter 7** discusses the conclusion of the thesis and scope of future work.

# Chapter 2

# Background

## 2.1 Literature Review

Human actions have a major in operating the systems in a systematic manner. However, human actions are a source of vulnerability which may disrupt the overall system performance. As a solution, human reliability assessment methods come up to examines the risk associated with human factors in the workplace. HRA was originated as a part of probabilistic risk assessment (PRA) in the US nuclear energy development programme. [13]. Technique for Human Error Rate Prediction (THERP) is among the first HRA methods developed for HEP estimation [15]. However, these first generation methods does not take into consideration internal or external human factors which affects performance. Human factors include the effects of workload, stress, psychological issues, illness [2] etc. Furthermore, research has shown that there are systematic influences on decision making and behavior that cannot be categorized simply as omissions or commissions [4].

Recently, in HRA approaches, attempts are made to improve its estimation by including more relevant PSFs or by incorporating values of PSF multiplier from empirical data [5]. PSFs such as sleep duration and fatigue are considered as important parameters for inclusion in HRA models [6]. Furthermore, efforts are made to alternate the traditional approach of assigning expert opinion human error probability values with more realistic empirical data [5]. Kim et al. proposed a remarkable work which followed statistical approach to estimate human error probabilities [9].

There has been various approaches which have utilized various aspects of EEG signals. In [1], power distribution and event-related brain potential (ERP) have been utilized to assess specific mental tasks, e.g. arousal level and cognitive depth. It has also been found that the EEG shifts from fast and low amplitude waves to slow and high amplitude ones in case of drop in arousal [10]. The studies have also found that in case of decreased alertness, an increase in low-frequency alpha and theta activity in cortical activation [3]. Therefore, the amount of alpha and theta power provides an adequate index of the level of fatigue that subjects experience. One of the components of ERP, the P300 which is defined as the most positive peak in a window between 200 and 500 millisecond have been used in identification of the depth of cognitive information processing. It has been reported that as the difficulty of the task increases, the amplitude of the P300 decreases [11]. In [14], a method known as Person-Specific Human Error Estimation (P-SPHERE) is given which evaluates human error probability by exploiting the advances of the dynamic human behavior using real values from EEG signals. It uses various user performance shaping factors (PSFs) to model human behavior.

For the purpose of Human Reliability Estimation, there are several existing methods that uses PSFs but there still remains a scope for further research. The reasons are:

1. Dependency on expert opinion for assigning PSF values.
2. Less Attention is paid to the dynamic nature of the human behaviour.
3. Less studies that solely focus on the physiological parameters to estimate Human Reliability.

# Chapter 3

# Methodology

## 3.1 Proposed Approach

Human Performance is known to be affected by various PSFs. These can be used to estimate the human performance even when the nature of human performance is dynamic and subjective. To find the human error probability efficiently, the factors are considered under different categories which appears in the workplace. The PSFs are divided into four categories on the basis of the impact on the working of an individual [14]. The categories are:

- **Environmental Factors -** Work Shifts, Work Processes
- **Human Factors -** Skill, Fitness for Duty
- **Task Oriented Factors -** Task Frequency, Task Complexity
- **Organisational Factors -** Procedures, Training

Among the above factors, some of the factors remain same for different subjects for a given task. But Human Factors vary among the individuals and can be used to differentiate between the Human Performances. In the category of Human Factors, the component of Fitness for Duty comprises of parameters like Mental Workload, Vigilance, Anxiety, Working Memory etc. These parameters directly affects the performance of the individual and hence are useful in determining the reliability of the subject. Our approach focuses on determining the PSFs for the above mentioned Human Factors using the physiological behaviour of the subject captured using EEG signals. Our approach is based on the P-SPHERE (person specific human error estimation ) approach as mentioned in [14]. The P-SPHERE approach takes in consideration all the above mentioned PSF categories, but our approach will only be depending on the physiological based parameters to evaluate HEP.

## 3.2 Performance Shaping Factors

In various HRA methods, the PSFs act as human error quantifying parameters. These PSFs are systematically evaluated such that the possible sources of human errors can be identified. The strength of the PSFs changes while performing a task due to change in human behaviour, task demands etc. This variation results in the shift of performance of the subjects. Therefore, to estimate HEP, the level of the PSFs must be well defined.

| Factors influencing human performance | Levels | Definition |
|---|---|---|
| Mental Workload | High | The Subject experiences extreme difficulty in performing the task. This is due to high task demand caused due to an increase in error rate, high response time, resulting in low performance. |
| | Nominal | The Subject can perform the task with high productivity and minimum error rate. |
| | Low | The Subject experiences minimum difficulty in performing the task due to less effort required by the task. |

Table 3.1: Levels and definition for the PSF Mental Workload [14]

### 3.2.1 Multiplier Evaluation for the considered PSFs

Our approach considers each subject's performance independently, hence the multiplier should be evaluated separately for every individual using the gathered data. The gathered data is used to estimate the transition probabilities for a subject changing its level of PSFs. and the probability of making an error in each state. To derive the multiplier values of the PSFs, we have used the principle of Continuous Time Markov Chain (CTMC) Model. The CTMC model is applied to random processes which exist in discrete state space but can change their values at any instant of time. Also, the

| Factors influencing human performance | Levels | Definition |
|---|---|---|
| Vigilance | High | The Subject is in a state of high alertness which is accompanied by high sensitivity towards detecting or observing activity which includes constant subconscious anticipation of danger or critical events[12]. |
| | Nominal | The Subject is active in performing the task. This represents that the individual's behavior is assertive in terms of the number of lapses, missed events and reaction time. |
| | Low | The Subject is in a state of diminished alertness level, which is accompanied by reduction in continuous detection or observation capability. |

Table 3.2: Levels and definition for the PSF Vigilance [14]

| Factors influencing human performance | Levels | Definition |
|---|---|---|
| Anxiety | High | The subject suffers from absenteeism, nervousness, indecisiveness resulting in bad judgement and poor performance. |
| | Nominal | The subject is well aroused and not in a state of over-stressed and unhappy can give a high quality performance. |
| | Low | The subject is in a state of boredom, lack of concentration and lack of motivation. |

Table 3.3: Levels and definition for the PSF Anxiety [14]

| Factors influencing human performance | Levels | Definition |
|---|---|---|
| Working Memory | High | The subject can control, regulate and actively maintain the task related information. |
| | Nominal | The subject can actively maintain the task-relevant information. |
| | Low | The subject is not able to hold and use the required information. |

Table 3.4: Levels and definition for the PSF Working Memory

state of the model at some time in future only depends on the current state of the model and not on its history. The CTMC model imitate the highly dynamic nature of humans as the state of a person can make transition from any state to the other at any instant of time. Furthermore, the human behavior is highly correlated to the present state rather than the past states that the person might have gone through.

The multipliers are evaluated in 2 steps [14]:

- The probability of the subject being in on of the defined levels is evaluated.
- The probability of the subject making an error while at a particular level is evaluated.

Depending on the individual performing the task, these PSFs can change from one level to another. The levels can be categorised as:

- Nominal State (st = NO) is the base state.
- Positively Affecting State (st = PF) is the state in which the individual performs the task in a performance improving scenario.
- Negatively Affecting State (st = NF) is the state in which the individual performs the task in a performance degrading scenario.

We would consider the probability of the errors separately in two states as:

- Error-Free State (st = NE) where the subject does not commit any error.
- Error-Occurrence State (st = EO) where the subject takes a wrong decision or performs a delay in action or performs an incomplete task.

### 3.2.2 Transition Rate Computation

Let $\alpha$ be the rate at which the PSF leaves state $i$ and $P_{ij}$ is the probability that the PSF goes to state $j$. Let $a_{ij}$ be the transition probability from state $i$ to state $j$. We can find the steady-state probabilities $[P = P_0, P-1, \ldots, P_r]$ using the transition probability of each state using the matrix equation,

$$\begin{bmatrix} P_0 & P_1 & \ldots & P_r \end{bmatrix} \cdot \begin{bmatrix} a_{00} & a_{01} & a_{02} & \cdots & a_{0r} \\ a_{10} & a_{11} & a_{12} & \cdots & a_{1r} \\ \vdots & \vdots & \vdots & \vdots & \\ a_{r0} & a_{r1} & a_{r2} & \cdots & a_{rr} \end{bmatrix} = \begin{bmatrix} P_0 & P_1 & \ldots & P_r \end{bmatrix}$$

Once steady state probabilities are computed, the multiplier is evaluated by multiplying the PSFs steady state probability with the error occurrence probability.

### 3.2.3 Human Error Probability Calculation

The steps to evaluate Human Error Probability (HEP) is as follows:

- Using the Continuous Time Markov Chain approach as discussed in Section 3.2.1 evaluate the considered PSFs.
- Perform the union of all the multipliers to get the error contribution from the factors.

$$\begin{aligned} P(HF) &= P(MW) \cup P(V) \cup P(WM) \cup P(A) \\ HEP &= P(HF) \end{aligned} \tag{3.1}$$

where, MW = PSF Multiplier for Mental Workload, V = PSF Multiplier for Vigilance, WM = PSF Multiplier for Working Memory, A = PSF Multiplier for Anxiety.

# Chapter 4

# Experiment

## 4.1 Introduction

As discussed in the previous chapters, an experiment needs to be designed to get the required data for various PSFs level classification. The experiment needs to be designed in such a way that different physiological parameters of Mental Workload, Anxiety, Working Memory and Vigilance are invoked properly. It should include components to evoke all the above mentioned characteristics in the same environment for all the subjects. Moreover, the experiment should be conducted in an isolated environment to remove the interference in the EEG signals from any artefacts.

## 4.2 Multiple Attribute Task Battery

The Multi-Attribute Task Battery (MATB) is a computer-based task designed to evaluate operator performance and workload. MATB provides a benchmark set of tasks and analogous to activities that aircraft crew-members perform in flight, with freedom to use by non-pilot subjects [7].

The MATB requires the simultaneous performance of monitoring, dynamic resource management, and tracking tasks. The simultaneous performance of multiple tasks is a central feature of the MATB and it is this feature that is consistent with most operational systems and thus makes the task useful for our purposes as a research platform. The Multi-Attribute Task Battery (MAT Battery) was originally developed in the early 1990's at LaRC (Comstock & Arnegard, 1992) and re-implemented under Microsoft Visual Studio.NET (VS.NET) [7] .

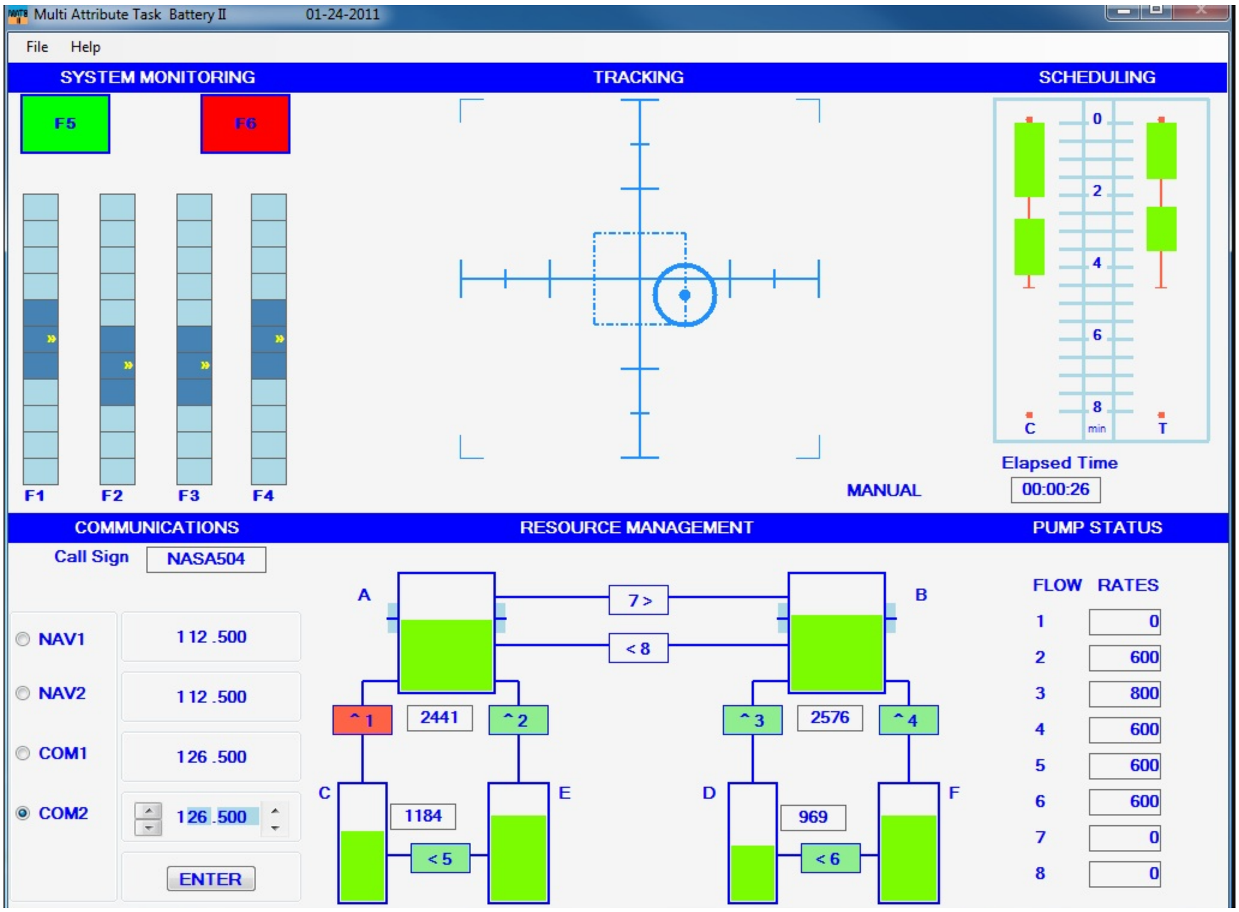


Figure 4.1: MATB Graphical User Interface

The different tasks which the subject has to perform and the physiological parameters invoked respectively are:

- **System Monitoring (SYSMON)**

  This task can be seen in the upper left window of the display. The demands of monitoring gauges and warning lights are simulated here. The subject responds to the absence of the Green light, the presence of the Red light, and monitors the four moving pointer dials for deviation from midpoint. This task will test the vigilance levels of the subject. After some duration of the task, the subject will have to be more attentive to perform the task with less errors.

- **Tracking (TRACK)**

  The demands of manual control are simulated by the tracking task. This task is located in the upper middle window. Using the Joystick, the subject keeps the target at the center of the window. This task can be automated to simulate the reduced manual demands of autopilot. This task will invoke the mental workload of the subject as well as the anxiety. Increasing the difficulty will lead in more mental workload as well as higher anxiety.

- **Communications (COMM)**

  This task presents pre-recorded auditory messages to the operator at selected intervals during the simulation. However, not all of the messages are relevant to the operator. The subject's task is to determine which messages are relevant and to respond by selecting the appropriate radio and frequency on the communications task window. This task involves the working memory and the vigilance characteristics of the subject.

- **Resource Management (RESMAN)**

  The demands of fuel management are simulated by the resource management task. The goal is to maintain tanks A and B at 2500 units each. This is done by turning On or Off any of the eight pumps. Pump failures can occur and are shown by a red area on the failed pump.The Resource Management window provides a diagram of the fuel management system. The six large rectangular regions are tanks which hold fuel. The green levels within the tanks represent the amount of fuel in each tank, and these levels increase and decrease as the amount of fuel in a tank changes. This task will include the vigilance and working memory parameter.

In all the above tasks, the cases when the subject makes an error will lead to more anxiety in the subject.

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