Declaration

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Abstract

Fatigue is a common symptom of weakness either physically or mentally. These symptoms may lead to a drop in motivation, weakened sensitivity, slowing of responsiveness and inability to give full attention. All of these problems can cause adverse effects, such as accidents, especially those that require full attention as drivers of vehicles, and rail operators, the pilot of an aircraft or ship operators. This research investigates systems to detect and quantify the signs of fatigue using non-invasive facial analytics.

There are four main algorithms that represent the major contribution from the PhD research. These algorithms encompass facial fatigue detection and quantification system as a whole. Firstly, a new technique to detect the face is introduced. This face detection algorithm is an affiliation of colour skin segmentation technique, connected component of binary image usage, and learning machine algorithm. The introduced face detection algorithm is able to reduce the false positive detection rate by a very significant margin. For the facial fatigue detection and quantification, the major fatigue signs features are from the eye activity. A new algorithm called the Interdependence and Adaptive Scale Mean Shift (IASMS) is presented. The IASMS is able to quantify the state of eye as well as to track non-rigid eye movement. IASMS integrates the mean shift tracking algorithm with an adaptive scale scheme, which is used to track the iris and quantify the iris size. The IASMS is associated with face detection algorithm, image enhanced scheme, eye open detection technique and iris detection method in the initialisation process. This proposed method is able to quantify the eye activities that represent the blink rate and the duration of eye closure.

The third contribution is yawning analysis algorithm. Commonly yawning is detected based on a wide mouth opening. Frequently however this approach is thwarted by the common human reaction to hand-cover the mouth during yawning. In this
research, a new approach to analyse yawning which takes into account the covered mouth is introduced. This algorithm combines with a new technique of mouth opening measurements, covered mouth detection, and facial distortion (wrinkles) detection. By using this proposed method, yawning is still able to detect even though the mouth is covered.

In order to have reliable results from the testing and evaluating of the developed fatigue detection algorithm, the real signs of fatigue are required. This research develops a recorded face activities database of the people that experience fatigue. This fatigue database is called as the Strathclyde Fatigue Facial (SFF). To induce the fatigue signs, ethically approved sleep deprivation experiments were carried out. In these experiments twenty participants, and four sessions were undertaken, which the participant has to deprive their sleep in 0, 3, 5, and 8 hours. The participants were subsequently requested to carry out 5 cognitive tasks that are related to the sleep loss.

The last contribution of this research is a technique to recognise the fatigue signs. The existing fatigue detection system is based on single classification. However, this work presents a new approach for fatigue recognition which the fatigue is classified into levels. The levels of fatigue are justified based on the sleep deprivation stages where the SFF database is fully used for training, testing and evaluation of the developed fatigue recognition algorithm. This fatigue recognition algorithm is then integrated into a Fatigue Monitoring Tool (FMT) platform. This FMT has been used to test the participant that carried out the tasks as ship crew in shipping bridge simulator.
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<th>Description</th>
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<tbody>
<tr>
<td>AAM</td>
<td>Active Appearance Model</td>
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<tr>
<td>AdaBoost</td>
<td>Adaptive Boosting</td>
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<tr>
<td>AECS</td>
<td>Average Eye Closure Speed</td>
</tr>
<tr>
<td>ARRB</td>
<td>Australian Road Research Board</td>
</tr>
<tr>
<td>ASM</td>
<td>Active Shape Model</td>
</tr>
<tr>
<td>ASTidD</td>
<td>Advisory System for Tired Driver</td>
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<tr>
<td>AU</td>
<td>Action Unit</td>
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<tr>
<td>AVMed</td>
<td>Institute of Aviation Medicine</td>
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<tr>
<td>BN</td>
<td>Bayesian Network</td>
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<tr>
<td>CAMSHIFT</td>
<td>Continuously Adaptive Mean Shift</td>
</tr>
<tr>
<td>CAS</td>
<td>Circadian Alertness Simulator</td>
</tr>
<tr>
<td>CAS-PEAL</td>
<td>Chinese Academic of Science - Pose, Expression, Accessories, and Lighting</td>
</tr>
<tr>
<td>CASIA</td>
<td>Chinese Academic of Science</td>
</tr>
<tr>
<td>CeSIP</td>
<td>Centre for excellence in Signal and Image Processing University of Strathclyde</td>
</tr>
<tr>
<td>CMU</td>
<td>Carnegie Mellon University</td>
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<tr>
<td>COPD</td>
<td>Chronic obstructive pulmonary disease</td>
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<tr>
<td>DFM</td>
<td>driver fatigue monitoring system</td>
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<tr>
<td>ECG</td>
<td>Electrocardiograph</td>
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<tr>
<td>ED</td>
<td>Distance between the centre of eyes</td>
</tr>
<tr>
<td>EDVTCS</td>
<td>Engine Driver Vigilance Telemetric Control System</td>
</tr>
<tr>
<td>EEG</td>
<td>Electroencephalography</td>
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<tr>
<td>EOG</td>
<td>Electrooculography</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>EMD</td>
<td>Distance between centre of mouth and the middle point between eyes</td>
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<tr>
<td>faceLAB™</td>
<td>Face Laboratory</td>
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<tr>
<td>FAID</td>
<td>Fatigue Audit Interdyne</td>
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<tr>
<td>FACS</td>
<td>Facial Action Coding System</td>
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<tr>
<td>FER</td>
<td>Focus of Eye Region</td>
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<td>FERET</td>
<td>Facial Recognition Technology</td>
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<td>FFS</td>
<td>Forward Features Selection</td>
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<td>FMT</td>
<td>Fatigue Monitoring Tool</td>
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<td>FRMS</td>
<td>Fatigue Risk Management System</td>
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<td>FSI</td>
<td>Flag State Implementation</td>
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<tr>
<td>FWR</td>
<td>Focus Wrinkles Region</td>
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<tr>
<td>GUI</td>
<td>Graphical user interface</td>
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<tr>
<td>HIV</td>
<td>Human immunodeficiency virus</td>
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<td>HOG</td>
<td>Histograms of Oriented Gradients</td>
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<td>HMM</td>
<td>Hidden Markov Model</td>
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<tr>
<td>HSI</td>
<td>Hue Saturation Intensity</td>
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<tr>
<td>HSV</td>
<td>Hue Saturation Value</td>
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<tr>
<td>IASMS</td>
<td>Interdependence and Adaptive Scale Mean Shift</td>
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<tr>
<td>ICAO</td>
<td>International Civil Aviation Organization</td>
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<tr>
<td>ICE</td>
<td>Iris Challenge Evaluation</td>
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<tr>
<td>IMO</td>
<td>International Maritime Organisation</td>
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<tr>
<td>IR</td>
<td>Infrared</td>
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<td>ISM</td>
<td>International Safety Management</td>
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<tr>
<td>Lab</td>
<td>Laboratory</td>
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<td>LBP</td>
<td>Local Binary patterns</td>
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<td>LDA</td>
<td>Linear Discrimination Analysis</td>
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<tr>
<td>LED</td>
<td>Light Emitting Diode</td>
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<tr>
<td>MIT</td>
<td>Massachusetts Institute of Technology</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>MLR</td>
<td>Multinomial Ridge Regression</td>
</tr>
<tr>
<td>MMU</td>
<td>Malaysia Multimedia University</td>
</tr>
<tr>
<td>mo</td>
<td>mount opening</td>
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<tr>
<td>NIR</td>
<td>Near Infrared</td>
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<tr>
<td>NN</td>
<td>Neural Network</td>
</tr>
<tr>
<td>PCA</td>
<td>Principal Component Analysis</td>
</tr>
<tr>
<td>PERCLOS</td>
<td>Prominent technique</td>
</tr>
<tr>
<td>PIE</td>
<td>CMU Pose, Illumination, and Expression</td>
</tr>
<tr>
<td>PsyKE</td>
<td>Psychology Knowledge Exchange &amp; Enterprise Unit University of Strathclyde, and Glasgow Sleep Centre</td>
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<tr>
<td>PVT</td>
<td>Psychomotor vigilance task</td>
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<td>RAAF</td>
<td>Royal Australian Air Force</td>
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<tr>
<td>RGB</td>
<td>Red Green Blue</td>
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<tr>
<td>RLBP</td>
<td>Regional Local Binary Pattern</td>
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<tr>
<td>SAD</td>
<td>Sum of Absolute Difference</td>
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<td>SAFE</td>
<td>System for Air Crew Fatigue Evaluation</td>
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<td>SART</td>
<td>Sustained Attention to Response Task</td>
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<td>SFF</td>
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<td>SVM</td>
<td>Support Vector Machine</td>
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<td>3D</td>
<td>Three dimensional</td>
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<td>TPMA</td>
<td>Three Process Model of Alertness</td>
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<td>UBIRIS</td>
<td>Irises database from University of Beira Interior</td>
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<td>University Ethic Committee of University of Strathclyde</td>
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<td>YAWN</td>
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<td>YcbCr</td>
<td>Luminance and chroma component colour space</td>
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<td>ZJU</td>
<td>Zhejiang University</td>
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## List of Symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<td>( \delta )</td>
<td>Delta</td>
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<tr>
<td>( \theta )</td>
<td>Theta</td>
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<td>( \alpha )</td>
<td>Alpha</td>
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<tr>
<td>( f )</td>
<td>PERCLOS curve over a certain period</td>
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<tr>
<td>( t_1 )</td>
<td>The time the eye is closed for only 20%</td>
</tr>
<tr>
<td>( t_2 )</td>
<td>The time when the eyes are 20% from completely closed</td>
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<tr>
<td>( t_3 )</td>
<td>The times from eye open to eye 20% open (after being closed)</td>
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<tr>
<td>( t_4 )</td>
<td>The times from eye open to eye 80% open (after being closed)</td>
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<tr>
<td>( r )</td>
<td>red</td>
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<tr>
<td>( g )</td>
<td>green</td>
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<td>( b )</td>
<td>blue</td>
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<td>( c_b )</td>
<td>Blue different chroma component</td>
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<tr>
<td>( c_r )</td>
<td>Red different chroma component</td>
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<tr>
<td>( hue )</td>
<td>Properties of colour</td>
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<tr>
<td>( y_{\text{min}} )</td>
<td>Minimum y axis</td>
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<tr>
<td>( y_{\text{max}} )</td>
<td>Maximum y axis</td>
</tr>
<tr>
<td>( x_{\text{min}} )</td>
<td>Minimum x axis</td>
</tr>
<tr>
<td>( x_{\text{max}} )</td>
<td>Maximum x axis</td>
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<tr>
<td>( R )</td>
<td>radius</td>
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<tr>
<td>( \epsilon )</td>
<td>epsilon</td>
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</table>
\[ B(x, y) \] A bounding rectangle

\[ sm \] Small region of pixels

\[ bg \] Large region of pixels

\[ g'(x,y) \] Enhanced input image

\[ g(x,y) \] Input image

\[ G_{l\min} \] The minimum input image intensities

\[ H_{i} \] The cumulative histogram

\[ X \] The intensity value

\[ gT \] The adaptive threshold

\[ P_{\min} \] The minimum pixel value

\[ P_{\max} \] The maximum pixel value

\[ sr \] The aspect ratio of the bounding box shape

\[ hbb \] Height of the bounding box shape

\[ wbb \] Width of the bounding box shape

\[ r \] The iris radius

\[ x_{0} \] The coordinate of the iris centre in the \( x \)-direction

\[ y_{0} \] The coordinate of the iris centre in the \( y \)-direction

\[ I(x,y) \] The input iris image

\[ G_{\sigma}(r) \] The Gaussian function
\[ \hat{q} = \{ \hat{q}_u \}_{u=1}^{m} \]

The probability of the colour histogram of the iris

\( M \)

The number of histogram bins

\( x_i \)

Normalised pixel location from 1 to \( n \) with the target iris centred at 0

\( \delta \)

Kronecker delta function

\( b(x_i) \)

The bin for pixel \( x_i \)

\( k \)

The Epanechnikov kernel function

\( C \)

Normalisation constant

\( \hat{p}_u(y) \)

The probability of colour histogram of the target iris candidate model

\( Y \)

Centre position of the current frame

\( H \)

Radius of weighting kernel

\( C_h \)

The normalisation constant

\( d(y) \)

The centre of the iris

\( \hat{p}(y) \)

Estimation of the Bhattacharyya coefficient

\( y_1 \)

New location targeted iris

\( w_i \)

The weight

\( M_{00} \)

Zeroth moment of the region

\( M_{10}, M_{01}, M_{11} \)

First-order moments

\( I(x, y) \)

Probability pixel value within the object region in \( x \) and \( y \) range

\( x_c, y_c \)

The centroid point of the region

\( M_{20}, M_{02} \)

Second-order moments

\( \mu_{20}, \mu_{02}, \mu_{11} \)

Rotation of ellipse

\( \theta \)

Degree of orientation of the ellipse
The semi-major axis of the ellipse

Area of region computed from the zero\textsuperscript{th} moment

Length 1

Length 2

Centre point of the right eye

Centre point of the left eye

Distance between centre points of the irises

Size of the FER

Sum of Absolute Difference (SAD) value of FER in between two frames

The normalise value of SAD

Width of FER

Height of FER

Threshold value of the iris area

The ratio of ED and EMD distances

Centre of right eye

Centre of left eye

The measured length of mouth

The height of the mouth

The ratio of $h_l$ to height of FMR

The result of Local Binary Pattern

Gray level values of the central pixel

Surrounding pixels in the circle neighborhood

xxii
\[ P \]  
Surrounding pixels

\[ R \]  
Radius

\[ ri \]  
Rotational invariant

\[ s(x) \]  
Function binary LBP

\[ u2 \]  
Uniform pattern

\[ \text{riu}2 \]  
Rotational invariant pattern with uniform pattern

\[ \text{ROR}(x,i) \]  
Circular bitwise right shift on the \( P \)-bit number \( x \) with \( i \) time

\[ \text{LBI}^u_{(P,R)} \]  
LBP uniform pattern

\[ \text{LBI}^{\text{riu}2}_{(P,R)} \]  
Combination of rotational invariant pattern with uniform pattern

\[ G_x \]  
The gradient for the horizontal directions

\[ G_y \]  
The gradient for the vertical directions

\[ \text{FWR}_{\text{SAD}} \]  
Sum of the absolute values \( \text{FWR} \)

\[ \text{Normalised}\,\text{FWR}_{\text{SAD}} \]  
The normalised value of \( \text{SAD} \)

\[ \text{BR} \]  
Blink rate

\[ T_{\text{sec}} \]  
Total time of eye closed

\[ A_{\text{sec}} \]  
Average time of eye closed

\[ A_{\text{CBR}} \]  
Accumulated \( \text{BR} \)

\[ A_{\text{CNDsec}} \]  
Accumulated Normalised \( T_{\text{sec}} \)

\[ A_{\text{CAtsec}} \]  
Accumulated \( A_{\text{sec}} \)
Publication

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Submitted: