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Fatigue Monitoring System

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A Thesis

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Abstract

This work provides an innovative solution for monitoring fatigue for users behind workstations. A web camera was adjusted to work in near infrared range and a system of 880 nm IR diodes was implemented to create an IR vision system to localize and track the eye pupils. The software developed monitors and tracks eyes for signs of fatigue by measuring PERCLOS. The software developed runs on the workstation and is designed to draw limited computational power, so as to not interfere with the user task. To overcome low-frame rate imposed by the hardware limitations and to improve real time monitoring, two-phases detection and tacking algorithm is implemented. The proposed system successfully monitors fatigue at a rate of 8 fps. The system is well suited to monitor users in command centers, flight control centers, airport traffic dispatches, military operation and command centers, etc., but the work can be extended to wearable devices and other environments.

Key words:
Fatigue detection, IR active illumination, eyes detection, eyes tracking, workstation operator's fatigue, PERCLOS, vigilance, alertness,

Chapter 1

Introduction

1.1 Problem statement

Fatigue is temporary diminution of the irritability or functioning of organs, tissues, or cells after excessive exertion or stimulation, weariness from bodily or mental exertion [1] and is widely recognized as an important determinant impacting human performance. As civilization development progresses, a human being is challenged to control larger and more complex operations and equipment where any kind of managing dysfunction or error might cause serious consequences that impact economics and life. The National Highway Traffic Safety Administration (NHTSA) published the statistics that approximately 100,000 crashes each year resulting in 40,000 injuries and 1,550 deaths are caused by drowsy drivers [2]. According to Safety Board, 31 percent of accidents fatal to track driver involved fatigue [3]. What also cannot be neglected is the economic cost of accidents resulting from fatigue.

Fatigue also influences human productivity and is closely related to profit loss. Martin Moore-Ede [4] reports that there is an estimated $508B of mutual loss in the global world economy caused by fatigue, out of which $360 is lost in productivity. Due to these reasons, there is a need to detect/monitor fatigue in environments where diminished level of alertness poses a high cost.

While the focus of published research has been in automotive field the issue is relevant to various decision making centers, flight control centers, airport traffic dispatches, military operation and command centers or any type of military or civil executive or monitoring facilities when human error caused by fatigue is in a high cost of life.

1.2 Nature of fatigue its indicators and monitoring

Fatigue can be defined as strive away from vital human abilities and can manifest itself into diminished sensory perception, weaker cognition, slower physical action and weaker memory functions. Many everyday factors contribute to human state of vigilance. Some of them are personal (e.g. diet, health related), others are environmental (e.g. caused by noise, vibration, motion), or they may be task related (e.g. physically or mentally straining tasks). Nevertheless, none of them are as significant as sleep, its lack and quality, and circadian cycle [5]. Therefore, everything that disturbs sleep and distorts the circadian cycle has a potential to result in fatigue, affects executive decisions and leads to degradation of such vital abilities like cognitive process, vigilance, judgment, outlook and communication [6]. The circadian is a natural rhythm that controls a living body's functions like sleep-awake cycle, process of digestion, immune system activity etc. This rhythm is maintained by circadian clock placed in human brain [6]. According to it, the rest/sleep time is scheduled at night and awakening time during the day. The circadian clock imposes a diminished alertness during the day between 3 a.m. to 5 a.m. and between 3 p.m. to 5 p.m., while accelerating alertness in the periods of 9 a.m. to 11 a.m. and 9 p.m. to 11 p.m. [5]. The circadian clock system is very resistant to immediate adjustment that is often required by the work schedule changes and its distortions, or caused time zone changes [7]. Besides sleep loss and disturbances in circadian cycle there are other physiological factors contributing to fatigue. They are insufficient hydration, illness and mental stress. But the weariness is not only caused by physiological aspects but also by the task related issues like cognitive load, physical load and situational awareness. Finally, to complete the picture, environmental circumstances have their role as well. Among them are: noise, vibration, sustained acceleration, temperature, hypoxia (insufficient oxygen density) and hyperbaric (abnormal pressure).

Although fatigue is empirically complex process to quantify and measure a number of metrics have been developed to describe it.

- Physiological measurements

  Various physiological cues can be an indicator of fatigue. The most popular of these is brain wave activity measured via electroencephalograph (EEG). Measurements acquired by EEG can serve to calibrate equipment for other methods related to fatigue and sleep. Another physiological measurement is the multiple sleep latency test (MSLT). Individuals undergoing the test are monitored as they fall asleep in a sleep favorable environment during the day. MSLT charts brain waves, heartbeat and records eye and chin movement, for analyzing quality of sleep and thus the level of fatigue [8]. While accurate, these methods are intrusive, restrictive and hard to apply in a field [7].

- Behavioral measures

  Measurements are collected through a device known as the actigraph. The device attaches as to the wrist and is sensitive to arm movement, the theory being that body movement, and specifically arm movement, is significantly correlated with EEG [7]. This method has been shown to be accurate in certain applications [9] However, the device does not provide fatigue levels to the system in real-time (data must be downloaded) and is limited to applications aimed at subjects with certain wrist activity e.g. soldiers [9]. Users working behind workstations or steering wheels will not benefit from such a device.

- Visual measures

These features are visually observed changes in eye closure, blink rate, face expression, head gaze and posture. According to Federal Highway Administration [10], the most reliable visual measure and the most promising of all measures in detecting drowsiness is PERCLOS (Percentage of Eye Closure). It reflects the percentage of eyelid closure over the pupil over time. Other potentially good indicators are average eye closure speed (AECS) and blink rate. A drowsy person blinks with noticeable lower speed [5]. Furthermore, there are indicators like head movement i.e. nodding and gaze dynamics. In a person with signs of weariness, gaze will stop at areas which are not potential field of interest for an extended period of time [7]. For workstation however, an indicator like gaze is not reliable due to the nature of the performed activity. Gaze is very static when a subject is focused on task at the screen. Due to the lack of intrusiveness, visual cues are very convenient for monitoring fatigue.

- Performance tests

Performance tests are another way that can be conducted to detect fatigue e.g. The Walter Reed Performance Assessment Battery. During these tests the subject performs a number of psychomotor, perceptual and cognitive tasks to evaluate his/her level of alertness. Additionally the outcomes require professional analysis. Although these tests are complex they are also reliable enough to be applied in clinical studies when patients are examined if they are able to drive a vehicle [7]. However, these methods are interruptive, hence not suitable to apply at the workstation.

The above measures have been used in the following systems:

- Readiness-to perform and fitness-for-duty systems

This approach utilizes performance tests to verify that the subject is ready to perform the desired task before duty. A good example is the ART90 system in which the subject undergoes a visual perception test followed by a selective attention test that requires high level of concentration to visual stimuli for over 20 minutes. The subject has to respond to relevant stimuli and reject irrelevant ones. In vigilance test the patient must follow the dot on the screen and react when noticing irregularities in the movement [11]. Although it provides reliable outcomes, this method is not suitable for real time requirements of alertness determination.

- Physiological model based technologies

These methods refer to predicting the level of alertness based on developed mathematical models supported by empirical analysis of sleep patterns of the subject and of the circadian cycle. US Army uses a sleep system, where the soldier wears a wristband that electronically records arm movement which is correlated with rest-activity cycle. This data is forwarded to central analyzing units, where basing on the sleep recuperation model developed, the command is able to estimate the fatigue level of the current soldiers [9].

- Operated system performance technologies

In these methods the data input that comes from human operator is being acquired and analyzed. If the human steering behavior doesn't match standardized pattern of a vigilant operator, the system indicates alarm. For instance Steering Attention Monitor (SAM) [12] reads and monitors micro corrective movements of a driver applied on steering wheel. In case these inputs disappear, the system emits a warning sound.

- On-line operator status monitoring technologies

These real time systems focus on extracting behavioral and visual cues like eye movement, head movement, facial expression, brain waves, heart rate etc. So they include the intrusive methods like EEG as well as non intrusive like PERCLOS [13].

1.3 Proposed solution

This work focuses on providing a solution that detects and monitors vigilance of the operator working behind the workstation. It consists only of a low budget web cam and infrared illuminators (unlike expensive lab equipment it doesn't require high cost components). As this system is designed to be incorporated into a workstation and to use its computation power, the stress has been on techniques that are effective but not computationally expensive. The most reliable visual cue [10] PERCLOS is used as a metric to determine the degree of fatigue of the working operator. With the aid of active near infrared illumination and near infrared sensitive camera system uses natural feature of retina i.e. strong reflection of light in such range to localize eye pupils and hence to apply processing to determine the percentage of eyelid droop over the eye. The system records fatigue related data in a not intrusive and convenient way so the user does not percept it as negative or destructing. This data can be analyzed to better schedule individuals on duty or to investigate mistakes.

1.4 Organization of Thesis

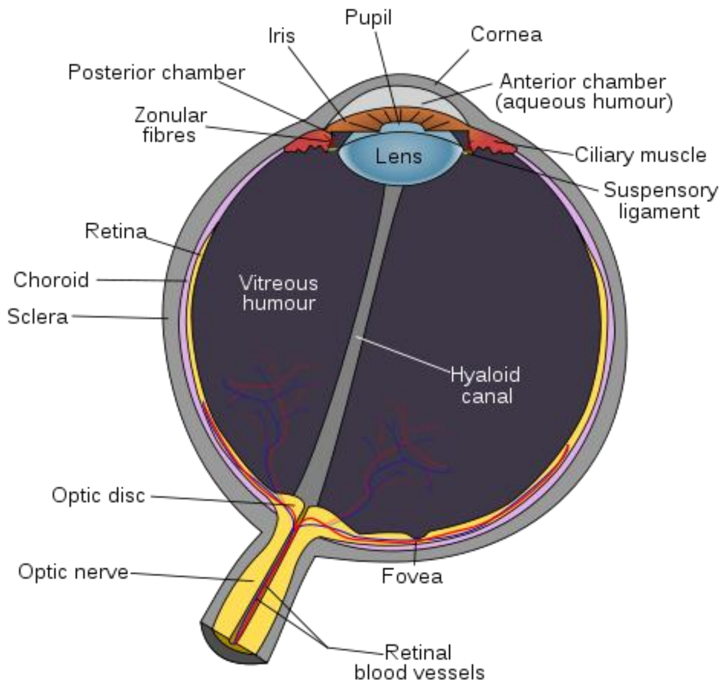
The thesis is organized as follows: Chapter 2 focuses on basics of fatigue detection using the image processing and on what has already been done in the field. Chapter 3 describes hardware configuration, system specification and limitations. Chapter 4 provides information about the experimentation conducted in lab. The work is summarized in the conclusion chapter.

Chapter 2

Image Processing in Fatigue Detection

2.1 Trends in Research

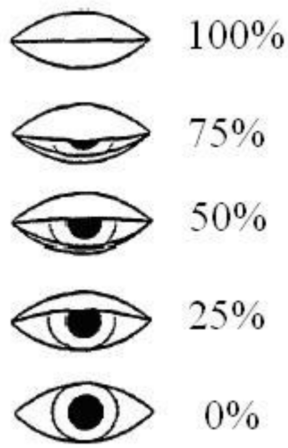
During last decade many efforts [14] [15] [16] [13] has been made to accurately determined operator's state of vigilance. Especially image processing become a very useful tool for extracting relevant data cues in behaviorally-visual methods of determining subjects fatigue. Most of the research was focused on obtaining data concerning eye futures like Percentage of Eye Closure (PERCLOS), Average Eye Closure Speed (AECS), blink rate, gaze, and face features like facial expression and yawing as well as posture changes e.g. head nodding. Recently two trends have been observed. First is to process visual data taken in its natural light [14] [15], second is to support scene light with active near infrared illumination [16] [13]. The advantage of the first is that no extra equipment other than camera is required; however utilized procedures and algorithms must be advanced enough to extract needed features only as effect of a software concept. Additionally, more complicated algorithms require more computation power and, hence, better and more expensive processing unit. On the other hand, in applications where this extra hardware (in meaning of an illuminator) is accepted, there is an extra profit of an independent and very supportive for the scene processing IR light. The light rays come through pupil (see Fig.1), reflection of this light from the retina, visible in imaged by IR camera eye pupils is very useful for eyes localization. In effect, the algorithms are simpler and computation power required for system to work is lower.



Reference picture helpful when speaking about eye physiology [17].

Figure 1. Schematic diagram of the human eye

PERCLOS parameter metric was established in 1994 as a drowsiness factor. By FHWA (Federal Highway Administration) and NHTSA (National Highway Traffic Safety Administration) it has been considered as a most effective metric of driver's fatigue [18]. It is a percentage of eyelid closure (Fig.2) over the pupil over the time and reflects slow eyelid closures ("droops"). Due to the fact that eye behavior varies between individuals different variations of PERCLOS parameter are allowed in research. The most frequently referred is P80 [19] [20] [21], the proportion of time in a minute that the eyes are at least 80% closed. Other values are also used e.g. P70 [18].



Percentage of Eye Closure [22], a value necessary for determining PERCLOS - one of the most effective visual parameter in detecting fatigue.

Figure 2. Percentage of Eye Closure

2.2 Survey on previous works: non active illumination approach

Young Du et al. [14] proposes in his work the system based on color analysis and crystallization. He uses interframe difference and YCbCr color space to localize movement and skin area based on mixed skin color model. Then by employing thermodynamic principle of minimum energy, Boltzmann theory and Metropolis rule, he finds areas of similarity to distinguish eye areas from rest of the face. Because during fatigue, eyes areas create narrower zones the ratios of these zones are used to signify a level of fatigue.

Paul Smith et al. [15] proposed the method that uses a single camera to detect and monitor head and eyes motion, eye blinking and also 3D gaze. Using color and region features, the corners of lips are located, based on skin color the face is defected and then after locating the eyes edges the eyes position is estimated. Detected features are used to create a 3D model that can be used to track head movement and hence distinguish if the eye occlusion is due to head rotation or blinking. The model can also provide information about gaze of the subject.

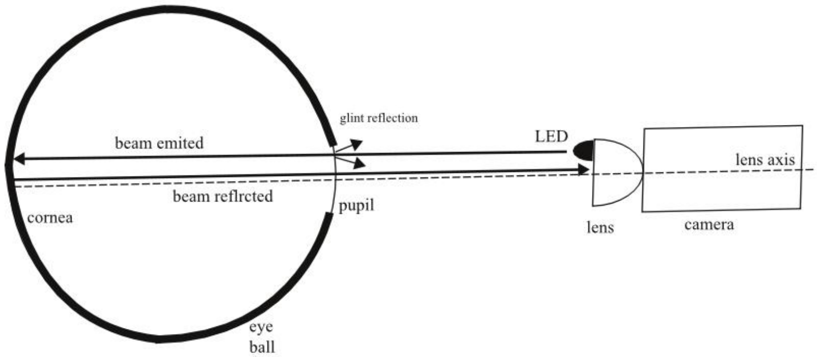
2.3 Basis of eye detection using active illumination

The concept of using active infrared illumination to detect the eye pupils was proposed as early as in 1993 by Y. Ebisawa [23].The process combines two important phenomena that take place when human eye is treated by near-infrared light source: the bright eye and the dark eye. The bright eye happens when eye is illuminated by near-infrared light source coaxial with the camera (Fig. 3, Fig. 5). The light comes through the pupil and after being reflected off the retina goes back through the pupil to reach the IR sensitive camera. Little portion of light is also reflected from the corneal surface and is called the glint. The dark eye effect (Fig. 4, Fig. 6) takes place when the light source is uncoaxial with the camera. In this situation eye pupil remains dark and the only light reflection is from the cornea mentioned earlier as glint. Provided that the two images are recorded at almost the same time, pupils' reflection is the only difference between them. Hence, if these two images are subtracted, the differential image will be zero with the only exclusion on pupil location areas (Fig. 7).

Other benefits of using in-axis and off-axis illumination:

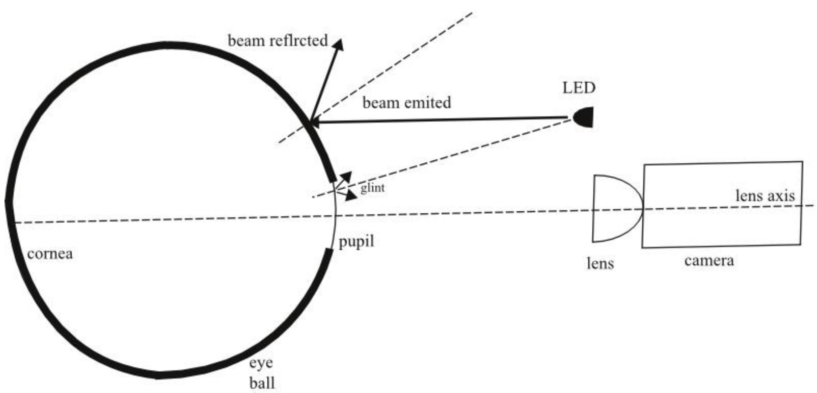
- Having an independent light source relieves the concern if ambient illumination is enough to lit the scene for processing e.g. in dark room conditions.
- Alleviate the problem of unwanted, processing complicating ambient light e.g. strong side sunlight: Although sunlight carries strong infrared light, this light is common for both situation coaxial and uncoaxial illumination and will disappear after subtracting.
- Since intensity becomes the dominating determinant, images can be processed in grayscale.

- Near-infrared illumination is invisible for the subject, hence is not disturbing.



Light beam emitted by LED after reflection from retina returns to be registered by camera.

Figure 3. Bright eye effect - Illumination with coaxial light



Due to position of LED placed off the lens axis reflected beam is not registered by camera.

Figure 4. Dark eye effect - Illumination with uncoaxial light

Figure 5. Bright eye effect

Figure 6. Dark eye effect

Figure 7. Differential Image

2.4 Survey on previous works: active illumination approach

Luis Bargasa et al. proposed a system [16] that uses active illumination and in real time monitors six parameters related to fatigue: Percentage of Eye Closure (PERCLOS), eye closure duration, blink frequency, nodding frequency, face position and fixed gaze. The position of eyes is detected by using active illumination system. A dedicated hardware is responsible to provide synchronized bright and dark eye images. To determined the PERCLOS parameter ellipses are fitted in eyes regions. Changes of PERCLOS in time are used to derive other important features like closure duration and blink rate. To obtain robust synthesis of different cues and cooperation between different stages of algorithm Final State Machine (FSM) is employed. It controls different dynamic situations of eye opening and closing to determine what current eye status is and in the case of eye movement whether to remain in eye tracking mode or move to eye detection stage. To detect nodding and face position, a 3D model is developed based on eye pupils and nostrils. In this case nostrils are detectable as dark areas surrounded by not so dark skin pixels. To detect gaze features, system uses the propriety that vigilant operator in order to pay attention to situation changes moves his gaze, thus, eyes unpredictably which causes the difference between the estimated and real position. As the fatigue grow gaze changes become less dynamic hence more predictable so the difference decreases.

Qiang Ji et al. [13] developed a system with two cameras: one wide-angle acquiring the scene, second focused on anticipated eyes region; this system uses multiple techniques that complement each other to achieve more robust fatigue prediction. It not only uses active near-infrared illumination to localize pupils using subtracting images but also combines this technique with applying Support Vector Machine (SVM) on dark eye images where due to unique intensity distribution of eye objects they can be found independently. To increase detection precision system joins both processes. Dedicated video decoder provides bright and dark eye images as even and odd frame sequences. To achieve better eye tracking system combines Kalman filter with mean shift tracker. Since the second camera is focused on eye region, it provides very precise hi-resolution data so that the parameters like PERCLOS or AECS are obtained from the shape of bright pupil. When eye is more occluded, pupil resembles more elliptical shape. For the face pose and thus head orientation estimation a 3D model based on weak perspective projection to a planar object is developed. Then Kalman tracking is used to register head movement in order to determine head nodding. Additionally, the gaze direction is determined depending on the face pose and relation between bright pupil center and glint center. The unique cue that Qiang Ji used as an extra fatigue determination factor is facial expression. Using the wavelet analysis he detects dynamic muscle changes especially in regions around the eyes (where fatigue manifests itself in low dynamics of expression changes) and mouth where yawing can be observed. To model fatigue from that many factors Bayesian network is used which combines extracted visual cues with statically entered data affecting operator such as temperature, humidity and noise which also contribute to level of fatigue.

2.5 Distinctiveness of this work

This work is focused on key that provides good balance between precision of fatigue detection, computation power needed, cost of the equipment and its complexity. Chosen solution is one of the most effective in the field. System uses active illumination as a method of eyes detection and PERCLOS as parameters for fatigue estimation. Nevertheless, there are a number of exclusive features which differentiate this work from others proposed in the field: To register image, system uses ultra low cost web camera and illuminator. The camera is adjusted to eliminate almost all visible light spectrum due to attached unique IR passing, visible band rejecting filter made of not exposed but developed photographic film. There is no dedicated hardware needed to synchronize dark/bright eye subtraction pairs. Applied algorithm is adjusted to consume minimum computation power. Experimentation phase was profiled to provide best parameter settings for executive workstation requirements.

Chapter 3

The intention of this chapter is to present how the concept of this work has come to life. It starts on statements and goals and passing through assumptions, specifications, limitations and hardware, ends up on system software algorithm details.

3.1 Purpose and goals

The goal of this work is to face a challenge to develop a human fatigue monitoring system that will detect the condition of a subject operating on a workstation. The system designed is relatively low power so it can draw energy from the workstation peripheral ports without extra power adapter. It does not absorb workstation computational resources. Mutual cost of the equipment is small so the system can be used not only in high cost and significance control centers but also on corporative, middle and low level office workstations. It can register subject vigilance record, evidence "black box" pre-event data for investigation, and support operator's performance registration for effective scheduling. In order to not have a negative interaction with the subject a solution developed uses non-intrusive method of extracting relevant cues for image processing. To satisfy the low cost, low power and low computation need criteria, concept is focused on extracting the PERCLOS factor data with the aid of active IR illumination and IR sensitive camera.

3.2 Assumptions

In order to meet goals and at the same time to come up with the real working solution some important assumptions have been made. Basically, theoretical workstation was situated as a PC computer station in office/lab environment. As a registering camera, a low cost web cam was used, after being modified to work in near IR range. An active illuminator consisted of two sets of near-IR LEDs to create two type of illumination, coaxial and uncoaxial. To support the work of the prototype hardware, provide the flexible adjustment and observability of its parameters, and allow quick modifications, laboratory equipment in forms of generator, multimeters, power supplies and oscilloscope have been used.

3.3 Hardware

3.3.1 Camera

The model used is a generic brand web camera (Fig. 9) that has the following specification. CMOS sensor consists of 350.000 Pixels; recording is up to 640 x 480 pixels; Camera uses USB port to connect to PC and has a manual focus ring.

Web cam used for image registration. Although there are already built in diodes, they don't meet requirements and were disconnected.

Figure 8. Web Cam (retailer picture)

3.3.2 Camera modifications

Majority of the web cams on consumer market are built to serve well in video internet communication in home/office environment. In such situation, these devices are optimized to reflect natural lighting condition, either daylight or artificial illumination. Therefore, the used camera had to be modified such that instead of visible light range (Fig. 9) it was tuned to near infrared spectrum.

In step one, the IR blocking filter was removed from the CMOS sensor. Because CMOS matrix in the sensor is sensitive for radiation energy from the spectrum much wider the visible light range manufacturers narrow it using filters to achieve narrower band that needs t be processed.

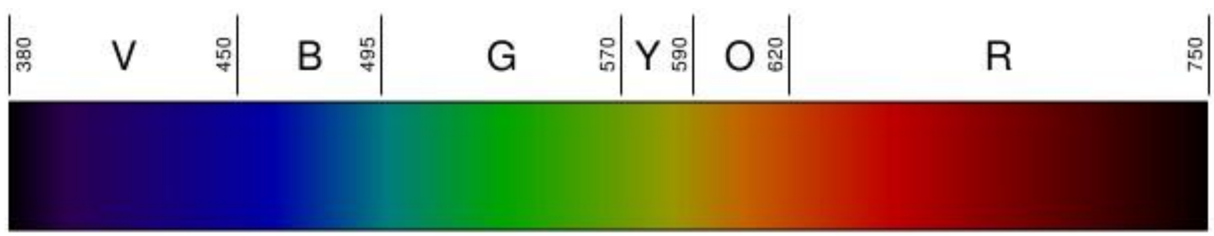


Figure 9. Visible light spectrum.

Visible light spectrum [24]. Visible red is located under 750nm. However CMOS sensor can detect radiation also above this barrier. Near infrared illumination operates around 900nm. Illuminator used in this system emits 880nm light.

Next figure set (Fig. 10, Fig. 11) is a comparison of web cams with and without IR blocking filter. Images are of the same subject, in the same room, under the same natural lighting condition. Difference in exposure settings can be neglected. Significant difference in sensor color perception can be noticed. Image with IR present looks more washed out.


Figure 10. Image from normal Web Cam

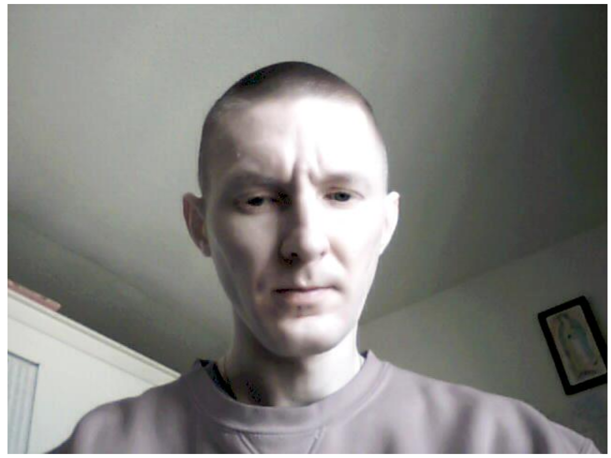


Figure 11. Image from Web Cam with removed IR blocker

In step two of camera modification an additional visible light blocking filter was added. In order to tune camera and illuminator, and profile camera sensitivity towards near IR range, and also away from visible range, thus the whole system could be more independent from environmental conditions, an extra visible light blocking filter was mounted on camera lens. The filter was prepared out of not exposed, developed photographic film, shaped to match the lens dimensions and glued. On the image set below (Fig. 12, Fig. 13) the difference between camera without and with visible light blocker is presented. The content of near IR radiation in daylight illumination is strong enough to light the scene

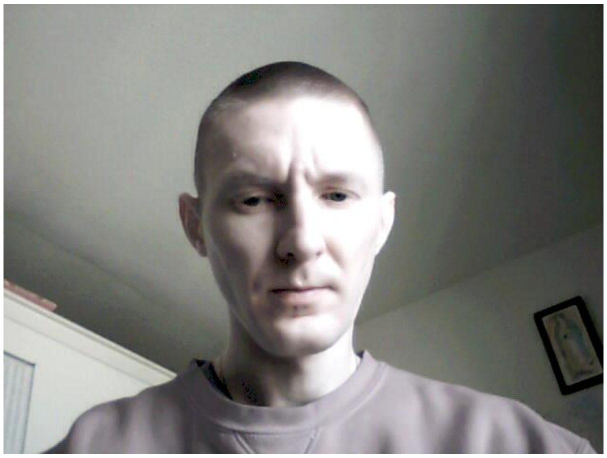


Figure 12. Web cam without IR blocker and <u>without</u> visible light blocker

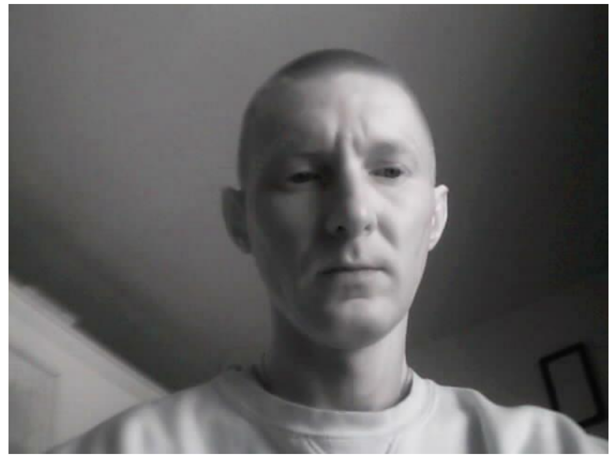


Figure 13. Web cam with no IR blocker and <u>with</u> visible light blocker

Camera Limitations

Inexpensive web cameras are able to register a scene with a speed of 15-20 frames per second (fps) in daylight. When illumination intensity decreases, in order for the CMOS sensor to be exposed correctly frame speed decreases as well. To correctly expose the camera used in this work that operates in near IR range, sufficient amount of light needs to be provided by IR illuminator. Under these high requirements of light intensity, used illuminator works in maximum of its emission capability. Also, a need of intensive light creates a need to provide relatively high current to diodes. This causes inertion and limits switching speed capability (more about illuminator in the next section). Due to above, recording speed was set to 8 fps (frames per second). What needs to be mentioned here is that this recording speed might slightly vary. It is caused by the fact that when the amount of light is not sufficient to expose CMOS sensor correctly in certain amount of time, camera fills frames with the same data so some of them are repeated. Moreover, the camera manufacturer driver doesn't let the settings to be overwritten manually to some fixed values. Therefore, in recorded image stream some dropped or repeated frames need to be expected and hence, provided software solution needs to address this fact.

3.3.3 Illuminator

In built prototype as the illuminator chassis, a cardboard plate was used in which LED sets were mounted. Illuminator consists of two sets of eight diodes emitting 880nm light distributed symmetrically in the same spacing between each other along the circumference of two coplanar concentric rings. The center of each of those rings is aligned to center of the camera optical axis.

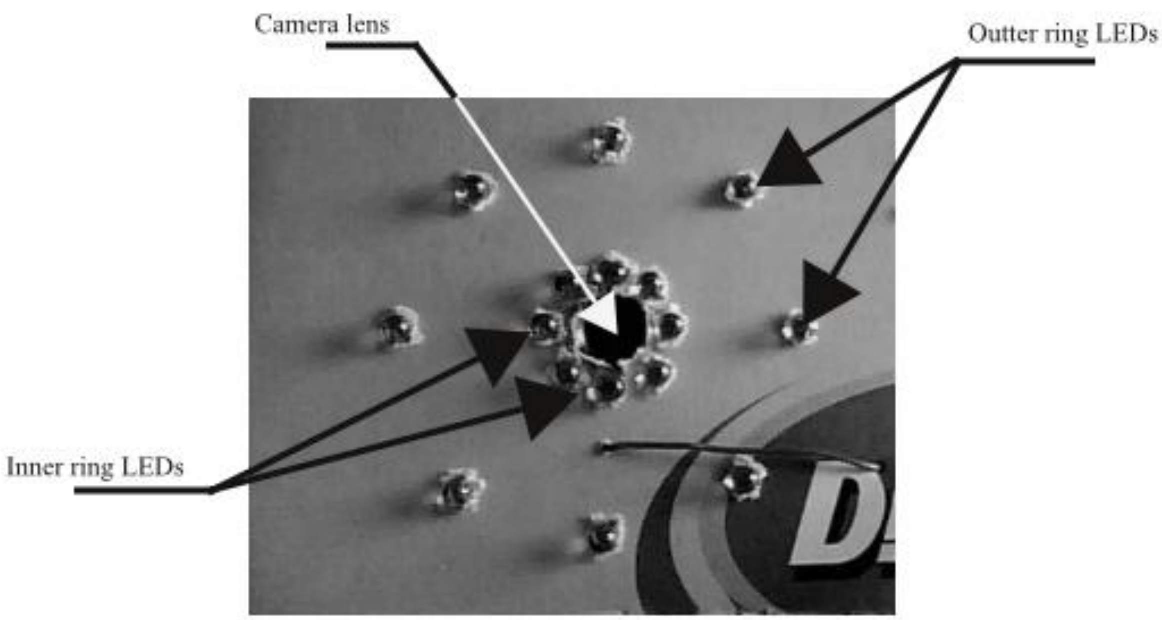


Figure 14. LED illuminator

LED SPECIFICATION: Type: OSRAM SFH 485, Dimensions: 5 mm LED package (T 1 3/4), anode marking: short lead, Forward current: 100 mA, Forward Voltage (100 mA): 1.5 V, Surge current: 2.5 A, Power dissipation: 200 mW, Wavelength at peak emission (100 mA): 880 nm, Spectral bandwidth at 50% of intensity: 80 nm

When the outer ring is on the dark eye effect is created when the inner ring is on the bright eye effect is produced. Switching stimulating signal is provided from waveform generator and after splitting it into two inverted waves, is applied on transistor keys that steer the LED sets (Fig. 15).

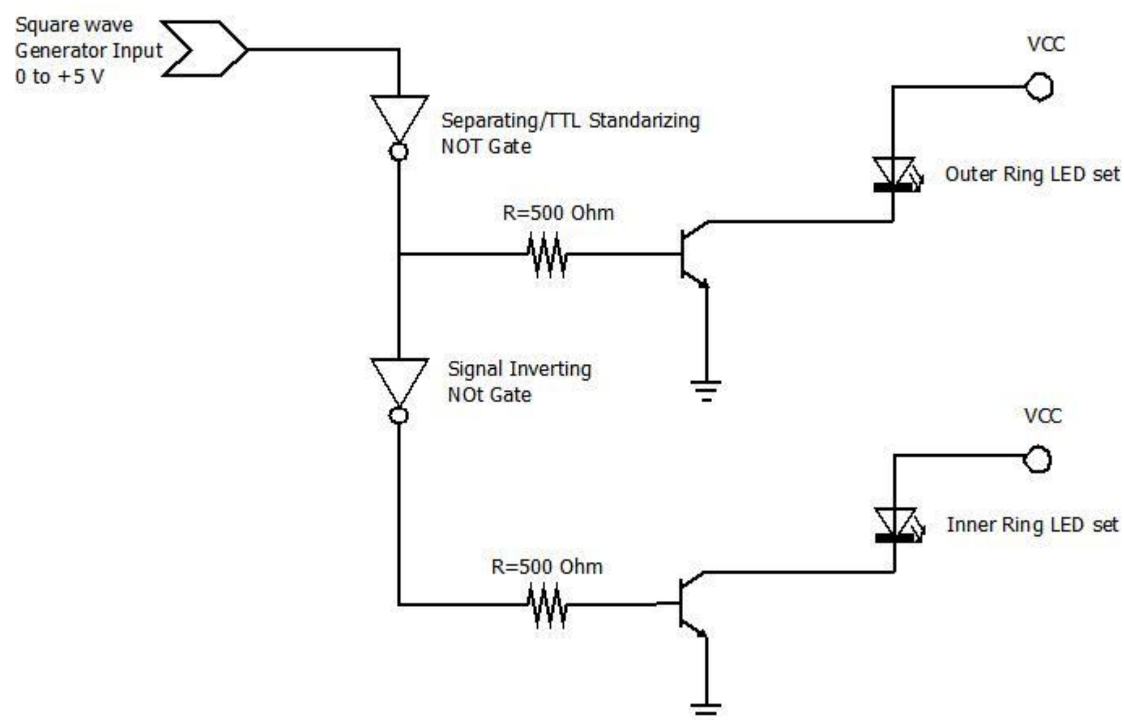


Figure 15. Inner/Outer ring switching circuit

Illuminator limitations

Due to high requirements for the illuminator to provide sufficient light for system to operate, there is some negative impact on illuminator switching speed. There are two bottle necks in the illuminator: transistor key's maximum current and diode's exciting and extinguishing time. Silicon NPN transistor type 2N2222, which is used for the project, has maximum collector current of 800mA. In order to provide decent illumination, VCC source is set to 5-6 V DC. Assuming a 1.5 V voltage drop across LEDs and a few ohms of VCC internal resistance we can expect that the transistor is working on its maximum limits. Additionally, during lab tests, an inertion to higher flashing speeds of diodes was observed. LEDs needed relatively long time to turn off completely after being excited with high current. In consequence of above, after series of experiments, initial stimulating square wave frequency from the generator was set to 2 Hz, which in turn transforms to 4 inner/outer ring blink transitions and gives 3 on/off eye detection pairs per second (blink1 & blink2, blink2 & blink3, blink3 & blink4). This illumination switching speed tunes with the recording 8 fps speed and creating complimentary frame pairs (frame2 & frame3, frame4 & frame5, frame6 & frame7 etc.) (Fig. 16). Considering the fact that the fatigue increasing process is rather a process of minutes not seconds this sampling speed should be sufficient to determine changes in PERCLOS parameter.

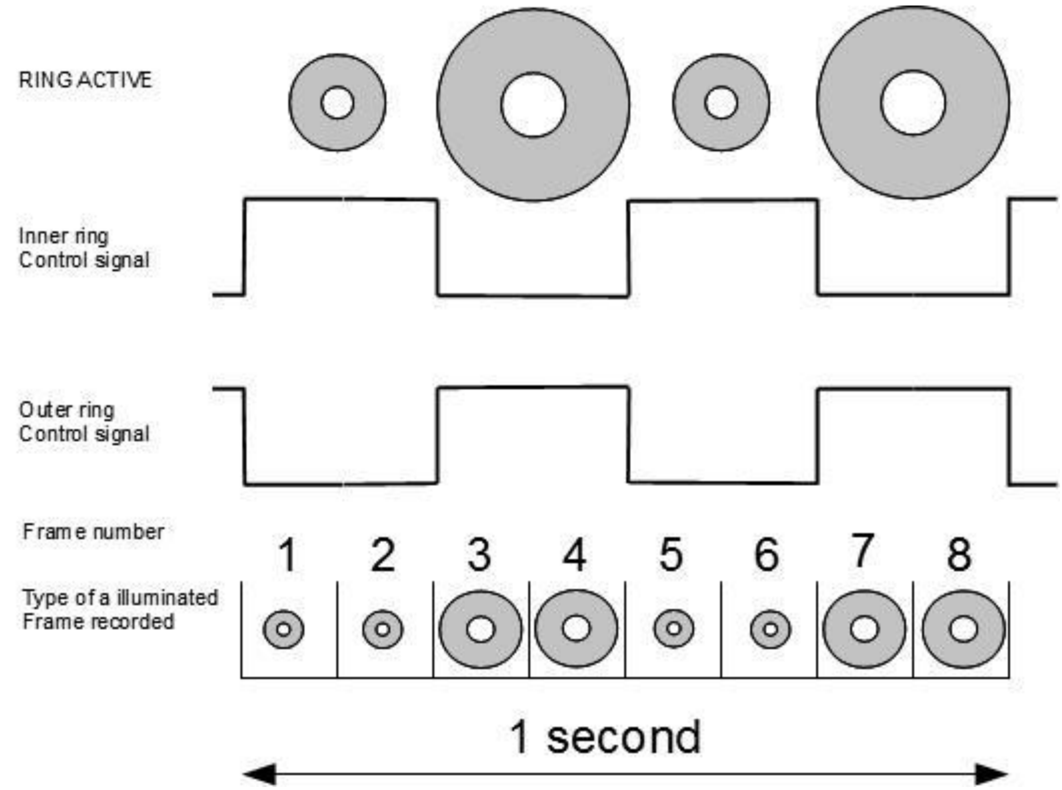


Figure 16. Switching illuminator rings time diagram

3.4 Software

3.4.1 Two phases system

The software concept of the system is based on two major phases (Fig.17). This division is a consequence of assumptions made at the beginning. Due to low cost and simplicity of the used hardware the problem of correct performing the procedure of eye detection based on dark/bright eye phenomenon arises. In order to conduct it correctly, a pair of dark/bright eye images needs to be provided. Thus the most obvious but technically not the easiest solution would be to establish a communication channel between the illuminator and camera frame registration so that each frame can be marked (synchronized) according to the state of illuminator. Coaxially illuminated frames would easily be distinguished from uncoaxial ones and selecting the right pair would not be a problem. This kind of solution was employed by Qiang Ji [13] in a form of synchronizing illuminator with even and odd frames of video decoder. In the work presented in this thesis, in order to achieve harmonious cooperation, illuminator flashing frequency and recording frame rate are adjusted separately, and synchronization is resolved by software. Additionally, the precise frame rate of the camera is not fully configurable due to inaccessible and non-adjustable device driver, which may drop or repeat frames to achieve best exposition of low quality CMOS sensor.

To overcome this lack of synchronization but still be able to use dark/bright eye method, a software technique of distinguishing images was developed and incorporated in phase I of the algorithm. Moreover, to eliminate a need of detecting eyes continuously, after their successful localization in phase I, phase II based on tracking was proposed. In phase II, inner ring is off and outer ring serves as static illuminator. Important advantage of this phase is that it doesn't need collaboration between inner and outer rings so the limitations of illuminator switching process are alleviated.

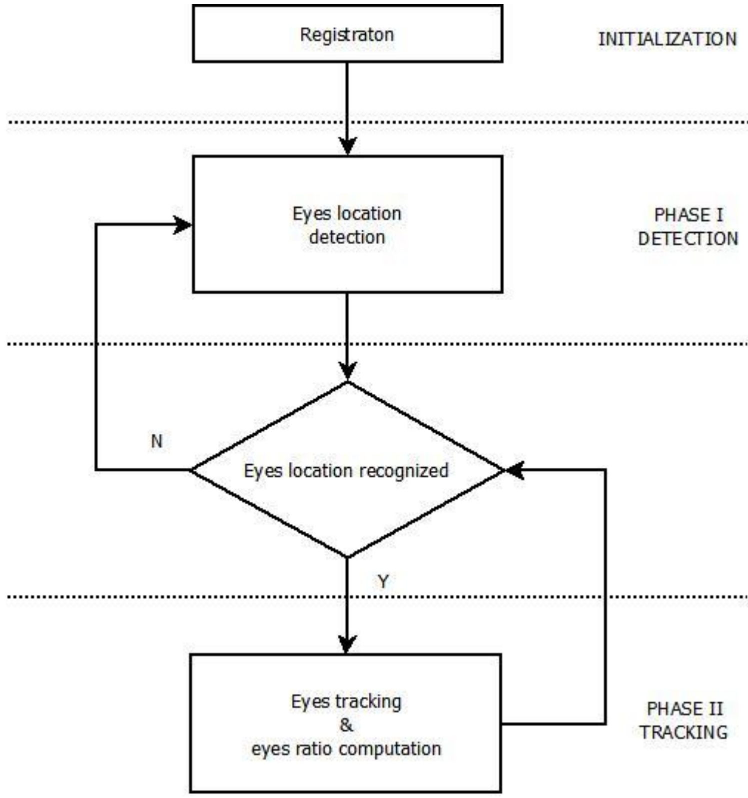


Figure 17. General software concept flowchart

After initialization which is basically taking a place in the front of the workstation and starting the process we go to the first phase called detection. This part is responsible for determining the location of subject's eyes and, speaking more precisely, coordinates (x1, y1, x2, y2) of subject's pupil centers. Second phase is called tracking and is responsible for maintaining valid pupil centers coordinates. In this phase knowing the eyes location, eye-openness ratio (r) parameter is calculated. Whole software process continuously verifies the presence of eyes and accordingly activates suitable phase. Relation between PERCLOS percentage variation and 'r' is the following:

$$P\% = (1-r)*100\%$$

Equation 1. PERCLOSE percentage factor with refer to 'r'

For example PERCLOS in P80 variation would be the friction of the minute that ‘r’ is smaller than 0.2.

3.4.2. Algorithm internal procedures

In order to present the major system algorithm in details at the following part of the chapter, first some crucial procedures that are responsible for certain tasks need to be explained. The first procedure called “ncentra.m” is responsible for finding eye centers coordinates from dark and bright eye images provided. Second is called “nratios.m” and is responsible for calculating eye-openness ratio on provided grayscale image.

Function “ncentra.m”

For better clarification of this procedure, the initial statement needs to be made that “ncentra.m” is not responsible for determining whether the pair of images, provided to be processed, is indeed the complimentary dark/bright eye pair. This is done in the main algorithm. When data comes to be processed in “ncentra.m”, it is assumed that it is suitable of processing.

On the flow chart below (Fig. 18) all the major steps of the procedure are shown. Function input data are two complimentary images and the level of threshold that their difference is subjected to. Function output are coordinates (x,y) of detected eye centers and number of detected centers (0,1 or 2) (Fig. 19).

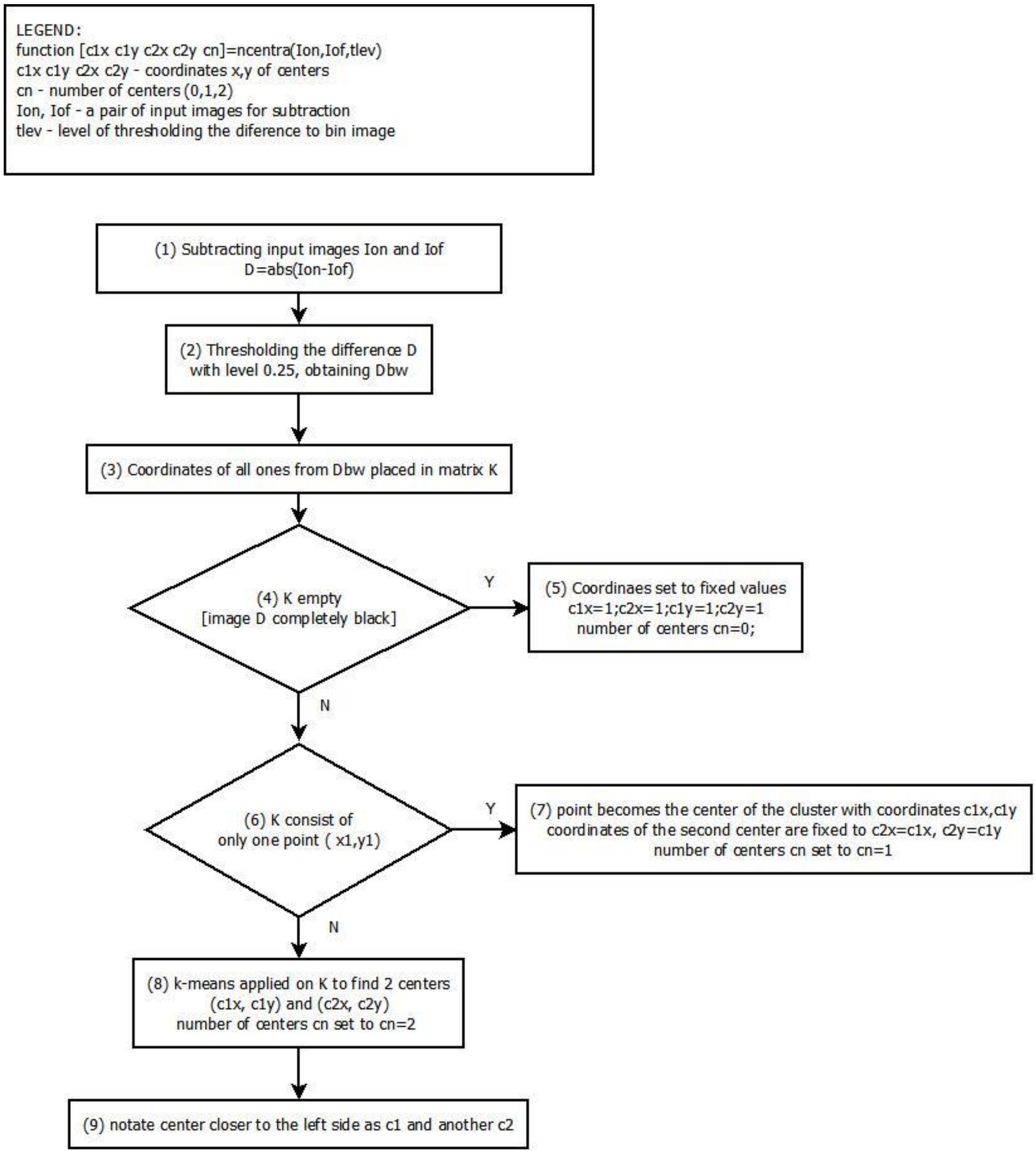


Figure 18. Flow chart of the ncentra.m function


Bright eye image 'Ion'


Dark eye image 'Iof'


(1) Differential image 'D'


(2)Thresholded image 'Dbw'

Function output c1x=155 c1y=89 c2x=238 c2y=88 cn=2

Figure 19. Illustration of certain stages of function ncentra.m

Function "nratios.m"

This procedure is an internal part of the whole algorithm and works in interaction with the data that comes along as the operation advances. To clarify the way it works some assumptions need to be made. They are the following: image with the subject is provided (Iof), coordinates of eyes centers are provided (c1x, c1y, c2x, c2y). The product of the procedure is the average eye-openness ratio (r) of the subject. Additionally, as an extra verification parameter, the function provides values vh1, vh2 indicating how many anticipated eye pixels are present on eye's vertical symmetry axes. This parameter helps to infer of an eye-like object occurrence (more details in Chapter 4).

Fig. 20 presents the "nratios.m" function chart flow and Fig. 21 some of the inter-process products. In the step one crop out the eye out of input image (Iof). Purpose of steps 2-5 is to provide a binary representation resembling the shape of eye iris. The final representation is the white object on black background. Step 6 verifies whether there are any white pixels in the center vertical axis of the image within the certain amount. When the eye is present, it appears as a white symmetric blob in the center of the image, but if it is not then the white areas are irregular and not symmetric. This part of the function was developed as an extra feature and is not the major verification of eye presence. More about verification is mention in the main algorithm section. In step 7, pixel width and height of the iris is counted to provide data for ratio (r). As mentioned, an eye is represented by regular white blob on black plane clearly separated from image edges. In case the white object has a contact with one of the edges it is considered as non-eye object which is verified in steps 8, 9, 10, 11. Step 12 is valid when one of the objects touches edges and one doesn't. This situation is considered as one eye processing. Steps 13 and 14 apply a linear correction for vertical and horizontal iris dimension. These adjustments were introduced to the process after ground data analysis. They improve computation outcome by adding linearly approximated corrections. Finally in the step 15 the average ratio of both eyes is calculated.

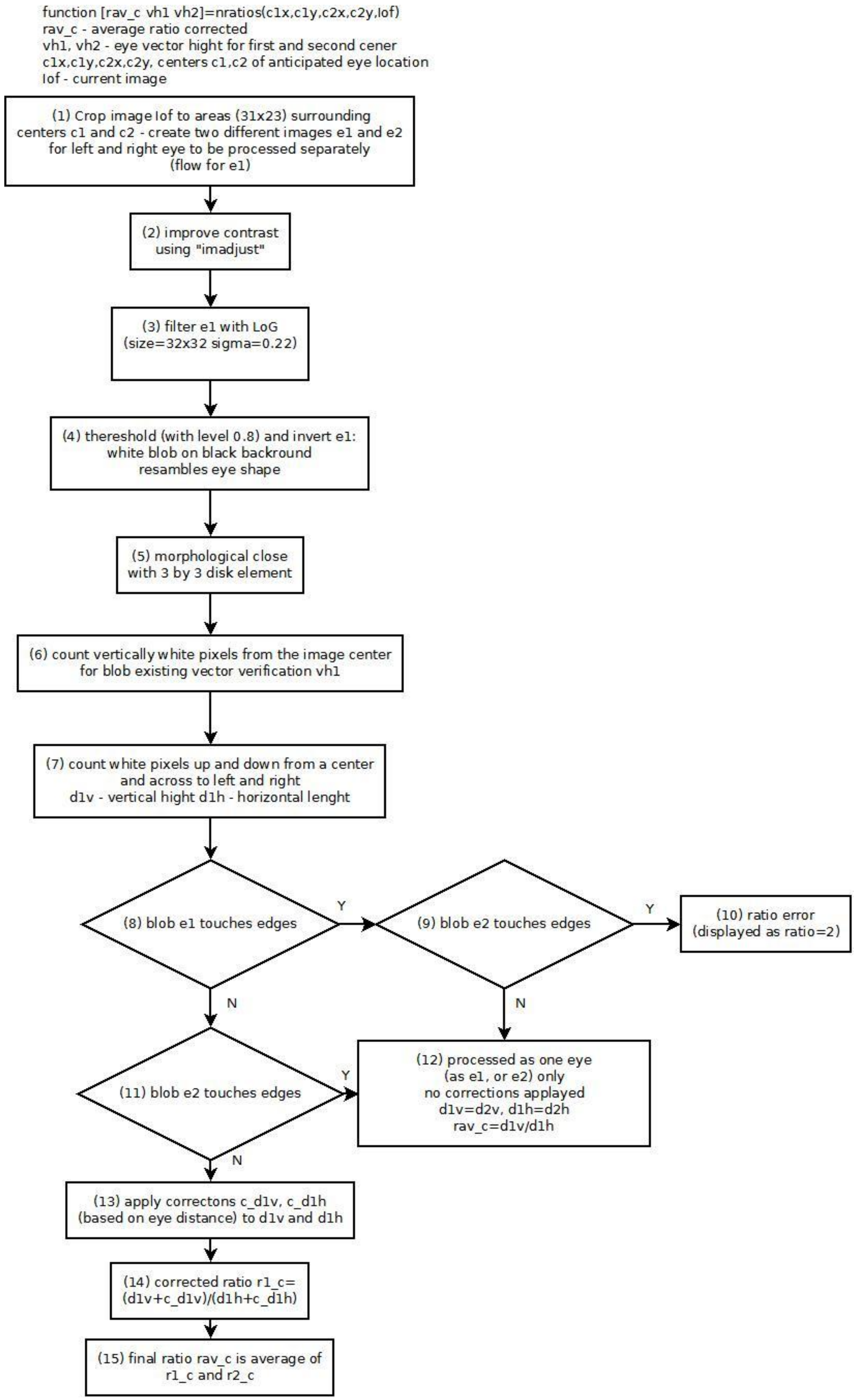


Figure 20. Flowchart of nratios.m function

In the table below, some intermediate products of the ‘nratios.m’ can be observed.

Initial image (Iof)

(1) Cropped eye

(2) Improved contrast

(3) Filtered with LoG

(4) Thresholded and inverted

(5) After morphological opening

Figure 21. Internal products of nratios.m function

3.4.3 Main program

Main algorithm (Fig. 22) consists of two parts: part responsible for detection that is activated in the beginning of the process as a phase I (and every time the eyes are lost) and part responsible for tracking eyes, activated as phase II after eyes are detected. The variable that determines which phase must be activated is kb (kb=1 is detecting, kb=0 is tracking) present at the beginning and in block 3, 6, 7, 13. In order to determine if the pair of images is good for detection process i.e. if it includes bright and dark eye images, blocks 1, 2, 3 perform subtraction of current pair and compare the maximum of the difference. Only complimentary images will produce a difference high enough to pass the criteria. In step 4, function "ncentra.m" (described earlier) determines position of eye centers. The process, after verification that two centers are present (Step 5), advances through blocks 5 and 6 to tracking phase. Once eyes are localized, location of their centers is maintained by tracking mechanism. The tracking window sets area of interest in vicinity of each eye (step 9) then a point of the lowest intensity is determined within this area (step 10). This point coincides with the center of eye's pupil. Through experiments the range of pupil intensity was determined in a certain range and it is verified in block 10. Step 14 updates the tracking information and step 15 is calculates the ratio (r) using "nratios.m" function to register it in block 17. If the tracked object does not meet the criteria (block 10) or if anticipated object is non eye-like (ratio > 0.85 or ratio=2, see block 10 in nratios.m) which is verified in Step 16, bad frame counter is activated. According to Scott LaFe [25], the average blinking time is 300-400 ms. So in order for the blinking not to affect tracking process, with 8 fps recording speed, eye is considered to be lost if the number of bad frames is greater than 3 (Block 11 and 12). Then kb is set to 1 (block 13) and system goes to phase I to start detection process from the beginning.

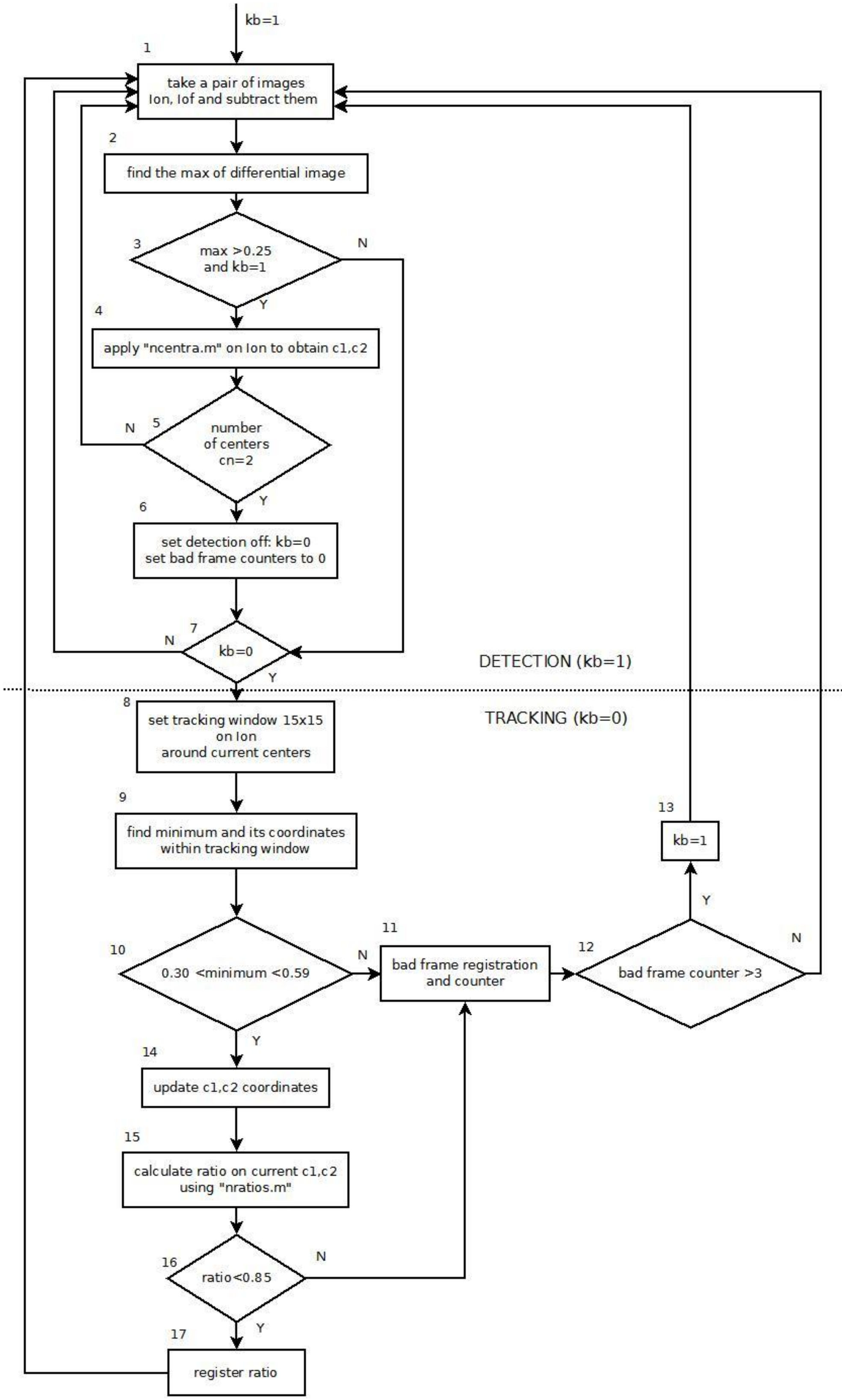


Figure 22. Main program flow chart

Chapter 4

4.1 Station and environment

To perform the lab experiments on assembled equipment a simulated workstation has been created.

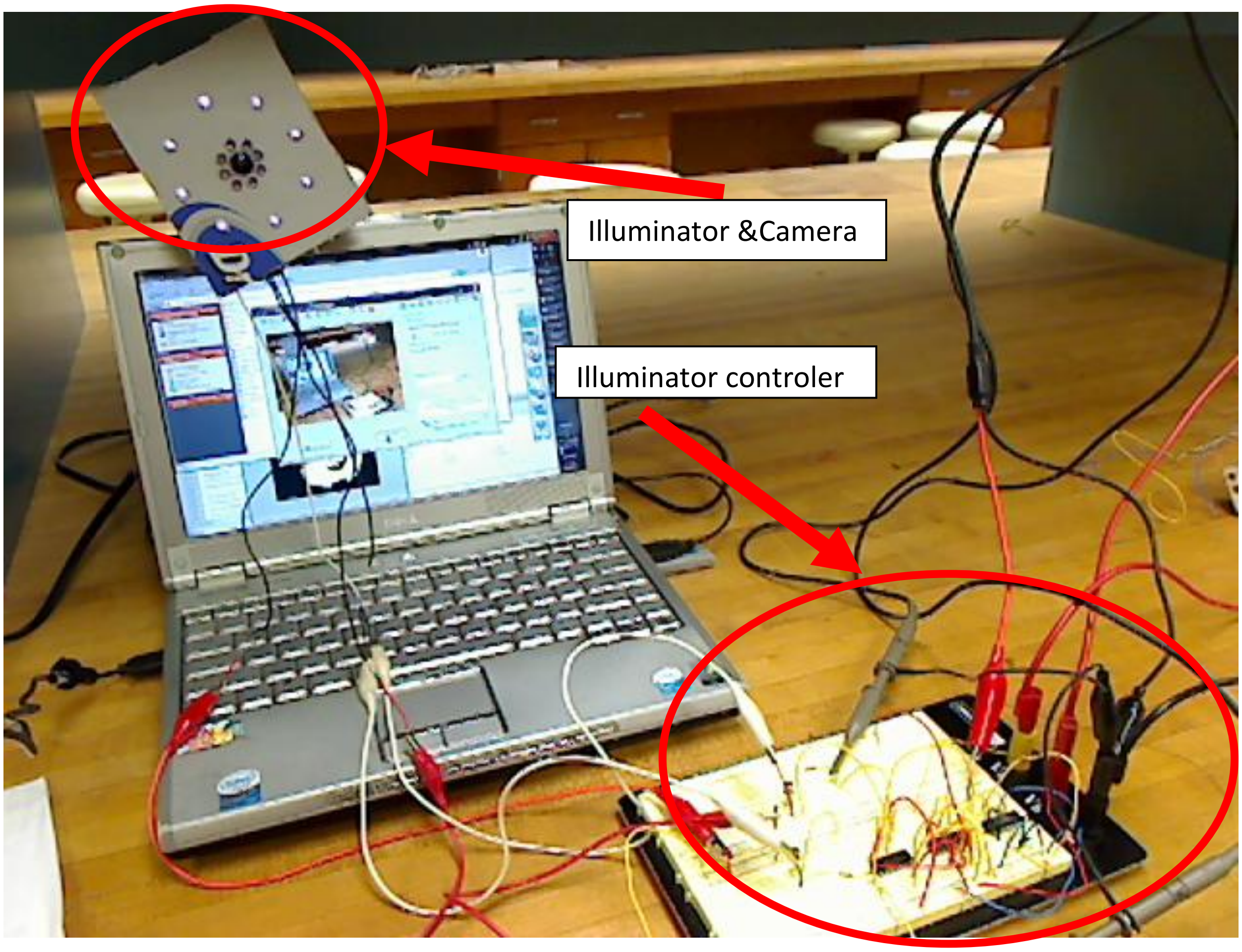


Figure 23. Experimental workstation

Stimulating signal was provided from function generator and DC power from power supply.

Oscilloscope was used to control frequency and voltage levels in the circuit.

The lighting in lab was mostly fluorescent light with some occasional daylight. On the figure (Fig. 24) below, the difference between regular camera image and IR camera registered on workstation was recorded. It can be seen that only a little portion of IR light is in fluorescent illumination. Most of the lighting on the face comes from the illuminator (Fig. 24b).

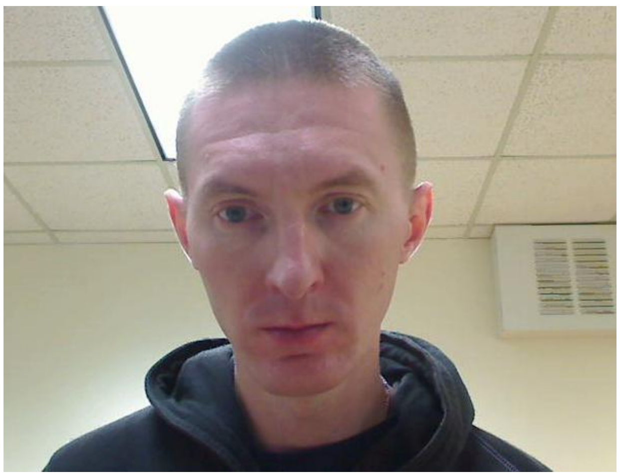


Figure 24a. Lab environment illumination

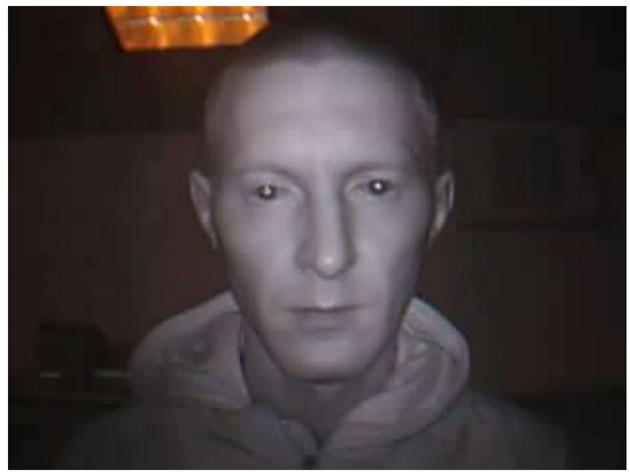
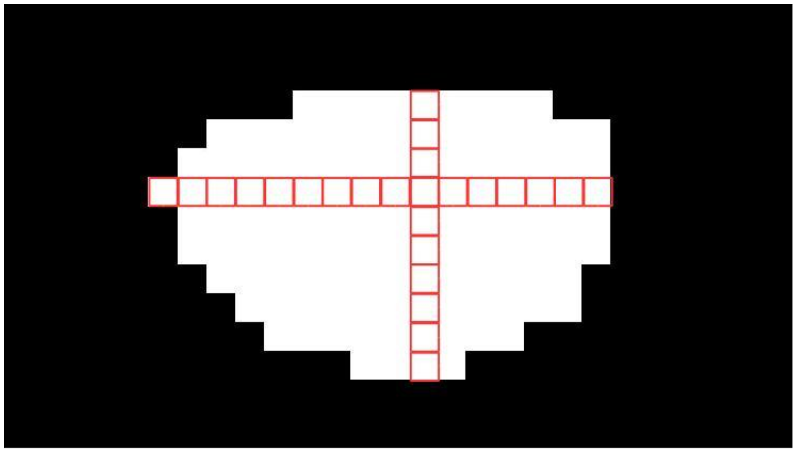


Figure 24b. Lab environment in near IR range

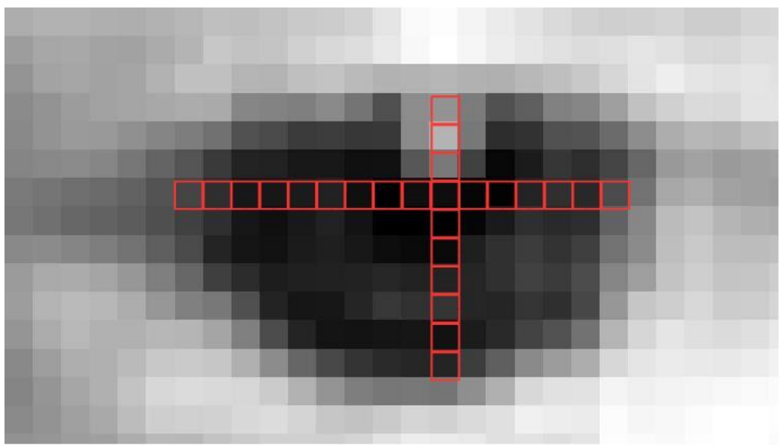
Figure 24. Lab environment in visible and near IR light

4.2 Ratio calculation and corrections

As a compromise between quality and processing speed, the recorded image resolution was set to 320 x 240 pixels. Under these circumstances, the area of interest around the eye was chosen to be 31 x 22 pixels. Considering that eye object should comfortably fit in this region, the average eye dimensions usually does not exceed 16 x 11 pixels. On the following figure (Fig. 25), the process of counting of the eye dimensions can be seen. The two images are presented, the original eye after contrast adjustment and the eye resembling blob on which “nratios.m” function performs calculation of ratio. It can be seen that even for a human eye some of the iris edge pixels might be difficult to be qualified either as belonging to eye or not.



Binarized eye representation



Original eye (contrast improved)

Figure 25. Eye ratio calculations

In the case above, the calculated ratio is dv/dh=0.625 (dv=10, dh=16). It can be easily seen that if one more dimension pixel is classified as eye's e.g. dv=11 then ratio change to 0.688 which is 10% difference. In spite of this it needs to be remembered that the PERCLOS parameter has different variation so appropriate thresholds can be set to ensure correct readings. In case above, both measurements can be classified as vigilant person's eye.

Ratio corrections

In order to observe average deviation of eye ratio calculating algorithm from ground data, two sets (‘a’ and ‘c’) of measurements was conducted. In relatively close time, in the same lighting under the same eye state condition, subject posture and facial expression 13 random images were registered at the same distance of 9 inches from the screen. Right after 12 random images were taken at the distance of 12 inches from the screen (Fig 26).

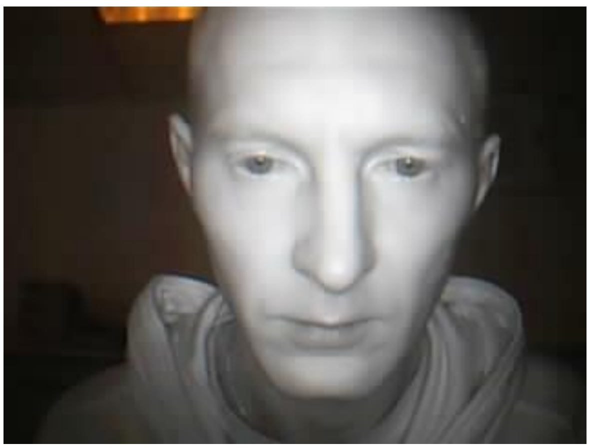


Figure 26a. Average image for set ‘a’

Figure 26b. Average image for set ‘c’

Figure 26. Average images for eye dimensions correction model

Based on this, data a linear model of approximation of dimension correction with respect to distance was developed. Distance from the screen has a direct reference to distance between eye centers. The final correction model linearly approximates correction of eye width and height with respect to distance between eyes. Precise description of terminology used in below table, which due to its size, spreads on two pages (table i and table ii), is placed in table iii.

Table i. Linear approximation of eye dimensions data

			GROUND									ALG				
file	d1v	d1h	r1	d2v	d2h	r2	r_av	eye dist	d1v	d1h	r1	d2v	d2h	r2	r_av	%before
a01	9	13.5	0.6667	9	14	0.643	0.655	78.026	9	13	0.692	9	14	0.6429	0.6676	-1.961
a02	8	12.5	0.64	9	13	0.692	0.666	76.007	8	12	0.667	8	13	0.6154	0.641	3.776
a03	8	13	0.6154	9	13	0.692	0.654	77.104	8	13	0.615	9	13	0.6923	0.6538	0.0071
a04	9	12.5	0.72	10.5	14	0.75	0.735	77.026	9	12	0.75	9	12	0.75	0.75	-2.041
a05	9	13	0.6923	9.5	13.5	0.704	0.698	77.058	9	12	0.75	9	13	0.6923	0.7212	-3.323
a06	8.5	13.5	0.6296	8.5	13	0.654	0.642	74.027	8	13	0.615	8	13	0.6154	0.6154	4.1042
a07	9	13	0.6923	8	13.5	0.593	0.642	78.006	9	13	0.692	8	13	0.6154	0.6538	-1.767
a08	8	13.5	0.5926	10	14	0.714	0.653	82.024	8	13	0.615	9	14	0.6429	0.6291	3.7248
a09	9	13	0.6923	9	14	0.643	0.668	78.026	9	12	0.75	9	14	0.6429	0.6964	-4.317
a10	9	13	0.6923	9	13.5	0.667	0.679	77.026	8	13	0.615	9	13	0.6923	0.6538	3.7804
a11	8	14.5	0.5517	8	15	0.533	0.543	79.006	7	13	0.539	8	14	0.5714	0.5549	-2.28
a12	8	13.5	0.5926	8	14	0.571	0.582	77	8	14	0.571	8	14	0.5714	0.5714	1.8231
a13	8	13.5	0.5926	9	14	0.643	0.618	78	8	13	0.615	9	14	0.6429	0.6291	-1.841
AVG	8.5	13.231		8.962	13.731			77.564	8.3077	12.769		8.615	13.385			-0.024
c01	7	11	0.6364	8	11.5	0.696	0.666	61.033	7	11	0.636	8	12	0.6667	0.6515	2.1783
c02	8	11	0.7273	7.5	11	0.682	0.705	61.008	8	11	0.727	7	11	0.6364	0.6818	3.2284
c03	7.5	11	0.6818	7	11	0.636	0.659	60	8	12	0.667	8	12	0.6667	0.6667	-1.154
c04	6.5	10.5	0.619	7.5	11	0.682	0.65	57.009	7	11	0.636	8	11	0.7273	0.6818	-4.822
c05	7.5	11	0.6818	7	11.5	0.609	0.645	58.078	7	11	0.636	7	12	0.5833	0.6098	5.495
c06	7.5	11.5	0.6522	7	10.5	0.667	0.659	57.035	7	11	0.636	7	11	0.6364	0.6364	3.491
c07	7.5	11	0.6818	8	11	0.727	0.705	59.034	7	12	0.583	8	11	0.7273	0.6553	6.9897
c08	7.5	11	0.6818	7.5	11	0.682	0.682	58.009	7	11	0.636	7	11	0.6364	0.6364	6.6613
c09	7	10.5	0.6667	8	11.5	0.696	0.681	59.009	7	11	0.636	8	12	0.6667	0.6515	4.3543
c10	7	10.5	0.6667	8	11	0.727	0.697	57.009	7	11	0.636	7	11	0.6364	0.6364	8.6904
c11	7	11	0.6364	6.5	10.5	0.619	0.628	57.009	6	11	0.546	7	11	0.6364	0.5909	5.8635
c12	6	10	0.6	7	11	0.636	0.618	57.035	7	11	0.636	7	12	0.5833	0.6098	1.3559
AVG	7.1667	10.833		7.417	11.042			58.439	7.0833	11.167		7.417	11.417			3.5276

Table ii. :Table i Continued

ALG

d1v dif	d1h dif	d1v cor	d1h cor	r1 cor	d2v dif	d2h dif	d2v cor	d2h cor	r2 cor	r_av cor	%after
0	0.5	9.1923	13.462	0.6829	0	0	9.3462	14.346	0.6515	0.6672	-1.894
0	0.5	8.1923	12.462	0.6574	1	0	8.3462	13.346	0.6254	0.6414	3.7184
0	0	8.1923	13.462	0.6086	0	0	9.3462	13.346	0.7003	0.6544	-0.089
0	0.5	9.1923	12.462	0.7377	1.5	2	9.3462	12.346	0.757	0.7473	-1.678
0	1	9.1923	12.462	0.7377	0.5	0.5	9.3462	13.346	0.7003	0.719	-3.004
0.5	0.5	8.1923	13.462	0.6086	0.5	0	8.3462	13.346	0.6254	0.617	3.8602
0	0	9.1923	13.462	0.6829	0	0.5	8.3462	13.346	0.6254	0.6541	-1.815
0	0.5	8.1923	13.462	0.6086	1	0	9.3462	14.346	0.6515	0.63	3.5835
0	1	9.1923	12.462	0.7377	0	0	9.3462	14.346	0.6515	0.6946	-4.042
1	0	8.1923	13.462	0.6086	0	0.5	9.3462	13.346	0.7003	0.6544	3.6877
1	1.5	7.1923	13.462	0.5343	0	1	8.3462	14.346	0.5818	0.558	-2.857
0	-0.5	8.1923	14.462	0.5665	0	0	8.3462	14.346	0.5818	0.5741	1.3541
0	0.5	8.1923	13.462	0.6086	0	0	9.3462	14.346	0.6515	0.63	-1.991
0.1923	0.4615				0.3462	0.3462					-0.09
0	0	7.0833	10.667	0.6641	0	-0.5	8	11.625	0.6882	0.6761	-1.518
0	0	8.0833	10.667	0.7578	0.5	0	7	10.625	0.6588	0.7083	-0.535
-0.5	-1	8.0833	11.667	0.6929	-1	-1	8	11.625	0.6882	0.6905	-4.768
-0.5	-0.5	7.0833	10.667	0.6641	-0.5	0	8	10.625	0.7529	0.7085	-8.928
0.5	0	7.0833	10.667	0.6641	0	-0.5	7	11.625	0.6022	0.6331	1.883
0.5	0.5	7.0833	10.667	0.6641	0	-0.5	7	10.625	0.6588	0.6614	-0.307
0.5	-1	7.0833	11.667	0.6071	0	0	8	10.625	0.7529	0.68	3.4779
0.5	0	7.0833	10.667	0.6641	0.5	0	7	10.625	0.6588	0.6614	2.9884
0	-0.5	7.0833	10.667	0.6641	0	-0.5	8	11.625	0.6882	0.6761	0.7402
0	-0.5	7.0833	10.667	0.6641	1	0	7	10.625	0.6588	0.6614	5.0973
1	0	6.0833	10.667	0.5703	-0.5	-0.5	7	10.625	0.6588	0.6146	2.093
-1	-1	7.0833	10.667	0.6641	0	-1	7	11.625	0.6022	0.6331	-2.414
0.0833	-0.333				0	-0.375					-0.183

Table iii. Legend for Table i

Parameter	Description
GROUND	ground data
ALG	data by algorithm
File	file of current image, a** - close set (9 inches), c** - far set (12 inches)
AVG	average value
d1v	eye 1 vertical dimension
d1h	eye 1 horizontal dimension
r1	eye 1 ratio
d2v	eye 2 vertical dimension
d2h	eye 2 horizontal dimension
r2	eye 2 ratio
r_av	average ratio
eye dist.	distance between eye centers
%before	percentage difference between current ALG ratio value and current GROUND value before applying correction
d1v dif	difference between d1v GROUND and d1v ALG
d1h dif	difference between d1h GROUND and d1h ALG
d1v cor	d1v corrected by applying the average difference between GROUND and ALG
d1h cor	d1h corrected by applying the average difference between GROUND and ALG
r1 cor	eye 1 ratio based on corrected dimensions
d2v dif	difference between d2v GROUND and d2v ALG
d2h dif	difference between d2h GROUND and d2h ALG
d2v cor	d2v corrected by applying the average difference between GROUND and ALG
d2h cor	d2h corrected by applying the average difference between GROUND and ALG
r2 cor	eye 2 ratio based on corrected dimensions
r_av cor	average ratio based on corrected eye 1 and eye 2 ratios
%after	percentage difference between current corrected ALG ratio value and GROUND value

The average corrections for dimensions (AVG) at both distances serve as entry data to linear model (d1v dif, d1h dif, d2v dif, d2h dif; from sets 'a' and 'c'). At the limit points corrections helped to improve ratio percentage error from 4.3 to 4.0 (at 9 inches) and from 8.7 to 5.1 % (at 12 inches).

4.3 Tracking performance

4.3.1 Investigated methods

The process of tracking the eye centers is based on analyzing behavioral and visual features of human eye. Method applied in main algorithm focuses on tracking an object using only one, most effective mechanism, which was selected after investigating several different approaches presented below. All the concepts come from the common idea of tracking minimum intensity point inside the iris. However, they use different methods of verification if the tracked object is indeed an eye center.

Presence of the object in vertical symmetry axes (height vector)

This concept is part of 'nratios.m' procedure and is based on detection of white pixels in investigated image. The eye is assumed to be a white symmetric blob on black background clearly separated from edges. For simplification the method calculates white pixels only in vertical axes of symmetry of the image. If the number of pixels exceeds a certain number, technique classifies the image as eye present. Although very abridged, the idea addresses the nature of this detection, where eye is present most of the time and disappears while blinking or drooping. This method was giving considerable effect but at the end was replaced by more effective one.

Distance between eyes verification

This technique is based on the fact that distance between human eyes is constant. Although, it needs to be mentioned, that through the lens of the camera 3D reality is projected on the plane. When the subject turns the head off of the screen, then the projected to the plane eye distance will change. Therefore, used concept doesn't use the global eye distance as variable but the difference of how it changes between frames. Considering nature of normal head movement, eye distance can change only in the certain limit between two consecutive frames. If the distance value falls outside, it means the tracking points are not eyes. Analyzing the natural head movement recorded with 8 fps, at set distance from the camera, the pupil location change shouldn't exceed 5 pixels. Based on this assumption, tracking was performed considerably well. The only weakness which provided false positives occurred during blinking. Tracked minimum jumped to eyelashes, however, within limited distance change, hence, the frame was registered as good, instead of lost eye one.

Fixed pupil intensity

This method proved to give the best results. Through experiments the limits between which the pupil intensity fits were determined. During monitoring, the minimum of intensity in the eye, which coincide with the pupil center, is tracked. Then it is verified if it matches certain intensity range. This technique withstands the eye blinks and droops. When the eye lid is down the skin and eye lashes are present. Minimum of their intensity doesn't match eye pupil criteria so the non-eye or covered eye frames can be detected.

4.3.2 Method comparison

To present the comparison between above methods in an illustrative way, two lab runs were selected. First (Table iv) consisted of 85 frames, during which the subject rotates head and blinks and second (Table v) consisted of 84 frames with a movement parallel to screen plane and blinks. All the methods satisfied tracking requirements when eyes were opened and they differed only during blinking, hence, only the frames with partially or fully occluded eye are considered here.

Table iv. Tracking comparison - Run 1

Bad frame number	Fixed minimum		Height vector		Distance change
	Left eye	Right eye	Left eye	Right eye	
*1602	1	0	0	0	0
**1603	1	1	1	1	1
*1604	1	0	0	0	0
**1619	1	1	1	1	1
**1636	1	1	1	1	1
**1652	1	1	1	0	0
*1653	0	1	1	0	1
**1665	1	1	1	0	1
**1666	1	1	1	1	0

Table v. Tracking comparison - Run 2

Bad frame number	Fixed minimum		Height vector		Distance change
	Left eye	Right eye	Left eye	Right eye	
**806	1	0	1	0	1
*807	1	0	0	0	0
**816	1	1	1	0	1
*817	1	0	0	0	0
**830	1	1	1	1	0
**845	1	1	1	0	1
*846	0	1	0	0	0
**862	1	1	1	1	0
*863	0	1	0	0	0
*864	0	1	0	0	0
**865	1	1	0	0	0
*866	0	1	1	0	1

TABLES LEGEND:

**	bad frame - eye completely occluded
*	bad frame - iris occluded, eye ball partially visible
1	image registered as bad frame
0	image registered as good frame
Fixed minimum	tracked minimum must be between .336 and .587 (eye center intensities)
Height vector	number of total white pixels from the pupil center >=5
Distance change	change of eye distance between 2 cons. frames >=5

Example below (Fig. 27) shows 4 consecutive frames of fixed minimum method from run 2.

Tracked minima can be observed.

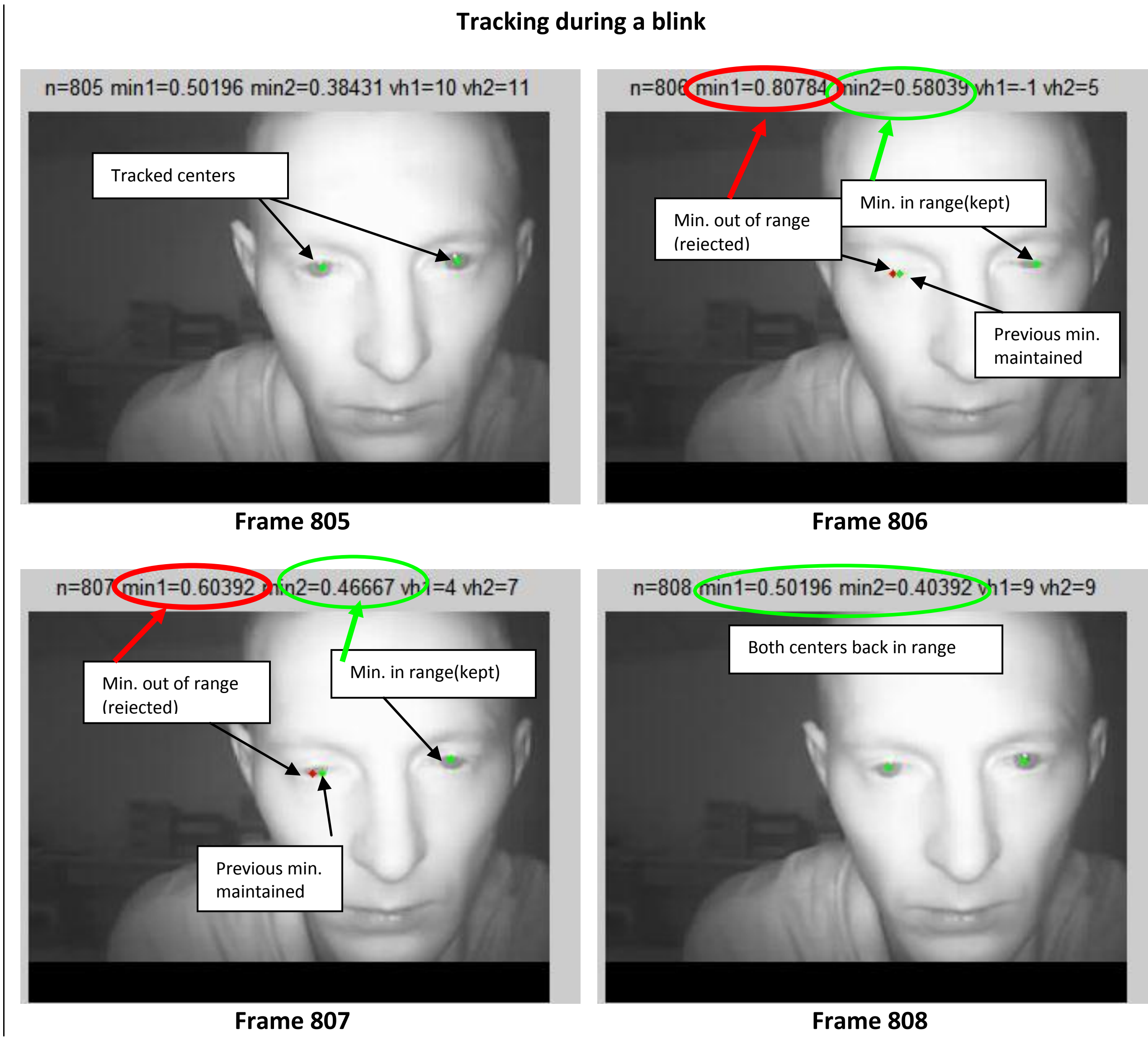


Figure 27. Tracking during blinking

The most effective option is the method of tracking fixed minimum, although, other methods show some positive outcomes as well. The natural tendency would be combining all these ideas so they could complement each other and make one solid and reliable system. This however, was avoided intentionally to not complicate the algorithm and save computation resources, thus, chosen method is a compromise between resources economy and accuracy.

4.4 Fatigue estimation

Evaluation of the fatigue is done based on eye lid drop level. Since fatigue is not a continuous factor, two states were established to describe it: warning and alert. Observing the symptoms of experiencing tiredness in subject condition, the descriptors were attached to the following PERCLOS variation and eye ratio limits (Table vi):

Table vi. Descriptors limits

PERCLOS	Eye ratio value	Descriptor
P40	<0.6	Warning
P50	<0.5	Alert

The proposed values differ from most common for automotive field P80. It is caused by the fact that an operator behind a workstation should keep himself in the best condition. On the other hand, for an operator behind the steering wheel, monitoring system warns in case of danger of falling asleep.

On the following figure (Fig. 28) the descriptors can be observed on sample images when applied to actual eye condition state.

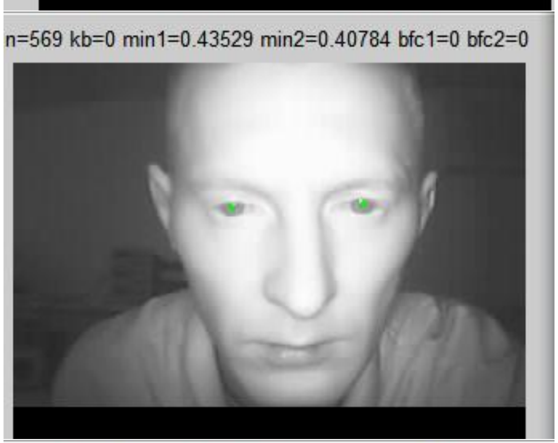
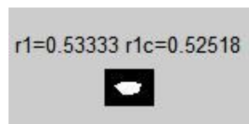
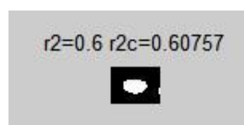
Current frame	Split ratios	Aggregated ratio & Fatigue descriptor
	 	0.66 Normal
	 	P40 0.57 Warning
	 	P50 0.49 Alert

Figure 28. Fatigue estimation and descriptors

Conclusion

The proposed fatigue detecting and monitoring system fits in contemporary trend of utilizing variety of possibilities that modern image processing has to offer. This solution makes use of analyzing visual cues of fatigue based on human eye behavior. As the most indicative of all visual metrics is PERCLOS, therefore, it has been adopted as a system core measurement. Since the system is designated as a workstation tool for fatigue detecting and monitoring, scheduling support, and investigation recording, it has been designed as convenient, inexpensive and nonintrusive combination of near IR camera and LED illuminator. To not absorb precious computation resources from workstation, to which the equipment is connected, it uses dark/bright eye effect, to localize eyes in the first phase of software algorithm and tracks eye pupils according to their intensity in the second phase. Certain limitations of the non professional hardware components, like ordinary web cam and lack of the frame synchronization gear, were satisfyingly overcome by applying adequate software solutions. They are interframe intensity difference verification and the mention two phase algorithm of detection and tracking of eyes. Hours of lab experiments contributed to the empirical improvement of system's shortcomings, caused by more computational friendly but less accurate image resolution. Based on the distance from the screen linear model of eye proportion corrections was developed. Also, the chosen method of eye tracking was the most effective between two others investigated. Although system is not resistant to errors, which may, in unfavorable situations, exceed 10% when calculating eye-openness ratio, presented application is able to satisfy the qualitative fatigue metric by indicating the state of alertness of the subject as normal, warning and alert.

The fact that presented work uses modified ordinary web cam as a near infrared device and the proposed algorithm includes innovative software response to unsynchronized frames problem makes this design unique among others. Also the future equipment that could potentially be developed based on described prototype, due to anticipated low cost, can serve not only in highly important control centers but also in normal corporative offices.

The results presented show that it is possible to develop a working prototype when operating under low budget restrictions. The solution proposed proved to be very responsive pioneer under limited resources of student project. It also opens a vast number of possibilities for modifications and improvements. Popular Moore's law claims that the computational power doubles every 18 months. By the time this project is submitted it is possible that the used 240x320 image resolution can be replaced by much higher but that will neither slow down the executing of the algorithm nor performance of the workstation. Increasing the resolution would significantly improve precision of the whole system. Also research using more sensitive camera would alleviate the need of to provide strong illumination intensity from the LEDs, and hence, could increase the frame rate of the system and decrease its power consumption.

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