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A Remote and Real-time Fatigue Measurement Solution Based on Eye Tracking Technique

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Abstract: Measuring fatigue is a key step of managing human fatigue risk because it provides objective data for fatigue prevention. This paper aims to develop a remote and real-time fatigue measurement solution based on eye tracking and computer vision technique. Firstly the framework and process of this solution was given. Then experiments of selecting fatigue measurement index was carried on and the results indicated that PERCLOS (Percentage of Eyelid Closure Over the Pupil Time) value is a reliable index for measuring fatigue and the threshold is suggested to be set as 0.5 when eye close threshold is set as 70%. Meanwhile a functional Fatigue Measurement Prototype System for air traffic controller was developed as an application case. Finally it concluded that this fatigue measurement solution is feasible and reliable, a more applicable Fatigue Measurement System basing on this solution is expected to be developed and applied in next step.

Key words: Eye tracking, fatigue measurement, safety, PERCLOS

INTRODUCTION

Fatigue is a serious and common issue concerning almost all areas of human working and it has been clearly identified as a significant risk factor increasing the likelihood of accident and injury (Dawson *et al*., 2011; Williamson *et al*., 2011). It is seemed as a threat to operation safety because of its impairments in human alertness and performance (Dawson and Reid, 1997). As far as the aviation transportation industry is concerned, fatigue risk exists widely among flight and cabin crews, air traffic controllers, technicians, mechanics, dispatchers and ramp workers. Especially pilots and controllers always suffer fatigue aroused by sleep loss, night and shift work and long duty cycles and also the pressure of remaining alert by their actions, observations and communications (Bennett, 2003). Although estimates vary, official statistics indicate that 70% of fatal accidents in commercial aviation relate to human error the risk of fatigue contribute 15-20% to the overall accident rate (Wang and Sun, 2011).

Fatigue measurement is the key link of fatigue risk management which will supply with objective data to fatigue prevention. Although lots of researches have been conducted on analyzing fatigue contributing factors and fatigue risks, work in the area of remote fatigue measuring was rarely found (Roach *et al*., 2004). One major problem to be solved is how we can measure fatigue in a reliable, quantitative and real-time way.

Basically current methods of measuring fatigue were divided as subjective measurement and objective measurement. The subjective measurement of fatigue is based on multi-dimensional scaling such as Pearson Fatigue Scale, Fatigue Severity Scale and Fatigue Impact Scale and so on (Gimeno *et al*., 2006). Though subjective measurement method is easy to use, it is difficult to quantify fatigue degree accurately. Meanwhile the measurement result could not be displayed in real-time and its reliability could be influenced by personnel difference easily. The objective measurement is based on the physiological phenomena and which can be accomplished by two ways. One way is to measure the changes of physiological signals, such as brain waves, heart rate, pulse rate and skin electric potential, as means of detecting a drowsy situation. The other way focuses on the physical changes, such as the inclination of the subject's head, sagging posture, or the open/closed state of the eyes. The measurements of these physical changes are classified into the contact and the non-contact types. The contact type involves the detection of movement by direct means, such as using a hat or eye glasses or attaching sensors to the human body. The non-contact type uses optical sensors or video cameras to detect the changes (Ji *et al*., 2004). The non-contact or non-intrusive method of measuring fatigue mainly depends on the face recognition and eye recognition technique. Face recognition is one of the few biometric methods that possess the merits of both high accuracy and low

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intrusiveness. The methods of monitoring fatigue based on face and eye recognition techniques were researched continuously in road driving field but few of them were used in aviation industry.

The comparison of above fatigue measurement methods is as the Table 1. As showing in Table 1, it's easy to find that the method of measuring eye-moving feature which has characteristics of real-time and non-intrusive is an applicable and reliable way to detect fatigue. The aim of this paper is to develop a remote and real-time fatigue measurement solution based on eye tracking and computer vision technique.

A REMOTE AND REAL-TIME FATIGUE MEASUREMENT SOLUTION

Framework and principle: In this study, we proposed out a remote and real-time fatigue measurement solution by applying eye tracking and computer vision technique. It could monitor and manage human fatigue from working field as well as remote terminal. Lots of similar online and remote laboratory solutions have ever been researched and applied into practice, but few products were found in fatigue measurement field. The framework of the solution is as showing in Fig. 1.

The basic principle of the solution is that we can measure human's fatigue state by detecting eye-moving feature, especially the eye blinking action. Therefore the main content of the solution is developing a fatigue measurement system relying on computer vision which can catch every user's eyelid-moving feature through wireless camera and calculate user's fatigue degree through the given measurement index and algorithm. The system is designed for multi-level users. First, it could detect different low-level operators' fatigue state and warn them if fatigue is detected at the same time. Second, the mid-user is an administrator who can monitor and manage the fatigue measurement and warning in working field. Third, as the high-level user, the decision maker of organization could examine the total status of staff's fatigue in a period and evaluate the fatigue risk existing in organization through the remote access on the system severs.

Hardware requirment: The hardware of fatigue measurement system mainly depends on wireless cameras, processors and servers. The camera could be a common CMOS or CCD lens and the processor could be the computer or Digital Signal Processor. Surely a video capture device is needed to record video if the DSP is

Table 1: Comparison of fatigue measurement methods

Method	Real time/non-real time	Intrusive/non-intrusive	Accuracy	Convenience
Questionnaire Survey	Non-real-time	Non-intrusive	Low	Good
Reaction Time Measurement	Non-real-time	Non-intrusive	High	Not good
Physiological Signal Measurement	Real time	Intrusive	High	Not good
Eye-moving Feature Measurement	Real time	Non-intrusive	High	Good

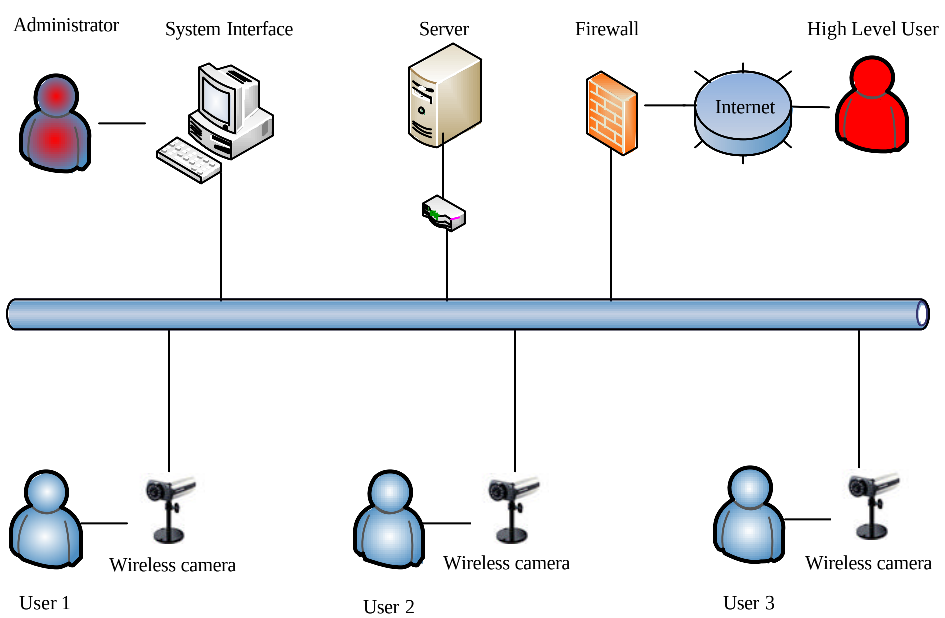

Fig. 1: Framework of remote and real-time fatigue measurement

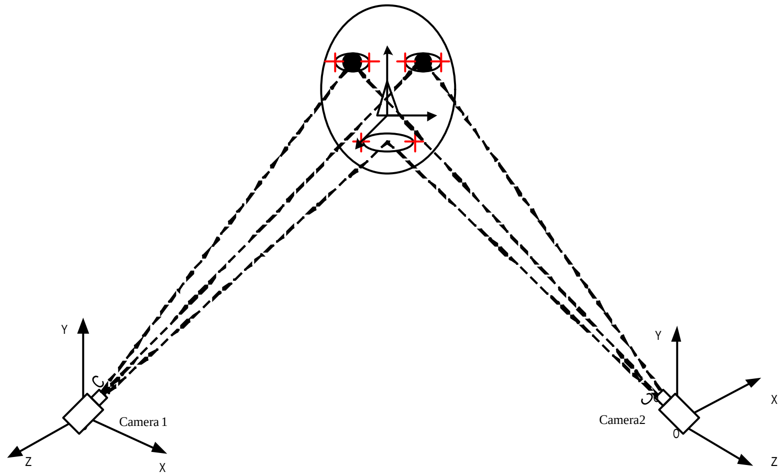

Fig. 2: Setting position of cameras

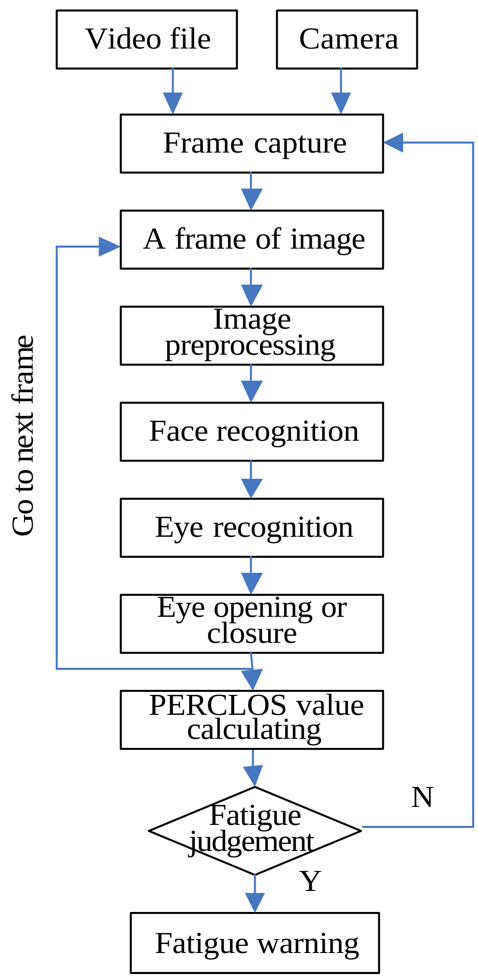

Fig. 3: Software architecture of Fatigue Measurement System

chose. In addition, the IR light could also be select hardware for better detecting and tracking. In our solution, we used two wireless cameras to catch the face feature from difference directions which aims to improve the recognition effects. The position is as showing in Fig. 2.

Software architecture: The software consists of four components that are face detection, eye detection, eye tracking and fatigue detection. The system process of software is as showing as Fig. 3.

Firstly a frame of image will be captured from an ordinary camera or video files. The first frame will be processed by using image process methods and then used for initial face detection and eye location. If any one of these detection procedures fails, then go to the next frame and restart the above detection processes. Otherwise, eye images are used as the dynamic templates for eye the current tracking on subsequent frames and then the fatigue detection process is performed. If eye tracking fails, the face detection and eye location restart on the current frame. These procedures continue until there are no more frames. When all frames in a time limit were detected over and a statistic regarded with eye-closed frames will be made later. The statistic value is called PERCLOS which is an accredited threshold of judging fatigue.

EXPERIMENTS ON FATIGUE MEASUREMENT INDEX

Definition of index: PERCLOS means the percentage of the intervals with closed eyes in a fixed time window, disregarding regular blinks. PERCLOS is the most

Fig. 4: FaceLAB eye tracker

potential and best way of fatigue menstruations and its data can really represent fatigue (Ji *et al*., 2004; Wang and Sun, 2011). As far as the fatigue measurement system is concerned, the simple way of calculating PERCLOS is to calculate the proportion of eye closure frames to the total frame number in a time limit. It is as the following formulation:

$$p = \frac{\sum f_c}{f_t} \quad (1)$$

where, f_c means eye closure frame, f_t means total frames in a time unit.

But whichever algorithm we choose, the final calculation result will be influenced by a parameter which is the threshold c for judging eye closure. Typical values for the threshold c are 70, 80 and 90% which respectively means the degree of eyelid dropping down and covering iris is 70, 80 and 90%. PERCLOS threshold will change greatly along with different c value. Meanwhile due to the difference in measurement equipment and operations, arguments on PERCLOS threshold of deciding fatigue still existed. For finding a more precise PERCLOS threshold index to be used in fatigue measurement system, the experiments on how PERCLOS value changes under different c was carried on in next step.

Experiments: The objective of experiment is to study the PERCLOS change in fatigue and non-fatigue state and also different Eye Closure Threshold (ECT, c value). It also aims to find an appropriate PERCLOS value for judging fatigue state.

The instrument used in the experiment is FaceLAB Eye Tracker (Fig. 4) which could produce accurate head and eye-movement data on-time, in the toughest of tracking environments. It also delivers data with the addition of a real-time PERCLOS fatigue assessment including raw data on the minutia of eyelid behavior. The data rate or sampling frequency of the system is 60 Hz.

Table 2: Calculation Result of PERCLOS Value

Eye closure threshold	Non-fatigue (n = 5) (M±SD)	Fatigue (n = 5) (M±SD)
70%	0.035±0.021	0.564±0.022
80%	0.024±0.016	0.189±0.045
90%	0.013±0.010	0.089±0.029

For clearly observing subject's fatigue state in a short time, an experiment of 36 h sleep deprivation was designed and implemented. 5 volunteers were involved in. PERCLOS values were measured in their fatigue and non-fatigue state with different Eye Closure Threshold. The measure time was controlled in 5 minutes for each subject.

Results and data analysis: Then the average PERCLOS value was calculated by using the recorded data and the final result is as Table 2.

The data analysis results showed that:

- The PERCLOS value expressed significant difference ($p<0.01$) between non-fatigue and fatigue state in all three eye closure threshold.
- The ECT made great influence on PERCLOS value. Especially in fatigue state, there is remarkable difference ($p<0.01$) on PERCLOS value between 70% ECT and 80% ECT

Based on above two points, we concluded that it is reliable to use PERCLOS value as the index of judging fatigue. The ECT is suggested to set as 70% and then the PERCLOS threshold of judging fatigue would be set as 0.5 accordingly.

DEVELOPMENT OF PROTOTYPE SYSTEM

Combining with previous fatigue measurement solution and the experiment results, we tried to develop a Fatigue Measurement and Warning Prototype System for Air Traffic Controllers. The hardware requirement was quite simple including a USB camera and computer. The main work of system development focused on algorithm design and software realization.

Algorithm design: The software of the prototype system is consisted of six modules which are Image Capture, Face Location, State Analysis, Data Output, Integration Warning and Data Inquiry. In this prototype system, other two fatigue judgment indexes were added as a

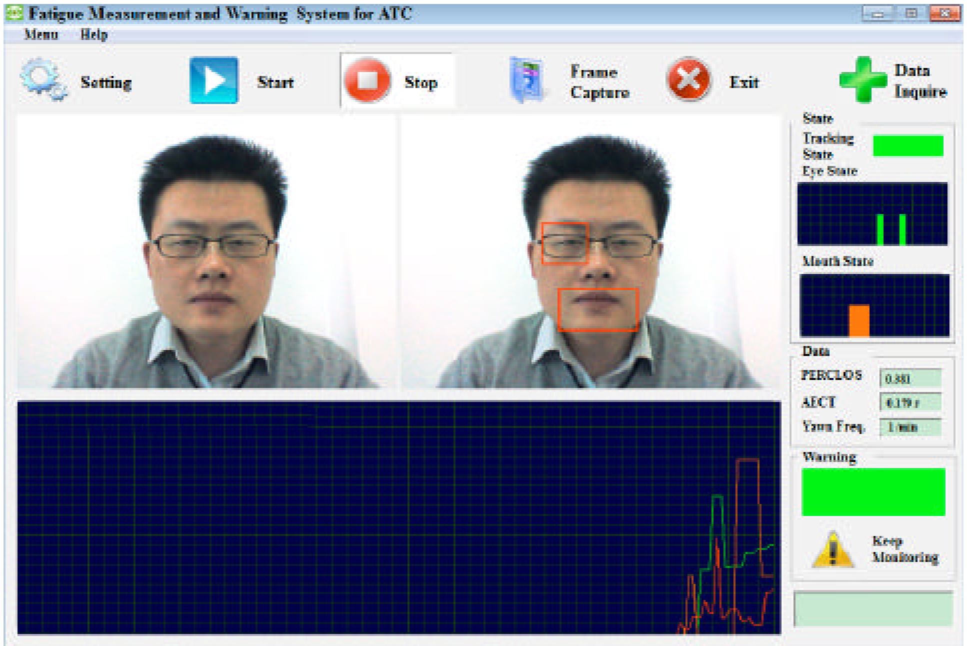

Fig. 5: Interface of Fatigue Measurement and Warning System

trying. One is average of eye closure time and the other one is yawn frequency. The weight of these three indexes could be adjusted in the system setting. The index of PERCLOS value should be allocated the maximum weight because of its reliability.

A lot of algorithm has been developed in the area of face and eye recognition. Among them the algorithms based on skin color segmentation are generally accepted and well-used (Orden *et al*., 2000). In this study, this algorithm was used with other ones together for improving recognition and tracking effect. Firstly the working video of ATC is recorded by USB camera and input into computer in real-time. Secondly for every video frame, the rough location on face and eye is finished by a cascade classifier based on weak classifier and cascade structure; the precise location on eye is finished by Adaboost classifier based on Harr-like feature (Viola and Jones, 2001). Thirdly the face binary image is obtained by using algorithm of median filter de-noising and binarization. The fourth step is the most important step and we can get the eye and mouth state of every frame, the pupil detecting algorithm and black pixel statistic algorithm is apply to decide eye state and the curve fitting algorithm is used for mouth state deciding. Fifthly based on the state analysis results of every frame in a time unit, the PERCLOS value, Average of Eye Closure Time (AECT) and Yawn Frequency could be calculated out. The fatigue state is determined by the three indexes and the warning will be given in voice and color if the integrated index beyond the threshold. The data inquiry module is also designed for observing the fatigue status of an air traffic controller in a long period such as one week or month.

System development: Based on above framework and algorithm, we used Visual C++ and Open CV as tool and finished the developing of prototype system. The main interface of the system is as Fig. 5. This image processing frequency of this system can reach 30-40 frames per second. The main functional area of the interface is explained as following.

System setting: Is to choose video input from camera or video files; to set all system parameters such as index weights, eye closure threshold, pupil detection, time unit for calculating PERCLOS and so on.

Start and Stop: Is to start measure and stop measure.

Frame capture: Is to capture the binary image frame for checking effect of image processing.

Data display: There are two parts for data display, one area is real-time display for 3 measure indexes and the other one is data inquiry results page.

Measure state: Is to display measure is success (green) or failure (red), blink state (green strip) and yaw state (yellow strip).

Warning area: Is to display fatigue warning in red color and words.

Curve display: is to display the data change along with time.

This prototype system was tested in laboratory environment and proved to be effective and extensible for applying into practice.

CONCLUSION

Fatigue is a general and serious issue in most of industry, especially for operators who need to work with irregular shift hours and heavy working pressure. Though there were lots of researches on fatigue have been done, currently few effective methods and tools of measuring fatigue in real time have been developed and applied into working practice.

This study aimed to propose out a remote and real-time fatigue measurement solution based on eye tracking and computer vision technique. Current fatigue measurement methods were summarized and the method of measuring eyelid-moving feature which has the characteristics of real time and non-intrusive was recommended. The framework and process of this method were given. Then experiments of selecting fatigue measurement index was carried on and the results showed that PERCLOS value is a reliable index for measuring fatigue and the threshold is suggested to be set as 0.5 when eye close threshold is set as 70%. Basing on the framework and experiments results, a functional Fatigue Measurement and Warning Prototype System for air traffic controller was developed as an application case.

The solution proposed in this study has the characteristics of real-time, non-intrusive and convenient for fatigue measurement. The prototype system confirmed the feasibility of this solution. However, the applicable Fatigue Measurement and Warning System which could be used in working practice is expected to be developed in future. This will be our main work task in next step. The final research product will be an effective support to manage human fatigue risks in working.

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