Computers in Biology and Medicine 98 (2018) 93–99

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/compbiomed

A computational approach to estimate postmortem interval using opacity development of eye for human subjects

İsmail Cantürk *, Lale Özyılmaz

Department of Electronics and Communications Engineering, Yıldız Technical University, İstanbul, Turkey

ARTICLE INFO

Keywords:
Postmortem interval estimation
Time after death
Time of death
Image processing
Forensic science
Forensic medicine

ABSTRACT

This paper presents an approach to postmortem interval (PMI) estimation, which is a very debated and complicated area of forensic science. Most of the reported methods to determine PMI in the literature are not practical because of the need for skilled persons and significant amounts of time, and give unsatisfactory results. Additionally, the error margin of PMI estimation increases proportionally with elapsed time after death. It is crucial to develop practical PMI estimation methods for forensic science. In this study, a computational system is developed to determine the PMI of human subjects by investigating postmortem opacity development of the eye. Relevant features from the eye images were extracted using image processing techniques to reflect gradual opacity development. The features were then investigated to predict the time after death using machine learning methods. The experimental results prove that the development of opacity can be utilized as a practical computational tool to determine PMI for human subjects.

1. Introduction

Postmortem interval (PMI) estimation is one the most debated and complicated problems in forensic science. The time of death should be determined correctly by revealing the elapsed time since death. PMI estimation is particularly crucial in criminal justice systems, where determining the time of death can help clarify some criminal cases by identifying criminals, determining inheritance, and decreasing the number of suspects [1].

Investigations on PMI estimation have focused on physical postmortem changes, such as cooling [2-5], stiffening [6-9], and decomposition [10-13]; or chemical changes, such as postmortem alterations of the electrolytes within the body fluids [14-21]. Forensic entomology has also been studied to predict PMI. In this method, the presence, age, and incidence timing of insects on corpses are investigated [22, 23]. Additionally, different techniques based on signal and image processing methods have been proposed to estimate PMI. Cantürk et al. [1] explored the correlation between tissue conductivity changes and time of death.

Postmortem opacity development of the eye has been indicated as a potential tool for PMI estimation [24-31]. Kumar et al. [25] reported opacity development of the corneal region according to personal observations without using image processing methods. Zhou et al. [26] and Liu et al. [27] studied postmortem eye changes of rabbits. They photographed the eyes of rabbits periodically after death and extracted some features from the images. The features were then classified with a classification algorithm. Kawashima et al. [24] investigated human subjects and took eye images of the subjects. They used RGB pixel values of the corneal regions and developed a mathematical formula to calculate the PMI.

Cantürk et al. [31] analyzed eye images of human subjects from ten cases that were taken periodically over 15 h. The study also medically interpreted the reasons for postmortem alterations of the eye. They analyzed three regions of the eye by extracting image features: corneal region, non-corneal region (sclera), and pupil. Although the opacity development in the corneal and non-corneal regions is correlated with postmortem interval, the postmortem pupil alterations do not exhibit this relationship. Additionally, further color features were observed to show better performance for grading opacity than textural features. In this study, a novel computerized method based on the outputs of the previous study [31] is developed. Since postmortem pupil changes are not significant, only corneal and non-corneal regions are included. An increased number of color features and different texture features are utilized. This new computational approach, which includes image processing and machine learning methods, was developed to estimate PMI of human

* Corresponding author. Yıldız Technical University, Faculty of Electrical and Electronics, Department of Electronics and Communications Engineering, 34220 Esenler, Istanbul, Turkey.

E-mail address: icanturk@yildiz.edu.tr (İ. Cantürk).

https://doi.org/10.1016/j.compbiomed.2018.04.023
Received 22 January 2018; Received in revised form 20 April 2018; Accepted 24 April 2018

subjects based on opacity development of the eye.

2. Materials and methods

The flowchart of the proposed approach to predict PMI is given in Fig. 1. In this approach, there are two main steps: (1) Image Processing, and (2) Computer Vision and Machine Learning. In the image processing step, corneal/non-corneal regions of the eye images are detected, and normalized pixel values for selected regions of interest (ROIs) are obtained. Subsequently, feature selection methods are used to reveal the most significant features of the relevant features in the ROIs. Finally, classification methods are utilized to predict PMI using the selected features. Details of the methods used in the proposed approach are given in the subsequent sections.

2.1. The dataset

In this study, the dataset collected by Cantürk et al. [31] was utilized. The dataset has approval of Clinical Researches Ethic Commission and was collected with permission. There are eye images in the dataset of one female and nine male subjects whose ages vary from 30 to 77 (mean: 48, standard deviation: 14.9)dataset. Definite selection criteria were utilized for inclusion of the cases to the study group by the researchers. Cases with prone death positions and some causes of death were discarded. Edema, and head and cervical trauma were also reasons for elimination from the research group. There are records for every 20 min across 15 h for each case. Therefore, there are 45 pictures for each subject. In total, the dataset includes 450 images.

2.2. Applied image processing methods

Image processing methods were utilized to automatically detect corneal and non-corneal parts of the eye, and extract features. Color and texture based features were extracted to represent the postmortem opacity changes of the regions. Corneal ROIs were selected between the sclera and pupil, and the non-corneal ROIs were of the sclera. The images were processed and analyzed using MATLAB 2014a.

2.2.1. Detection of the corneal and non-corneal regions

The corneal and non-corneal parts of the eye are extracted automatically by image processing methods. However, the dataset also includes some facial parts of the cases. Thus, the eye region must be segmented. For this purpose, the images were processed as follows: the eye region of the images was detected using the Viola–Jones algorithm represented in [32]. The Viola–Jones detector applies a machine learning based approach. Different types of eye models are developed and then used to detect the eye in a picture. A sample image showing the eye region in the picture as detected by the algorithm is given in Fig. 2a.

After segmenting the eye region, Otsu's threshold method [33] was utilized to find the corneal part of the eye. Otsu's method calculates a threshold from intensity image and converts it to a binary (black and white) image using a defined threshold. This method successfully separated the corneal region because of the high difference in intensity between the two regions. After thresholding, morphological closing and opening operations were successively performed to fill tiny gaps and remove small parts (see Fig. 2b). Morphological operations deal with small gaps and parts while preserving the shape and size of larger ones.

The maximum and minimum points of the corneal regions were then calculated horizontally and vertically. Since the corneal region has a circular shape, the horizontal and vertical diameters are the differences between the maximum and minimum rows, and between the maximum

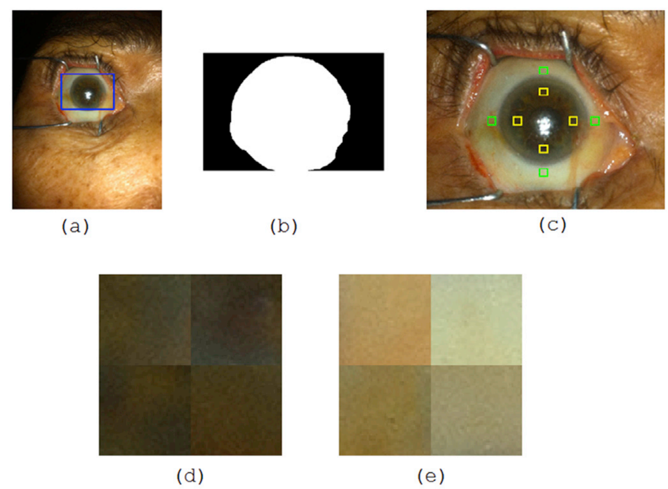

Fig. 2. (a) Viola–Jones detector is used to find the eye (b) Binary image which represents corneal boundaries after Otsu's threshold method and morphological operations (c) Corneal and non-corneal ROIs (d) Joined image for corneal region, (e) Joined image for non-corneal region.

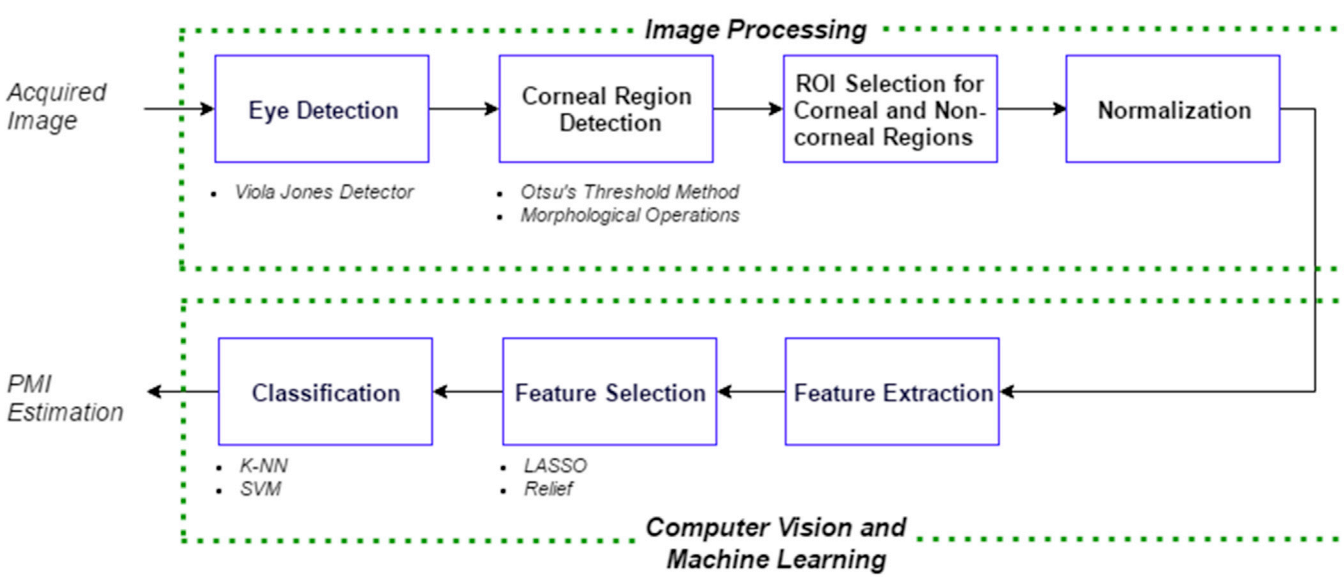

Fig. 1. The proposed approach to predict PMI.