JOURNAL OF FORENSIC SCIENCES

J Forensic Sci, January 2016, Vol. 61, No. 1
doi: 10.1111/1556-4029.12989
Available online at: onlinelibrary.wiley.com

TECHNICAL NOTE

TOXICOLOGY/GENERAL

Georgia Koukiou,[1] M.Sc.; and Vassilis Anastassopoulos,[1] Ph.D.

Drunk Person Screening using Eye Thermal Signatures*

ABSTRACT: Temperature distribution on the eyes of drunk persons is studied by means of thermal infrared images. The sclera and the iris are of the same temperature for the sober person, while for the intoxicated person, the sclera temperature increases. Consequently, only the thermal images from the drunk persons are necessary for intoxication screening. Forty-one participants drank in a controlled alcohol consumption procedure. Their breath alcohol concentration was above the threshold of 0.2 mg/L of exhaled air, which corresponds to about 0.5 mg of alcohol per cubic centimeter of blood. Histogram modification algorithms were employed to prove that for 36 among the 41 intoxicated persons, the sclera becomes hotter. The Student *t*-test verified with over 99% confidence the drunk discrimination capabilities of the procedure. The forensic science potential contribution of the method is that face infrared imagery is available to the authorities for supporting intoxication in case of criminal actions.

KEYWORDS: forensic science, forensic intoxication, drunk screening, eye biometrics, infrared imaging

Iris Identification is a very important noninvasive biometric (1–5) procedure used so far for security purposes. It has been extensively used in the past, and research results are on the market in robust and high-performance commercial products. A unified framework has been presented in (6) in relation to iris biometrics based on random projections and sparse representations. The work in (7) presents an implementation of an iris recognition algorithm employing phase-based image matching—an image matching technique using phase components in 2D discrete Fourier Transforms (DFTs) of given images. In (8), four advances in iris recognition are presented, that is., (i) more disciplined methods for detecting and faithfully modeling the iris inner and outer boundaries with active contours, leading to more flexible embedded coordinate systems; (ii) Fourier-based methods for solving problems in iris trigonometry and projective geometry; (iii) statistical inference methods for detecting and excluding eyelashes; and (iv) exploration of score normalizations, depending on the amount of iris data that are available in images and the required scale of database search. In (9) algorithms suitable for recognizing persons by their iris patterns have been tested in many field and laboratory trials, producing no false matches in several million comparison tests. Finally, in (10) is investigated the matching of iris images captured in the near-infrared electromagnetic spectrum, before and after alcohol consumption. A near-infrared scanner is employed for illuminating the eyes. Due to alcohol consumption, the pupil dilates (10), a fact that causes deformation in iris pattern, possibly affecting iris recognition performance.

Recently, emphasis has been given to acquiring information from faces in thermal infrared spectrum (11–13). The main reason is that the temperature of the face depends mainly on the physiological condition of the person (14). The human face being in a mean temperature around 300 K, radiates according to the Wien Law as a perfect black body (15), with maximum at 10 μm wavelength. Thus, this region of electromagnetic spectrum (7–13 μm) is the most appropriate for acquiring face information.

Drunkenness is a challenging physiological condition to be investigated using infrared imagery. This is because arteries and vessels of an intoxicated person increase activity with the consumption of alcohol (15). The face and especially the eyes are good candidates for examining this change of blood vessel's activity. It is expected that the sclera and the iris (see Fig. 1) will behave differently when a person consumes alcohol due to different vessels density in the two regions. Few publications in the literature deal with thermal infrared imaging for drunk persons' identification (16,17), while most of them refer to automotive antidrunk driving systems, which utilize electrical signals from the heart or brain (18).

In this article, the temperature distribution on the whole eye is examined before and after alcohol consumption. Experimentation is based on thermal infrared acquisitions in the range of 7–13 μm, by means of a passive thermal infrared camera. Half a liter of red wine was given to 41 volunteers in order to create a sober-drunk database [www.physics.upatras.gr/sober/]. All participants had a breath alcohol concentration (BrAC) above the threshold of 0.2 mg/L of exhaled air, which corresponds to about 0.5 mg of alcohol per cubic centimeter of blood (blood alcohol concentration—BAC) (19,20). It is observed that the

[1]Electronics Laboratory, Department of Physics, University of Patras, 26504 Rio, Greece.

*The proposed research procedure, "detection of intoxicated persons by means of thermal infrared imagery," was approved by the Bioethics Committee of the University of Patras, as the procedure followed complies with all national and international bioethics criteria (56/2013 Presidential law and the 2010/63 EU directive). This decision was validated by the Senate Assembly of the University of Patras.

Received 16 Feb. 2014; and in revised form 11 Oct. 2014; accepted 23 Oct. 2014.

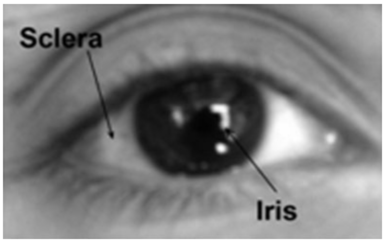

FIG. 1—*The parts of the eye. Sclera is surrounding iris which is actually a muscle controlled part of the eye to adjust the size of the pupil. Sclera lies on a net of blood vessels.*

temperature difference between the sclera and the iris is zero for the sober person and increases when somebody consumes alcohol. For the drunk person, iris appears darker compared to sclera which means that the sclera temperature increases. Thus, in a drunk screening procedure, the infrared images of the sober person are not needed. Histogram modification algorithms are employed when necessary, to show off the gray level difference between the sclera and the iris for intoxicated persons. The discrimination capability of the procedure is verified using the Student *t*-test. It is found a confidence of over 99% in drunk person discrimination. An early version of this article appeared in (21) without any mathematical evidence.

The work layout is as follows. In the section "infrared data used" is explained the way the infrared images employed in the experiment were acquired. In the next section, the histogram modification algorithms used and the experimental results obtained are described. The statistical inference regarding the discrimination capabilities of the proposed method by means of the Student *t*-test is presented in the "drunk discrimination assessment" section. At the end, the conclusions are drawn.

Infrared Data Used

The infrared images used in this work were acquired by means of the Thermo Vision Micron/A10 Model infrared camera (18 mm, f/1.6) of FLIR Company. Its operating range is from 7.5 to 13.0 μm, and it adjusts automatically its dynamic range (gray levels) to the minimum and maximum temperature of the scene. Thus, the obtained information is in the thermal infrared where the maximum of the Wien curve lies (9.5 μm for 300 K). Actually, the human skin emits electromagnetic radiation as an almost black body at this exact region of wavelengths (15).

In this experimental procedure, 41 people were involved, 31 males and 10 females. Each person consumed four glasses of red wine, 120 mL each (13% vol.), in one-hour time period (a total of 480 mL of wine, i.e., 62.4 mL of alcohol). The first acquisition of 50 frames for each specific person was obtained just before starting alcohol consumption, whereas the second acquisition of 50 frames 30 min after drinking the fourth glass of wine. In each acquisition, the sequence of 50 frames was obtained for each person with a sampling period of 100 m sec between the frames. The mean value of the 50 frames of a specific person is demonstrated in Fig. 2, sober at the left and drunk at the right. The resolution of the infrared images is 128×160 pixels. The camera was quite close to the face of the person so that the thermal image contains only the eyes widthwise (see Fig. 2).

The experimental procedure requires the availability of the thermal images of an intoxicated person as well as the thermal images of the corresponding sober person so that comparisons

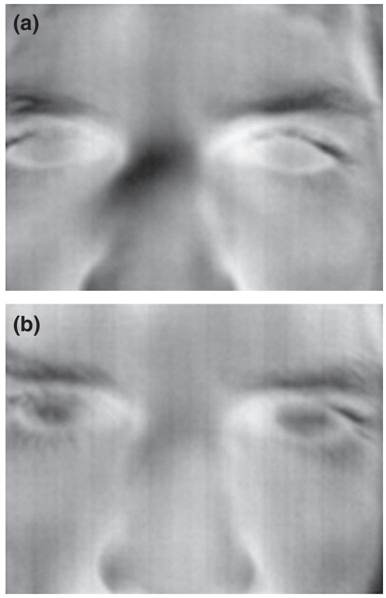

FIG. 2—*The mean value of 50 frames for a sober person (a) and a drunk person (b). No preprocessing has been applied on the images. It is evident for this person that the sclera becomes hotter compared to the iris when the person consumes alcohol.*

can be carried out. Consequently, the people participating in the experiment have to be conscious about the requirements of the procedure. Researchers, working in the Department of Physics, University of Patras, were asked to participate as only these persons could be aware about the needs of the experiment. All participants were healthy and well aware of a possible risk they were undertaking. They also accepted their personal data to be available on the Web for possible use by the scientific community [www.physics.upatras.gr/sober/]. In the specific database, all data such as age, weight, and sex are recorded.

The terms "drunk" or "intoxicated" are attributed to the person that has consumed four glasses of red wine or a total of 62.4 mL of alcohol. This quantity of alcohol was the maximum that the researchers could consume in order to participate in the experiment. No blood tests were conducted in order the blood alcohol content be known. According to various tests available on the web, only three glasses of wine are enough for any person to go beyond the limit of breath alcohol concentration (BrAC) which is 0.2 mg/L of exhaled air and corresponds to about 0.5 mg of alcohol per cubic centimeter of blood (blood alcohol concentration—BAC) (19). Furthermore, according to current studies, the correlation between BrAC and BAC is almost linear (20).

It was noticed that with the same quantity of alcohol, the participants are affected differently. This was found out by the measurements carried out by the police using an alcoholmeter (breathalyzer). The breathalyzer used by the police was the LION SD-400 by Pacific Data System (unit Device Identifier 073887D). The breathalyzer was calibrated 7 days before the test. With the quantity of 62.4 mL alcohol given to all participants, the breath alcohol content varied from person to person between 0.22 and 0.9 mg/L. It was found that this was the maximum concentration and was reached almost half an hour after the consumption of the last glass of wine. This is the reason why in the experimental procedure the second acquisition was obtained at this time instant. After that, the indication regarding the breath alcohol content started to decrease. The females were affected more than the males. The heavier participants were affected less than the thinner ones. Specifically, for the males participated in the experiment, the breathalyzer indication ranges from 0.22 to 0.37 mg/L of exhaled air. For the heaviest males, the indication was the lowest. For the females, this indication is much higher ranging from 0.49 to 0.89 mg/L. Finally, these measurements were normalized to the participant weight by obtaining the product weight × breathalyzer_indication. This index ranges from 19 to 26 for the males and from 30 to 50 for females.

Finally, it is worth mentioning that the people participated in the experiment were calm and in normal physical and psychological condition during the experiment. No illness, no psychological stress, other pathological reasons, or any kind of body exercise were recorded for any one of the participants. They were asked to be present in the room of the experiment half an hour earlier and to keep calm till the first acquisition of frames. We have to mention that our intention with this work is to distinguish drunkenness from normal condition (sober). No other kind of abnormality is considered. During the acquisition procedure, the temperature and a dim light in the room were kept unchanged.

Experimental Results

In 28 among the 41 people who participated in the experimental procedure, it is evident by a simple comparison of the thermal images that the sclera becomes hotter compared to the iris after alcohol consumption. As shown in Fig. 2 as well as in the right image of Fig. 3, the iris appears darker (cooler) while the images are depicted in their original form without any kind of preprocessing. In four more people, the iris appears darker than the sclera for the drunk person only after applying a histogram equalization algorithm. Such cases are demonstrated in Fig. 4 (right images for the drunk person). For all these participants, the sclera and the iris are of the same temperature in case of the sober person appearing with almost the same gray level.

Moreover, another four persons revealed the temperature difference between the sclera and the iris for the intoxicated person

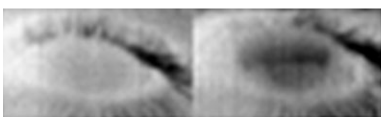

FIG. 3—*Thermal Infrared images of the same eye of a person sober (left) and drunk (right) (person 5). The images are shown in their original form without any kind of preprocessing. The sclera is evidently hotter (brighter) than the iris for the drunk person.*

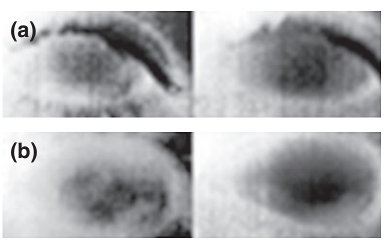

FIG 4—*Using a histogram equalization algorithm the eyes of two different persons (persons 11 and 13) present an iris with lower temperature after alcohol consumption. The algorithm was applied in the thermal images of the eye for the sober persons (a) as well as for the corresponding images in the case of the drunk persons (b).*

only when other special histogram modification algorithms were applied. Some of these cases are depicted in Figs 5–7, respectively. Particularly, in Fig. 5 are shown the original images of the eye of person 21, for the sober and drunk cases, respectively. These images have been modified using a histogram modification algorithm which clips all values lower than 0.5 and higher than 0.75, while it stretches the rest histogram to occupy the whole histogram range (MATLAB imadjust ([0.5 0.75], [0 1])). In Fig. 6, results are obtained for the same person 21 from a contrast stretching algorithm which was applied to the original images.

In Fig. 7, results are provided when a logarithmic transformation is applied to the original data of person 37. In this specific case, the iris of the drunk person is dark and occupies larger area compared to the sober one.

In all these cases, the sclera becomes hotter after consuming alcohol and this is evident from all images on the right of Figs 5–7. Most of the eight participants for whom special analysis was required to determine a difference in eye temperature were males with BrAC just above the limit and around 0.3 mg/L. Some of them were also used to drinking wine or other spirit occasionally. Only one individual was female with BrAC quite high (0.6). However, this individual is also a frequent consumer of alcohol.

Finally, for five persons, no algorithm succeeded to show off increased temperature for the sclera in the case of drunk persons. These persons were also used to drinking wine or other spirit occasionally. These individuals were four men and a woman with BrAC lower than 0.40 mg/L. These five cases are statistically verified in the next section and are explicitly recognized in Table 1 as being the persons 2, 12, 23, 33, and 41.

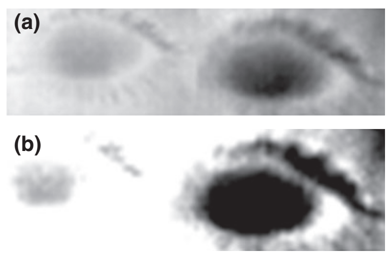

FIG. 5—*(*a*) The original images of the eye of person 21, for the sober (left) and drunk (right) cases, respectively. A histogram modification algorithm which clips all values lower than 0.5 and higher than 0.75 and stretches the rest to occupy the whole histogram range (MATLAB imadjust ([0.5 0.75],[0 1])) gives the images in (*b*).*

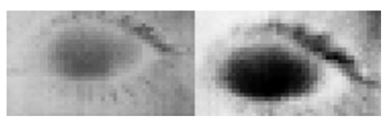

FIG. 6—*The results obtained after applying a contrast stretching algorithm on the original images of person 21 (sober left, drunk right).*

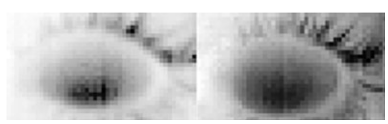

FIG. 7—*The results obtained when a logarithmic transformation algorithm is applied to the original data of person 37 (sober left, drunk right).*

TABLE 1—*The ratio of the mean value of the pixels inside the sclera's ellipsoidal ring over the mean value of the pixels inside the iris (small ellipse).*

#	Person	Sclera Mean Pixel Value OVER Iris Mean Pixel Value (Sober)	Sclera Mean Pixel Value OVER Iris Mean Pixel Value (Drunk)
1	John	1.056	1.188
2	Artimis	1.288	1.167
3	Vassiliskar	1.059	1.518
4	Konst	1.112	1.669
5	Petros	1.046	1.232
6	Patty	1.097	1.163
7	Rigas	1.152	1.441
8	Nikos	1.065	1.142
9	Nefeli	1.089	1.221
10	Thanos	1.042	1.234
11	Giorg	1.057	1.157
12	Vasil	1.269	1.255
13	Tsagaris	1.046	1.223
14	Tris	1.095	1.232
15	Theox	1.016	1.227
16	Nausika	1.058	1.192
17	Lia	1.126	2.106
18	Lampros	1.031	1.137
19	Kwstas	1.037	1.136
20	Konstantinos	1.024	1.131
21	Ilias	1.035	1.163
22	Giorgos	1.130	1.185
23	Kalpaksis	1.690	1.267
24	Frag	1.076	2.535
25	Dionisis	1.015	1.118
26	Dimitris	1.205	1.383
27	Pasxalis	1.051	1.218
28	VassilisA	1.034	1.220
29	Krodiras	1.071	1.200
30	Christos	1.113	1.239
31	Anna	1.190	1.325
32	Alkis	1.038	1.221
33	Antonis	1.265	1.265
34	Iliasv	1.084	1.270
35	Thanasis	1.051	1.218
36	Vicky	1.009	1.105
37	Elpis	0.991	1.065
38	Spiliop	1.039	1.133
39	Loukas	1.027	1.130
40	Manos	1.048	1.146
41	Takis	1.036	1.020

Drunk Discrimination Assessment

In this section, the temperature difference between the sclera and the iris is monitored, and the way it changes with alcohol consumption is thoroughly examined. Specifically, the increase in darkening of the iris compared to the white background of the sclera is studied. For this purpose, the region of the eye is divided into two subregions: one containing the iris and the other the sclera. Schematically, the two regions are represented in Fig. 8. The inside ellipse contains the iris while the outside ellipsoidal ring the sclera. The two shapes have been selected to have the same and constant area for the eyes of all persons having participated in the experiment. Based on the statistics of the pixels in these two regions, two different estimation procedures were carried out which are described in the following.

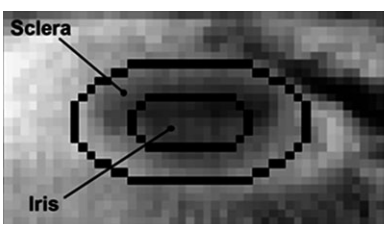

FIG. 8—*The two regions, small ellipse (iris) and ellipsoidal ring (sclera) are those in which the mean pixels value is evaluated.*

In the first procedure, the ratio of the mean value of the pixels inside the sclera's ellipsoidal ring to the mean value of the pixels inside the iris (small ellipse) is calculated. The values of the pixels correspond to intensity values. Since the two regions have been selected of the same area for all persons, they contain for every person the same number of pixels and the measurements of the ratios are consistent from person to person. Moreover, as the ratio is measured on the same image, its value is not affected by the auto ranging facility of the camera.

This first procedure has been performed on the left eye of each participant, in both the cases when he is sober and when he has consumed alcohol. Consequently, two ratios of the mean value of the sclera's ring to the mean value of the iris are available. These two ratios are given in Table 1, when the previously described experimental procedure was applied on the thermal images of all 41 persons. It is observed that the ratio of the mean pixel value on the sclera's ring to the mean value on the internal ellipse increases when the person has consumed alcohol. Specifically, it is evident from Table 1 that in 36 from the 41 cases, the specific ratio increases with alcohol consumption, while only in 2 cases, it decreases (persons 2 and 23), and in the rest 3, it remains almost the same (persons 12, 33, and 41). These results are analyzed in the following using the Student's *t*-test, in order to support statistically the drunk screening capabilities of the proposed method from eye thermal images. A significant conclusion should be that the means of the two columns are different with high confidence.

In the second procedure, is estimated the variance of the pixels contained in the whole large ellipse, which includes the pixels of the sclera as well as those of the iris. This evaluation was performed for the left eye of each participant when the person is sober and when he is drunk. Therefore, two variances for each participant have been calculated, corresponding to sober and drunk person, respectively. In Table 2, are illustrated the two variances for all persons participated in the experiment. It is observed that the variance increases in case that the person has consumed alcohol. Specifically, among the 41 participants, only 4 (participants 2, 12, 21, and 23) presented decreased variance in the region of the eye for the drunk person compared to the sober one. Three of these participants coincide with those in Table 1 who presented a decrease in the intensity ratio with alcohol consumption. For the three persons, the BrAC was lower than 0.40. For person 2, the BrAC was 0.6 mg/L. An explanation that could be provided is that these individuals were used to consuming alcohol. However, other causes such as the mood of the persons could affect this behavior. The statistical inference regarding the drunk screening capabilities of this feature is analytically explained in the following.

From the two procedures devised for estimating the darkening of the iris in persons who have consumed alcohol, the Student's *t*-test was applied in order to confirm the differentiation of the results between sober and drunk people. For the data in Table 1, the test statistic for this task is the Welch's *t*-test (22) which is used when the two population variances are in general different:

$$t = \frac{\bar{x_1} - \bar{x_2}}{S_{\bar{x_1}-\bar{x_2}}} \quad (1)$$

with $S_{\bar{x_1}-\bar{x_2}} = \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$,

TABLE 2—*The variance of the pixels contained in the large ellipse, which includes the pixels of the sclera as well as those of the iris.*

#	Person	Variance for Sober	Variance for Drunk
1	John	222.5	242.3
2	Artimis	723.1	471.4
3	Vassiliskar	473.0	1457.7
4	Konst	293.5	1790.9
5	Petros	112.2	303.5
6	Patty	353.5	379.4
7	Rigas	527.9	906.7
8	Nikos	305.1	389.4
9	Nefeli	197.4	655.2
10	Thanos	255.0	667.5
11	Giorg	181.3	522.5
12	Vasil	594.2	589.2
13	Tsagaris	303.7	1264.9
14	Tris	234.3	645.6
15	Theox	134.3	529.4
16	Nausika	129.7	316.5
17	Lia	624.4	2157.3
18	Lampros	67.1	200.1
19	Kwstas	237.2	282.9
20	Konstantinos	166.2	259.7
21	Ilias	203.1	189.7
22	Giorgos	206.2	522.9
23	Kalpaksis	832.5	596.3
24	Frag	151.8	1010.3
25	Dionisis	171.5	373.9
26	Dimitris	367.2	798.1
27	Pasxalis	248.0	427.2
28	VassilisA	443.5	553.2
29	Krodiras	193.5	240.9
30	Christos	324.5	402.9
31	Anna	298.8	614.9
32	Alkis	107.5	400.7
33	Antonis	503.7	672.5
34	Iliasv	555.2	948.4
35	Thanasis	119.3	381.0
36	Vicky	305.6	787.4
37	Elpis	247.4	642.0
38	Spiliop	93.9	248.9
39	Loukas	33.3	82.3
40	Manos	45.3	98.6
41	Takis	97.7	100.0

where $n_1 = n_2 = 41$, is the size of the sample, and s^2 is the unbiased estimator of the variance of the data in each columns of Table 1. The distribution of t is the Student t-distribution (22) with m degrees of freedom.

According to the measurements, for the two last columns in Table 1, the statistic t is found to be 3.8939. The degrees of freedom is 55. Thus, our confidence that the two means are different is 99.95%. Furthermore, given that the data resulted from the same sample of persons tested in two different conditions (sober and drunk), the paired t-test has been applied as well where $t = \frac{\bar{X}_D}{S_D/\sqrt{n}}$ with $n-1$ degrees of freedom, where n is the number of samples, an approach which is more sensitive. In this case, the evaluated t equals 4.0694 which again corresponds to 99.95% confidence that the two means are different.

In a similar way, for the two last columns in Table 2, the statistic is found 4.0688. In this case, the degrees of freedom is 54.38. Accordingly, our confidence that the two means are different is 99.98%. Furthermore, given that the data resulted from the same sample of persons tested in two different conditions (sober and drunk), the paired t-test with $t = \frac{\bar{X}_D}{S_D/\sqrt{n}}$ and $n-1$ degrees of freedom has been also applied, where n is the number of samples. In this case, the evaluated t equals 5.0691 which corresponds to 99.99% confidence that the two means are different.

Conclusions

In this work, experimental results were presented which describe the temperature changes on the human eyes when somebody consumes alcohol. Thermal images were used during the experimental procedure for this purpose. The basic evidence is that the iris remains in the same temperature while the sclera increases its temperature with alcohol consumption. Consequently, the iris appears darker in the thermal imagery. A physical explanation is that the sclera contains a denser blood vessels network than the iris, which increases the temperature of the sclera with alcohol consumption. In the experiments, 36 among 41 persons who consumed alcohol presented darker iris in their thermal imagery.

Two features are used for statistically verifying the ability of the sclera–iris thermal difference for drunk person discrimination, that is, the ratio of the mean value of the pixels in the sclera over the mean value of the pixels in the iris, as well as the variance of the pixels all over the eye. The basic approach for proving that the two features are suitable for drunk person discrimination inference is to employ each one as parameter in the Student's t-test procedure. According to the experimental results, it can be concluded with confidence over 99%, using either features, that a person has drunk. In some of the cases, preprocessing is needed and the drunkenness is evident from the darker iris.

According to the presented material, an infrared imaging system could capture the thermal signature of the eyes of a person and provide a first assessment whether a person has consumed alcohol or not. As for the sober person, the sclera and the iris are of the same gray level (temperature), only the infrared image of the eye of the drunk person is necessary for examination. After that, the suspected person should pass through additional tests for alcohol consumption. This is the basic forensic science potential of the proposed method. The proposed test is positive at any alcohol concentration level above the threshold of 0.2 mg/L of exhaled air.

Acknowledgments

This research has been co-financed by the European Union (European Social Fund—ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF)—Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund.

The authors would also like to thank the researchers who participated in this study.

References

1. De Marsico M, Nappi M, Riccio D, Tortora G. NABS: novel approaches for biometric systems. IEEE Trans Syst Man Cybern C Appl Rev 2011;41(4):481–93.
2. Choi JY, De Neve W, Ro YM, Plataniotis KN. Automatic face annotation in personal photo collections using context-based unsupervised clustering and face information fusion. IEEE Trans Circuits Syst Video Technol 2010;20(10):1292–309.
3. Benedikt L, Cosker D, Rosin PL, Marshall D. Assessing the uniqueness and permanence of facial actions for use in biometric applications. IEEE Trans Syst Man Cybern A: Syst Humans 2010;40(3):449–60.
4. Jain AK, Bolle RM, Pankanti S, editors. Biometrics: personal identification in network society, 1st edn. Boston, MA: Kluwer Academic Publishers, 1999.
5. Zhao W, Chellappa R, Phillips PJ, Rosenfeld A. Face recognition: a literature survey. ACM Comput Surv 2003;35(4):399–458.

6. Pillai JK, Patel VM, Chellappa R, Ratha NK. Secure and robust iris recognition using random projections and sparse representations. IEEE Trans PAMI 2011;33(9):1877–93.
7. Miyazawa K, Ito K, Aoki T, Kobayashi K, Katsumata A. An iris recognition system using phase-based image matching. Proceedings of the IEEE International Conference on Image Processing; 2006 Oct 8-11; Atlanta, GA. Piscataway, NJ: IEEE Xplore, 2006;325–8.
8. Daugman J. New methods in iris recognition. IEEE Trans Syst Man Cybern B Cybern 2007;37(5):1167–75.
9. Daugman J. How iris recognition works. IEEE Trans Circuits Syst Video Technol 2004;14(1):21–30.
10. Arora SS, Vatsa M, Singh R, Jain A. Iris recognition under alcohol influence: a preliminary study. Proceedings of the 5th IAPR International Conference on Biometrics (ICB); 2012 Mar 29-Apr 1; New Delhi, India. Piscataway, NJ: IEEE Xplore, 2012;336–41.
11. Socolinsky DA, Selinger A. A comparative analysis of face recognition performance with visible and thermal infrared imagery. Proceedings of the 16th International Conference Pattern Recognition; 2002 Aug 11-15; Quebec City, Canada. Piscataway, NJ: IEEE Xplore, 2002;217–22.
12. Buddharaju P, Pavlidis JT, Tsiamyrtzis P, Bazakos M. Physiology-based face recognition in the thermal infrared spectrum. IEEE Trans PAMI 2007;29(4):613–26.
13. Zhao S, Grigat RR. An automatic face recognition system in the near infrared spectrum. In: Patrick AS, Yung M, editors. Proceedings of the 4th International Conference on Machine Learning and Data Mining in Pattern Recognition; 2005 July 9-11; Leipzig, Germany. Berlin Heidelberg, Germany: Springer-Verlag, 2005;437–44.
14. Khan MM, Ingleby M, Ward RD. Automated facial expression classification and affect interpretation using infrared measurement of facial skin temperature variations. ACM Trans Autonomous Adapt Syst 2006;1 (1):91–113.
15. Pascoe DD, Mercer JB, de Weerd L. Physiology of thermal signals. In: Diakides NA, Bronzino JD, editors. Medical infrared imaging. New York, NY: CRC Press, 2008.
16. Koukiou G, Anastassopoulos V. Drunk person identification using thermal infrared images. Int J Electron Security Digital Forensics 2012;4 (4):229–43.
17. Koukiou G, Anastassopoulos V. Facial blood vessels activity in drunk persons using thermal infrared. Proceedings of the 4th International Conference on Imaging for Crime Detection and Prevention; 2011 Nov 3-4; London, UK. Piscataway, NJ: IEEE Xplore, 2011;1–5.
18. Wu YC, Xia YQ, Xie P, Ji XW. The design of an automotive anti-drunk driving system to guarantee the uniqueness of driver. Proceedings of the International Conference on Information Engineering and Computer Science; 2009 Dec 19-20; Wuhan, China. Piscataway, NJ: IEEE Xplore, 2009;1–4.
19. International Center of Alcohol Policies. ICAP Blue Book – Module 16: Blood alcohol concentration limits. Washington, DC: International Center of Alcohol Policies, 2014.
20. Jones AW. The relationship between Blood Alcohol Concentration (BAC) and Breath Alcohol Concentration (BrAC): a review of the evidence. London, U.K.: Department of Forensic Genetics and Forensic Toxicology, National Board of Forensic Medicine, Linkoping, Sweden and Department for Transport, 2010;8.
21. Koukiou G, Anastassopoulos V. Eye temperature distribution in drunk persons using thermal imagery. Proceedings of the International Conference of the Biometrics Special Interest Group (BIOSIG); 2013 Sept 4-5; Darmstadt, Germany. Piscataway, NJ: IEEE Xplore, 2013;1–8.
22. Papoulis A. Probability, random variables and stochastic processes, 3rd edn. New York, NY: McGraw-Hill, 1991.

Additional information and reprint requests:
Georgia Koukiou, Ph.D.
Electronics Laboratory
Department of Physics
University of Patras
26504 Rio
Greece
E-mail: gkoukiou@upatras.gr