Monitoring Eye Fatigue Using Flexible Piezoelectric Sensors

Chaofeng Lü*, Shuang Wu, Yangyang Zhang, Yangkun Du

Department of Civil Engineering, Zhejiang University, Hangzhou 310058

*Corresponding author, E-mail: lucf@zju.edu.cn

Eye fatigue is a symptom induced by long-term work of both eyes and brains. Without proper treatment, eye fatigue may incur serious problems such as fatigue driving, special work operating faults, or even ophthalmic diseases[1, 2, 3, 4]. Current studies on detecting eye fatigue mainly focus on computer vision detect technology. However, these methods can be very unreliable due to occasional bad visual condition[3, 4]. As a solution, we proposed a wearable conformal in vivo eye fatigue monitoring device that contains an array of piezoelectric nano ribbons integrated on an ultrathin flexible substrate. By detecting strains on the skin of eyelid, the sensors may collect information about eye blinking, and, therefore, reveal human's fatigue state.

We first report the fabrication of the flexible ribbon-structured piezoelectric ceramic transducer (PZT) sensing device and the experimental characterization of the responses of the piezoelectric sensors. During the fabrication process, traditional photolithographic method and transfer printing technology are used to ensure the flexibility and durability of the device. The device contains 12 individual PZT sensing units (1.5μm thick) integrated in series and parallel. Every PZT unit is clamped with Au electrode and Pt electrode. After been interconnected with gold wires, all units are laminated on a flexible thin Kapton substrate (1cm×2cm×30μm) which is directly bonded to human skin during operative conditions. After polarization, the device showed impressive response when the Kapton film is under bending stress. The output voltage curves yield key information about the motion of human eyelid closure, through which testees' real-time fatigue state can be assessed. The voltage amplitude shows the eye slide speed while the interval of peak and valley suggests the crucial time when eyelid are completely closed.

We also present the theoretical solution of a simplified model that is established on the basis of the post-buckling analysis of a stiff film on flexible substrate[5]. When strains are applied onto human eyelid, the laminated thin film, together with eyelid epidermis, yield an orderly sinusoidal buckling behavior[5, 6]. To reveal the relationship between output voltage and deformation on human skin, the

electromechanical coupling of the piezoelectric material layer is considered[7]. Analytic expressions of output voltage are obtained and compare very well with the experimental measurements. Through these expressions, we also performed numerical calculations by applying different input strains, which are manipulated by controlling the eye blinking parameters, such as blinking speed, the time of eyelid closure, blinking frequency, etc. Finally we analyzed the differences in geometric features of the output voltage curves.

During certain visually guided activity, driving for instance, the eye closure time should be of great concern. This device may efficiently detect overlong eye closure time and hopefully give out feedback in time so that unexpected situations can be prevented. In addition, the theoretical models may provide useful tool to guideline the design of this kind of flexible sensors for detecting real-time deformation of human skins.

Keywords: eye fatigue; sensor; piezoelectricity; biomedical; electromechanical analyses

Acknowledgements.
This work was supported by the National Natural Science Foundation of China (Nos. 11322216, 11621 062 and 11321202).

References .

[1] Horne J A, Reyner L A. Sleep related vehicle accidents[J]. Bmj, 1995, 310(6979): 565-567.

[2] Connor J, Norton R, Ameratunga S, et al. Driver sleepiness and risk of serious injury to car occupants: population based case control study[J]. Bmj, 2002, 324(7346): 1125.

[3] Yammamoto K, Higuchi S. Development of a drowsiness warning system[J]. Journal of the Society of Automotive Engineers of Japan, 1992, 46(3): 127-133.

[4] Ji Q, Zhu Z, Lan P. Real-time nonintrusive monitoring and prediction of driver fatigue[J]. IEEE transactions on vehicular technology, 2004, 53(4): 1052-1068.

[5] Gaba D M, Howard S K. Fatigue among clinicians and the safety of patients[J]. New England Journal of Medicine, 2002, 347(16): 1249-1255.

[6] Stato S. Does fatigue exist in a quantitative measurement of eye movement[J]. Ergonomics, 1992, 35(5): 607-615.

[7] Khang D Y, Jiang H, Huang Y, et al. A stretchable form of single-crystal silicon for high-performance electronics on rubber substrates[J]. Science, 2006, 311(5758): 208-212.

[8] Jiang H, Khang D Y, Song J, et al. Finite deformation mechanics in buckled thin films on compliant supports[J]. Proceedings of the National Academy of Sciences, 2007, 104(40): 15607-15612.

[9] Ding H, Chen W. Three dimensional problems of piezoelasticity[M]. Nova Science Publishers, 2001.