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A Wearable Head-Mounted Sensor-Based Apparatus for Eye Tracking Applications

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Abstract – *This work presents a novel approach to eye-tracking systems using eye-glass like apparatus equipped with relatively cheap IrDA sensors and IrDA LEDs connected to a computer. The proposed system produces very low dimensional feature vectors for processing as compared to its competitors that process video data acquired from a digital camera. Consequently, the computational requirements of the proposed system are low. Furthermore, the apparatus is lightweight and can be directly worn. A prototype system is developed in our laboratories and tested to observe its capabilities. Preliminary results show that the approach provides a promising human-computer interface system with plausible accuracy.*

Keywords – *Eye tracker, gaze tracker, human-computer interface, wearable systems, sensor based systems.*

I. INTRODUCTION

Eye tracking systems proved to be versatile tools for many problems in human-computer interface systems. Basically, they are used for providing better usability of a computer or a system for people, including disabled people. Several research projects and products regarding eye-tracking systems can be found in the literature [1-10] and in the market. Most of the available eye tracker systems work by processing the video data acquired from a digital camera. This observation indicates that the video camera usage has become a traditional solution. Despite its popularity, such video frame analysis systems require high amount of computational power to perform the desired interpretation. The price of the camera system may not be the reason for the high price of such systems. Instead, the complexity of the algorithms and the computational power requirements directly reflect to the price of the overall system.

An alternative solution, based on an eye-glass like apparatus equipped with a few cheap light sensors, is proposed in this work. Both the hardware and the computational requirements of the system are desired to be low-cost, without a mobility compromise. Since the wearable apparatus contains light sensors, the cost was kept low. Furthermore, since the number of light sensors is small, the generated feature vector has a very low dimension as compared to the size of a typical video frame captured from a camera. As a result, the computational complexity of the system is significantly lower than that of camera based systems. Similar studies can be found in [11], [12]. It must be noted, however, that, these studies were not found in forms of tangible products.

II. EYE TOUCH SYSTEM

Eye Touch system (ETS) consists of components such as infrared light sensitive apparatus (ILSA), data acquisition device (DAQ), computer software and external power supply. Figure 1 shows the ETS's block diagram. The system was initially planned to be demonstrated and tested in laboratories; therefore components such as DAQ and power supply were not avoided. In its final form, ETS is desired not to necessitate such components. Such implementation and cost studies were not previously found in forms of tangible products.

Each ETS component's function is briefly explained as follows. The infrared light sensitive apparatus is eyeglasses frame without any lenses. ILSA is equipped with few IrDA sensors and IrDA LEDs mounted on a frame to detect the movements of the iris. ILSA is connected to the data acquisition device and power supply over a 14-channel cable. This cable carries 12 channel analog voltage signals to the DAQ as well as the power from power supply for the sensors and LEDs.

Data acquisition device (NI DAQPad-6015 of National Instruments) samples the output of sensors on the ILSA with a 16-bit resolution at the sampling rate of 10 Hz. Then, it serves the sensor information over a USB interface to the application running on a computer. The available DAQ device currently receives a reference voltage from a power supply.

The application software is developed in Microsoft Visual Studio 2003 with the DAQ's own function library. According to the acquired sensor data, the application decides for a corresponding mouse action.

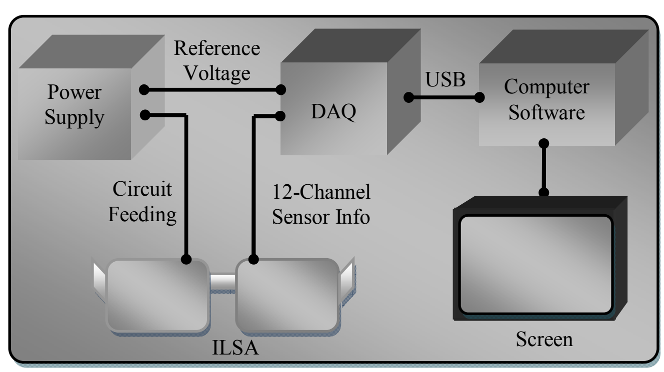

Fig. 1. Block diagram of the Eye Touch system.

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A. ILSA Prototype

Two ILSA prototypes were developed. The first prototype (ILSA-1) was reported in [13]. Based on the experience gained in developing ILSA-1, the second prototype (ILSA-2) was designed and implemented to overcome certain problems related to ILSA-1. A comparison of ILSA-1 and ILSA-2 is given Table 1.

Table 1. ILSA-1 and ILSA-2 comparison.

	ILSA-1	**ILSA-2**
No of IrDA sensors	8	12
No of IrDA LEDs	8	12
Sensor-LED pair	Attached	Detached
LEDs' illumination	Focused	Homogeneous
LEDs' light intensity	High	Low

The rationale behind the modifications over ILSA-1 is due to the following observations: (1) The separate sensor readings due to the focused illumination of the eyes is rather unassociated and leads to poorer tracking performance for ILSA-1. (2) High intensity of the LED light makes eyes tire quicker.

ILSA-2 is shown in Figure 2. There are 6 sensors and 6 LEDs in the left and right portion of the frame. Furthermore, the sensors are surrounded with opaque cylindrical plastic covers which are oriented for the light emission from a specific region of the eye surface.

Fig. 2. ILSA-2 prototype - front view and rear view.

IrDA sensitive sensors used are TSL262R light-to-voltage optical sensors, which are manufactured by TAOS. TSL262R responses the light in 800~1100 nm wavelength range with a sharp peak at 940 nm. Since LD271 IR LEDs emit light at about 940 nm wavelength, the pairs match well.

B. Eye Touch Software

Eye Touch software application consist of two main schemes: training and tracking. The training scheme performs calibration of the system since the size, movement range or geometrical shape of the eye varies among people. The tracking scheme is responsible for collecting and interpreting the acquired information from the apparatus via DAQ. This scheme is implemented in two ways, namely, Region Detector and Cursor Tracker.

Region Detector. The Region Detector application starts running with the training scheme. During the training, it separates the screen into 12 regions. Then, the user is asked to look at one of these regions one by one for some time, while the software collects samples over twelve channels and computes an identifier vector of 12-dimensional for each region as explained in [13] in detail. Figure 3 shows a screenshot from the training application, where the colored bars indicate the sensor output levels read from twelve sensors.

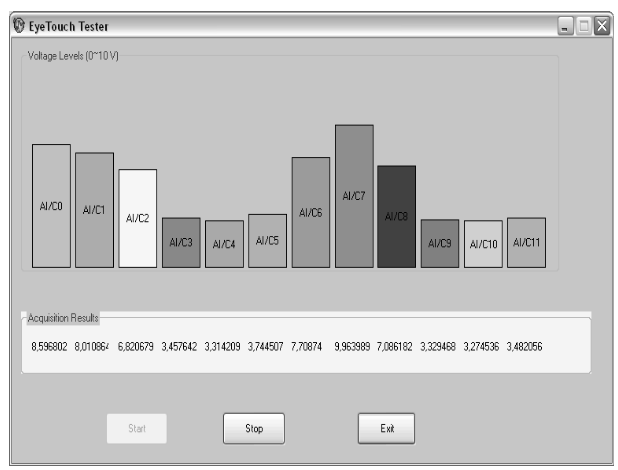

Fig. 3. Region detector training application.

After the completion of training scheme, Region Detector becomes ready for the tracking scheme where twelve boxes are revealed on the screen and each of them stands for one of the specific regions. The Region Detector continuously collects data in real-time and predicts the region which is being looked at by the user. The predicted box is highlighted as illustrated in Figure 4.

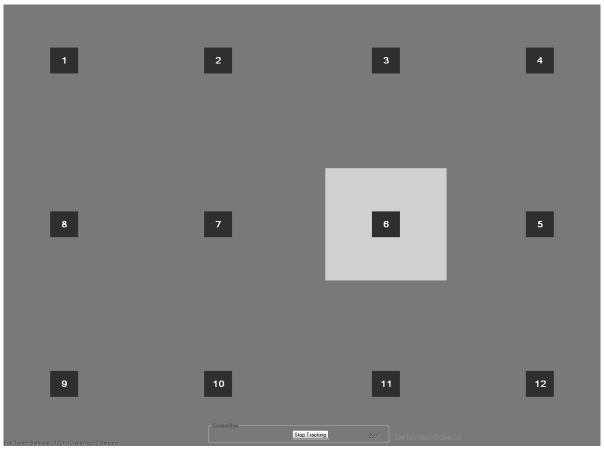

Fig. 4. Region Detector tracking application.

Cursor Tracker. The Cursor Tracker application is more complex and more versatile than the Region Detector, since it provides full control of the Windows mouse cursor including the click operations. After a training phase similar to the previous case, the application operates by supporting three main mouse operations: standing still, moving in one of the four directions (right-left-up-down), and click operations. Further details on the cursor tracker application can be found in [13].

III. EXPERIMENTAL RESULTS

Experiments conducted on ILSA-2 are presented to show its usability for the eye-tracking applications.

Figure 5 shows the sensor output voltage values that were acquired during the Region Detector's training scheme. Each vertical column stands for one of the classes (each class corresponds to one region on the screen) of Region Detector. Each line represents the output of one sensor and 10 samples were collected for each class. The readings from sensors 1, 2, 3, 7, 8, 9 are for the left eye and sensors 4, 5, 6, 10, 11, 12 are for the right eye. The responsiveness of the system is apparent from the sharp boundaries of class level transitions.

Figure 6 renders the output voltage data of three sensors, namely Sensor 3, Sensor 4 and Sensor 10 for 12 different gaze locations corresponding to 12 classes. The 3-D plot clearly shows the suitability of the data for classification purposes. That is, all twelve classes appear to be easily identifiable using any classification algorithm.

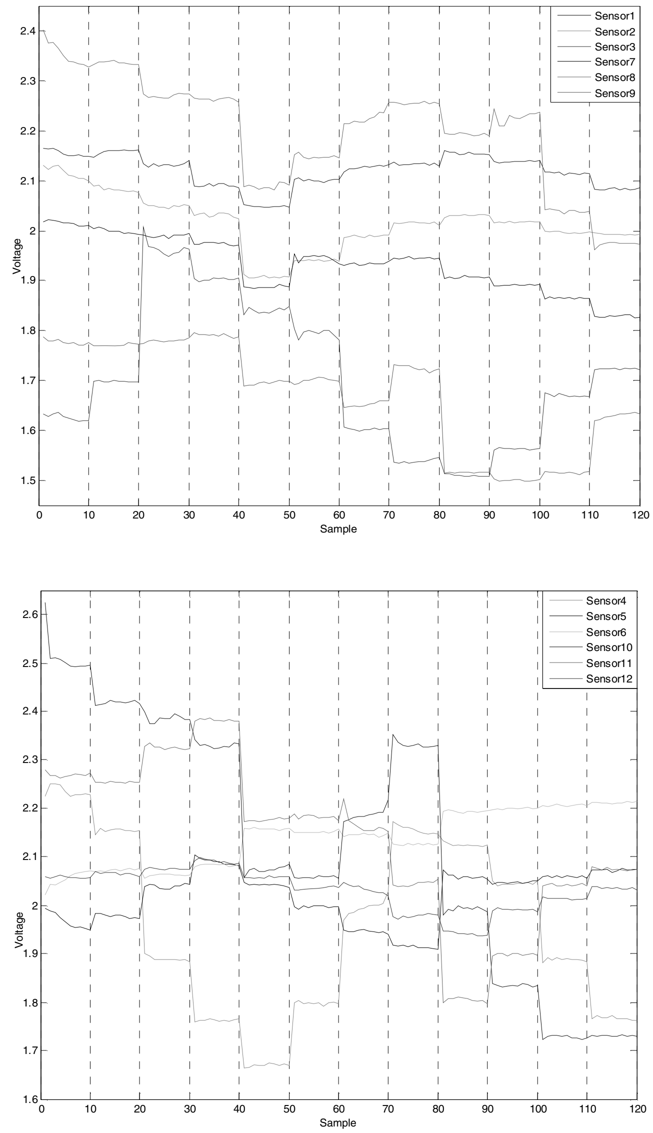

Fig. 5. Voltage vs. sample sketch of the data acquired during the training scheme.

The performance of ILSA-2 is also tested on real users. Each user is allowed to use Region Detector application after mandatory training phase. Users are requested to randomly look at one of twelve regions on the monitor. Then, Region Detector highlights the current region being looked at by the user (user-region) as in Figure 4. Finally, the user tells whether the Region Detector indication is correct. This process is repeated for 20 times per user and the performance of ILSA-2 for each region is determined based on 14 different users. The results obtained are reported in Table 2. Note that, during the experiments, users were not allowed to move their heads, which could otherwise reduce the application's performance.

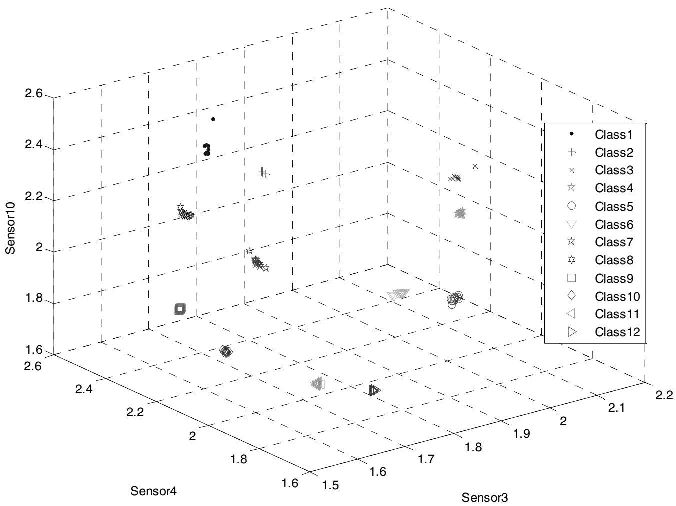

Fig. 6. Output voltage data of sensor 3, 4, and 10.

According to Table 2, ILSA-2 performed well for six regions (with 100% recognition performance) and performed satisfactorily for the others. As a result, comparing the user evaluation performance with ILSA-1, ILSA-2 was observed to improve the performance of Region Detector application by about 20%.

Table 2. A performance study of ILSA-2 for Region Detector application.

Region	Performance (%)	Region	Performance (%)
1	100	7	92.85
2	89.28	8	92.85
3	100	9	96.42
4	100	10	100
5	96.42	11	100
6	96.42	12	100

IV. CONCLUSIONS

In this study, an improved eye tracking system based on portable and low cost components in a wearable form is proposed and implemented. The elimination of classical video camera and corresponding high computational cost is the main advantage of the proposed system. The first implementation (ILSA-1) used focused LEDs and light frequency matching of the sensor/emitter pair was ignored. Diffused lighting and better light frequency matching is observed to improve both quantitative and user evaluation test results in ILSA-2. The experimental results and user opinions indicate that the proposed system constitutes a promising user interface alternative in certain circumstances where hand control may be inconvenient.

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REFERENCES

[1] COGAIN NoE (in EU IST 6th framework): Communication by Gaze Interaction, *http://www.cogain.org*.
[2] L. H. Yu and M. Eizenman, "A New Methodology for Determining Point-of-gaze in Head-mounted Eye Tracking Systems". *IEEE Trans. on Biomedical Engineering,* Vol.51, No.10, pp. 1765-1773, 2004.
[3] M. Akay, I. Marsic, A. Medl, and G. Bu, "A System for Medical Consultation and Education Using Multimodal Human/machine Communication". *IEEE Trans on Information Tech. in Biomedicine*, Vol.2, No.4, pp. 282-291, 1998.
[4] A. Amir, L. Zimet, and A. S.-Vincentelli, "An Embedded System for an Eye-detection Sensor". *Computer Vision and Image Understanding,* Vol. 98, pp.104–123, 2005.
[5] R. S. Allison, M. Eizenman, and B. S. K. Cheung, "Combined Head and Eye Tracking System for Dynamic Testing of the Vestibular System". *IEEE Trans. on Biomedical Engineering,* Vol.43, No.11, pp. 1073-1082, 1996.
[6] D. Droege, T. Geier, and D. Paulus, "Improved Low Cost Gaze Tracker," *Proc. The 3rd Conference on Communication by Gaze Interaction – COGAIN 2007*, Liecester, UK, 3-4 Sep. 2007.
[7] D. Agrafiotis, N. Canagarajah, D.R. Bull, and M. Dye, "Perceptually Optimised Sign Language Video Coding Based on Eye Tracking Analysis," *Electronics Letters*, Vol.39, No.24, 2003.
[8] D. Li, J. Babcock, and D. J. Parkhurst, "openEyes: A Low-cost Head-mounted Eye-tracking Solution*"*. ACM Eye Tracking Research and Applications Symposium - ETRA 2006.
[9] D. Li and D. Parkhurst, "Open-source Software for Real-time Visible-spectrum Eye Tracking". Proc. The 2nd Conference on Communication by Gaze Interaction - COGAIN 2006.
[10] J. S. Babcock and J. B. Pelz, "Building a lightweight eyetracking headgear". ACM Eye Tracking Research and Applications Symposium - ETRA 2004.
[11] J. P. H. Reulen, J. T. Marcus, D. Koops, F. R. De Vries, G. Tiesinga, K. Boshuizen and J. E. Bos, "Precise Recording of Eye Movement: the IRIS Technique*"*. Part 1, *Medical and Biological Engineering and Computing 26*, 1, 20-26, 1988.
[12] SKALAR IRIS IR EYETRACKER, *http://www.crsltd.com/ catalog/skalar /index.html*.
[13] C. Topal, Ö. N. Gerek, and A. Doğan, "A Head-mounted Sensor-based Eye Tracking Device: Eye Touch System", ACM Eye Tracking Research and Applications Symposium - ETRA 2008.