The Eye-Catching Mirror: Interactive Multi-View Mirror with Eye-Gaze and Head Coordinated Control

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ABSTRACT

Since the invention of the traditional mirror, hundreds of years have elapsed. Despite the usefulness of the traditional mirrors, several limitations still exist, i.e., difficulties to observe blind spots such as one's back, and can only provide one angle of view. Here, we intend to design and produce a better digital mirror, the Eye-Catching Mirror (ECM), that is easier and more convenient to use. Our ECM can provide the user with multiple views, other than only from the front. By recognizing one's head and gaze movement, we design our ECM can zoom in and switch view according to the user's commands. Also, selfies are taken randomly to capture the daily colorful moments. The user study suggests that the ECM can facilitate the users to check their blind spots, and users reported that they find the ECM is interesting and useful to use.

KEYWORDS

Eye gaze tracking, Face landmark detection, Parallel computing, HCI, and Movement recognition

ACM Reference Format:
Hongzhi Zhu, Zhuoheng Li, and Yang Hai. 2018. The Eye-Catching Mirror: Interactive Multi-View Mirror with Eye-Gaze and Head Coordinated Control. In *Proceedings of EECE 518*. ACM, New York, NY, USA, 7 pages. https://doi.org/NAN

1 INTRODUCTION

Mirror is one of the most frequently used object in our daily life, without which, people can barely have a clear view of themselves. Even with a mirror, sometimes, people can still encounter difficulties, i.e., when trying to see one's back, and when one is not tall enough to have a good view in the mirror. To overcome the difficulties, we propose the design of the ECM, as a digital replacement for the traditional mirrors. Our ECM can capture user's gaze and head motion as control inputs to ease the procedure to use our mirror, as well as providing broadened views from different angles. Such design, to the best of our knowledge, is novel. The realization of the ECM integrates multiple human computer interface (HCI) technologies, as well as computer vision (machine learning) methods. Three component technologies are involved in our ECM, which are: gaze tracking technology, head-movement recognition, and digital mirror technologies, and we have a brief review next, respectively.

In the late 1980s, Hutchinson et al., [1] proposed the idea of human computer interaction using eye-gaze position as input. There are 4 basic methods of tracking human eyes: electro-oculography, scleral search coils, infrared oculography and video oculography [2]. For their noninvasive characteristics, the infrared oculography and video oculography methods are the most commonly used methods. However, the measurement accuracy is not as good as that with search coils or electro-oculography. Recently, the eye-gaze tracking methods are broadly applied in a wide range of HCI methods. Many of the recent works also employs the gaze position as control input to the system as assistive tools for the disabled [3–5]. However, eye gaze assisted control cannot be overtaxed as a reliable control method. The usually encountered issue is the Midas Touch Problem [6]. What is more, according to Kowler [7], the eye movement can be more sophisticated than what a simple tracking method can handle, as eye movements are controlled both consciously and unconsciously. If the eye gaze moves in an unpredicted manner, the four methods above may fail to produce a reliable tracking result.

Head movement recognition was a challenging research topic before the emergence of machine learning techniques and advancement in computer's processing power. The traditional way of monitoring the head movement is using the mechanical and/or electrical position tracker [8]. Although this kind of method gives us an accurate way of recording body movements, the direct contact device might be very high in cost and might also hinder body movements. Now, thanks to the machine learning methods, plenty of head movement recognition methods have been proposed. A survey can be found at [9]. The human facial features give researchers more critical information on identifying the exact head movement from place to place. Some hi-tech companies are using face recognition to identify the users, this verification can recognize the difference of static picture and real people. In our project, a similar facial recognition program is applied for head movement recognition.

The combination of using head and gaze movement as control input is not a new technology but the application scenario is rather limited [10]. By tracking the joint movement of eye gaze and head, the researchers can obtain more useful information about the user. However, only a few HCIs have employed the joint movements to easy the operation flow or to improve user experience. Caspi [11] uses the eye-head combination control to reduce the task load for the user to operate the retinal prosthetics. Another example indicate that, the head-eye control expanded the degree-of-freedom

EECE 518, April 2018, UBC

ACM ISBN NAN.
https://doi.org/NAN

of a user's operation range, increasing the operation flexibility and liability [12].

Another technology we need to adopt is the digital mirror technology [13]. We can easily spot a digital mirror in a public place. However, a common feature of such products is that, there are rarely interactive elements in the product design. So this type of product should be seen as a mixture of mirror and display rather than a combination. An interesting application developed Sharp is the Magic Mirror [14], users can virtually try the Uniqlo products and save the fitting process. Some of the ideas in our project are similar to that, for example, using a front camera as the information source, the information is processed and the feedback is provided as well. One of the aim of a mirror-like HCI is reflecting most of desired information without delay which is the design idea of our project.

For the design of ECM, we tend to take the advantages of the aforementioned technologies and produce a HCI replacement for traditional mirrors. To demonstrate our design and the resulting product, the rest of this paper is organized as follows: 1) The overall design objectives and methods are elaborated in Section 2; 2) The demonstration of our ECM as well as the results of user study are presented in Section 3; and 3) The last part in Section 4 discusses the limitations and future works of our system.

2 SYSTEM DESIGN

The HCI system we tend to built is the ECM. It is a digital HCI replacement for traditional mirrors, helping people adjust appearances without omitting a tiny piece of detail in an efficient, convenient way. To achieve our intended objectives for the ECM, we need to employ a user friendly design and also utilize multiple technologies.

2.1 The Target Functionalities

To achieve our goal, we design the ECM to consist three parts:

(i) The input devices, which includes several webcams and an eye gaze tracker. The webcams are positioned such that they can film the user from different angles. In our product, we use three webcams, and we place one in the front, one in the back and one from the right side of the user. The eye gaze tracker are positioned in the front to trace the user's point of gaze.
(ii) The processing center, namely the laptop in our case, is the processing unit to receive all the inputs and interacts with the user.
(iii) The user interface, which is the laptop's display, acts as an interactive mirror that displays what is recorded from one of the webcams.

With each part, the whole system can improve users' mirror viewing experience by providing more angles of view as well as employ body movements to control the user interface. Delivering the user's needs as well as to facilitate smooth use of our ECM, the following functionalities are designed.

(i) Head movement triggered change of view. The front webcam can record the user's face, and from the recorded video stream, we intend to apply the face landmark recognition algorithm to recognize the user's head movement. When the user shake his or her head to the left, the processing center can recognize the movement and change the source of the video stream from the current webcam to the webcam left to the current one. If the user shakes head to the right, the video stream from the webcam right to the current webcam will be displayed on the interface.
(ii) Head movement triggered zooming at eye-gaze point. When the processing center detects that the user nods his or her head, the zooming command will be sent out to the interface. Therefore, what is shown on the interface is the zoomed video stream centered at the user's gaze point.
(iii) Randomly taken multi-view selfies. Since most of the unforgettable moments can happen unexpectedly, we also design the random selfie functionality into the ECM that can capture the movement randomly while the user is using our system.

2.2 Methods

As what is discussed in Section 2.1, the ECM is a system consists of several component hardwares and softwares. In order to achieve desired functionalities, several basic functionalities have to be achieved first, which are:

(i) Face landmark detection;
(ii) Eye gaze point estimation; and
(iii) Synchronization and data sharing between different hardwares with different sampling frequency

For rest of the section, we propose several methods to achieve the aforementioned basic functionalities, and from there, we can come to the overall design of the ECM.

2.2.1 Face landmark detection. Recognizing face landmarks is an ongoing research topic in the field of artificial intelligence and HCI [1]. In our ECM system, as we try to employ the head movement as the input control command, inevitably, we need to use the face landmark detection algorithm. There are plenty of algorithms proposed in the literature, some of the most popular ones include [15], [16] and [17]. In our ECM, we utilize the open source dlib library [16] to detect facial landmarks.

The dlib library contains a pre-trained machine learning algorithm and is capable of detecting 68 facial landmarks on our face. Figure 1 shows two examples of detected 68 facial landmarks [1].

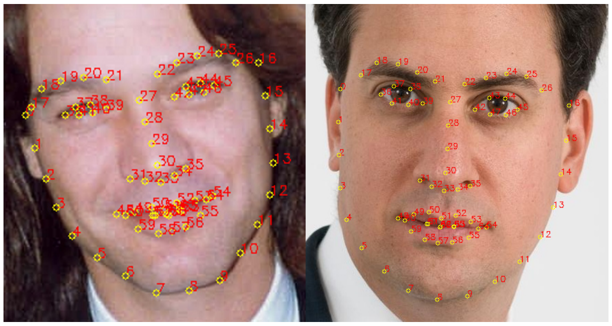
Once we can detect the face landmarks, it is not hard for us to detect if the user is nodding or shaking his or her head. The detection of the nodding movement is done by finding the position of the 30^{th} face landmark, denoted as (x_{30}, y_{30}), which is the position of the nose tip on the image, with respect to the 8^{th} face landmark and 27^{th} face landmark, denoted as (x_8, y_8) and (x_{27}, y_{27}) respectively. When the user is facing the webcam normally without any nodding, the ratio r_{nod}:

$$r_{nod} = \frac{y_{27} - y_{30}}{y_{30} - y_8} \tag{1}$$

is around 1. But when the user is nodding, the ratio will increase. A threshold can be set such that when r_{nod} increases and exceeds

[1]Origin: Ed Miliband image by the Department of Energy, licensed under the Open Government License v1.0; and Eddie Van Halen image by Alan Light, licensed under the Creative Commons Attribution 2.0 Generic license. Available at http://matthewearl.github.io/2015/07/28/switching-eds-with-python/

Figure 1: Examples of detected face landmarks.



1.3 and then decrease back to the value around 1, the processing center will recognize that a nodding event has occurred.

For the detection of shaking head to the left or to the right can be done similarly by calculate the ratio r_{shake}:

$$r_{shake} = \frac{x_2 - x_{30}}{x_{30} - x_8} \tag{2}$$

where (x_2, y_2) and (x_{14}, y_{14}) are the positions of face landmarks 2^{nd} and 14^{th} respectively. We set that when r_{shake} increases and exceeds 3.0, followed by a decrease, the processing unit will perceive the event of shaking one's head to the right; and when r_{shake} decreases and drops below $\frac{1}{3}$, followed by a rebound, the processing unit will perceive the event of shaking one's head to the left.

What is worth mentioning is that the dlib library can only perform the detection of landmarks on human face at the rate around $6Hz$ if using only a single thread. To avoid delay and have a higher processing rate, we need to turn to the parallel computing methods, which will be discussed in Section 2.2.3.

2.2.2 Eye gaze point estimation. Eye gaze tracking is gaining its popularity in the recent decade as people believe that one's gaze point directly reflects one's attention, which is useful information for HCI designs and psychology related researches [18]. In our ECM system, we intend to use the joint movement of the head and eye to control the zooming functionality. Since the gaze point directly measures the position where the user's attention is, we argue that zooming at the user's gaze point is very natural and efficient. However, due to measurement noise and inaccuracies, what the eye gaze tracker measures may not reflect the actual position of the gaze point. Therefore, a moving average filter of length 40 is applied to the measured gaze point data to smooth out the noise and stabilize the measurement [19].

2.2.3 Hardware synchronization and data sharing. As component hardwares used in our ECM system can have different sampling frequencies, synchronizing inputs from different hardware sources can be a major issue if we want to have a smoothly working system. Therefore, it is not surprising to turn to the CPU parallel computing architecture for solutions. The OpenMP [20, 21] is the API that enables parallel computing with shared data memory, which can be of good help if we can employ it in our system.

2.2.4 Algorithm Design. Figure 2 shows the flowchart of the algorithm for the ECM. Once the program starts, it sequentially initiate webcams, the eye-gaze tracker and the user interface (UI). Once the preparation part is done, the algorithm is going to the parallel part which contains 4 independently executed thread loops, which are 1) the UI thread, that controls the display on the UI; 2) the webcam thread, that charges the task of reading video stream from each webcam; 3) the eye-gaze thread, that takes the task of acquiring measured eye-gaze position from the gaze tracking; and 4) the control tread, where all the inputs from webcams and gaze-tracker are gathered and processed to control the UI. These 4 threads are independent and therefore they can be executed at different rate. Therefore, hardwares that work at different sampling frequencies may not cause delay in our algorithm, and our algorithm can always acquire the most updated data from each component hardware. Acquired data are shared between all threads, solving the problem of hard synchronization and data sharing. It can be also noted, that in the webcam thread, idling thread is called to perform the face landmark detection task, which increases the throughput of the face landmark detection algorithm and avoid delays. Once the user terminates the algorithm, all these 4 thread loops are stopped and connected hardwares are closed to end the algorithm. One additional function that is executed in the control loop is to take selfies randomly. Once the user finished using the ECM, he or she can check the randomly taken multi-view selfies at the program folder. Hopefully, the selfies can help capturing the very moment the user want to share.

3 RESULT

In this section, two components of the result of our ECM are discussed. The first is the resulting product according our design idea and methods used. The second is the user test result, which evaluates the effectiveness and usefulness of our system.

3.1 System Layout

In this subsection, we specify all the equipment details. we also show the actual product we have built as well as introduce the procedure to use our product.

3.1.1 Equipment details. Figure 3 shows the setup of our ECM. We use three webcams, where webcam 1 is the Logitech C270 HD webcam, webcam 2 and 3 are Logitech C170 webcam. The three webcams are positioned to have three views of the user at the center. One webcam is placed in the front, one webcam is place to the right side of the user, and the last one can record from behind. All webcams have a sampling frequency of $30Hz$. The gaze tracker we use is the GP3 Gazepoint tracker. It can track a position of the gaze point at an accuracy between 0.5 deg -1.0 deg of visual angle, and it has a sampling frequency of $61Hz$. The processing center we use is the dell Inspiron 15 7000 laptop. It has the Intel Core i7 7700HQ CPU with 4 cores (8 independent threads), which allows for efficient processing of acquired data under the parallel architecture. The user interface is the laptop's display. It is a 15.6 inch screen of 1920×1080 resolution, with a refresh rate of $60Hz$.

3.1.2 How to use. As what is shown in figure 3, to use our ECM, the user needs to sit at the center of the ECM. He or she needs to adjust all 3 webcams to make sure they can capture the best image

Figure 2: Flowchart of the algorithm

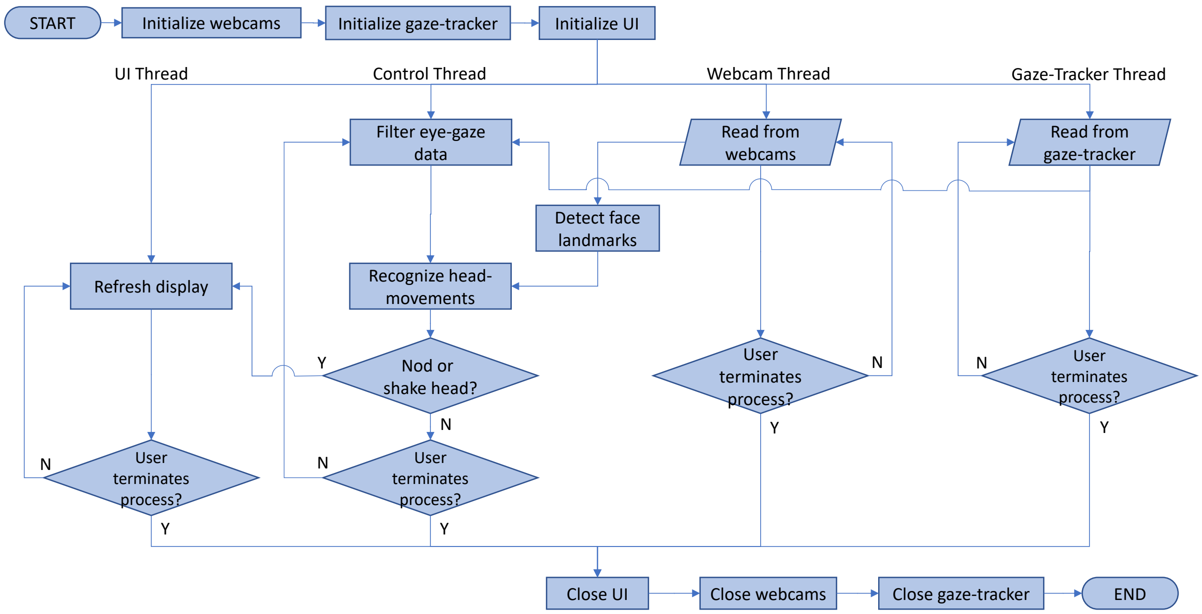


Figure 3: System Setup

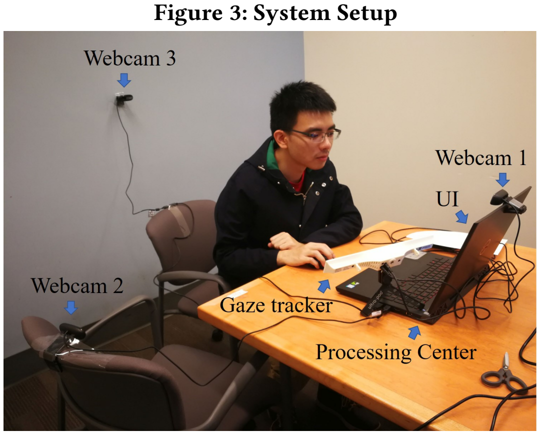
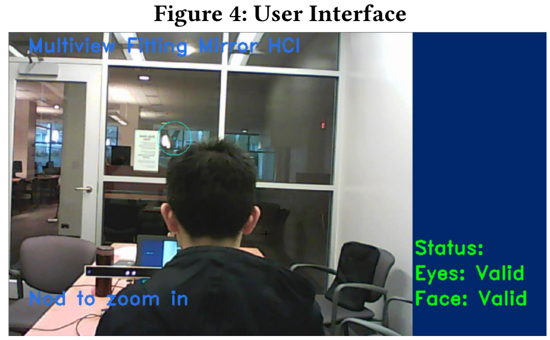


Figure 4: User Interface



of the user at the center. A calibration procedure is needed for the gaze-tracker to have an accurate measure of the gaze point.

Once the calibration is finished, the main UI will pop up on the screen. Figure 4 shows the UI. It is a back view of the user. The 3 webcams will be recording the user simultaneously but only one stream of the video will be shown at the main UI. The video stream from the front webcam will be continuously use to record the head movement of the user in order to control the UI. By shaking the their head to the right or to the left, the users can switch the source of the video stream that is displayed on the UI. By nodding the user's head, he or she can zoom in or out the video stream at the position where he or she was gazing at. The light blue dot with the circle indicates the position of the gaze point on the screen. The status bar at the right bottom corner of the UI indicates if all input devices are working properly.

To exit the program, the user can press the Esc button on the keyboard. Then the randomly taken multi-view selfies will pop up and the user can pick the liked ones to share with others or save them for later use. Figure 5 shows an example is the multi-view selfies.

3.2 User Study

3.2.1 Participants. A total of 7 participants (UBC students) took part in the user study, which was composed of 5 males and 2 females. Participants range from 18 to 30 years old. All of the testees are daily users of digital camera for selfies, so they can perform naturally when using our system. Besides, all of the participants

Figure 5: Multi-view Selfies

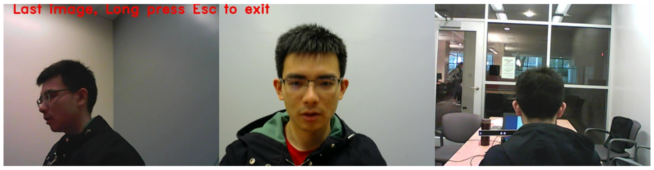
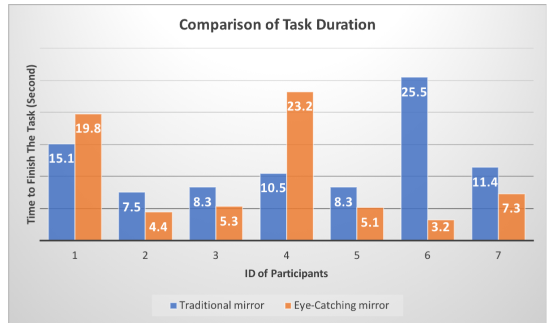


Figure 6: Comparison of Task Duration



use traditional mirrors every day, so their comparisons about the ECM and traditional mirrors are reliable.

3.2.2 Experiment design. The experiment was performed in a study room and the whole system included a laptop, an eye-gaze tracker and three external webcams. The laptop was placed on the desk at which the participant seated, and the screen of the laptop was used to simulate the mirror. The eye-gaze tracker was put beside the laptop in order to capture the movement of testees' eyes. Moreover, three webcams were fixed in front of, behind and on the right of the testee respectively so the testee could get three different view-angles and switch among them on purpose.

The experiment was divided into three parts: pre-survey, user-test and post-survey. Before each participant tried the ECM, they were asked to fill a pre-survey, which aimed to record users' habits of using mirrors. During the user-test, participants experienced the system under instruction and finished several tasks independently. Finally, every user was asked to fill a post-survey to tell their first-hand experience and additional comments.

3.2.3 Questionnaire. There were two questionnaires in the experiment, the pre-survey and the post-survey.

Pre-survey. The pre-survey mainly consisted of three categories:

(i) Statistics on users' habitual actions of using traditional mirrors, especially when they were looking at blind spots in front of the mirror. This type of questions are supposed to find the inconvenient conditions when users are dealing with a traditional mirror.
(ii) A measure of testees' sensibility of their appearance. It reveals testees' dependency and willingness of using the view-switch and zoom-in function of the system.
(iii) An evaluation on testees' interest in standing before the digital mirror.

The target of the pre-survey was to collect participants' information on the extent how they wanted to use mirrors on a daily basis. Besides, it also aimed to know people's approaches to see different view angles of themselves in front of traditional mirrors.

Post-Survey. After the testees finished the user-test, they were asked to fill another survey, which covered the following fields:

(i) Basic information (age, education background, etc.).
(ii) User's frequency of using mirror every day.
(iii) An evaluation of the difficulty to use our HCI, which measures the usability of the system.
(iv) Users' feeling of the improvement in efficiency of appearance finishing comparing to traditional mirrors.
(v) An evaluation of the new function (including the new ways of interaction) of the ECM, which reveals the system's most valuable parts to users.
(vi) Users' concern about their privacy when using this system in a public or private environment.

The goal of the post-survey was to further understand participants' habits of using mirrors and get user's evaluation of the system's efficiency and highlights.

Both quantitative and qualitative data was gathered in the surveys in order to analyze users' experience comprehensively afterwards, and thus produce an accurate and objective data analysis results.

3.2.4 Task. In the User-test stage, we firstly introduced our system to the user. After the system finished calibration with the user, the participant had several minutes to get familiar with the system operations. Then the testee was asked to fulfill a series of tasks:

(i) A small piece of paper with a word written on it was stuck on the back of the testee, and the testee was asked to use the system to read out which word was on the paper. The tester would observe the user's behavior to evaluate the ease of use of the system and record the time it took to finish the task to assess the improvement in efficiency.
(ii) A small piece of paper with another word written on it was stuck on the back of the testee, and testee was asked to use the system (with only the front webcam on) as a traditional mirror to read out which word was on the paper. The tester would record the time it took to finish the task as a comparison to evaluate the performance of the ECM system.
(iii) The small piece of paper would be intentionally left on the testee's back while the testee was doing the post-survey. The tester would remind the participant only if the experiment had finished and the participant still forgot the take it off. The result was recorded to evaluate the participants' sensibility to their appearance.

3.2.5 Analysis.

Quantitative. Figure 6 shows the time participants spent finishing the task. We can see there was a significant decrease (by about 62% on average) in time for most users (5 out of 7) to use the ECM to read out stickers on their back. For skillful users (User ID: 6), this

Figure 7: Level of Difficulty of Using The HCI

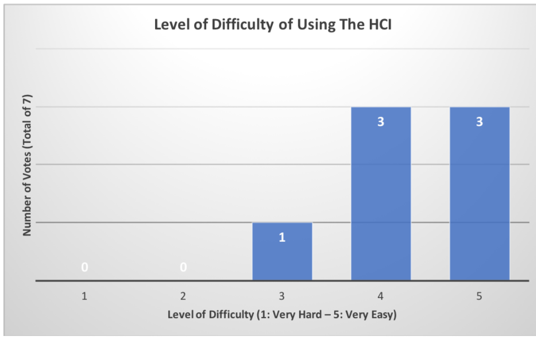
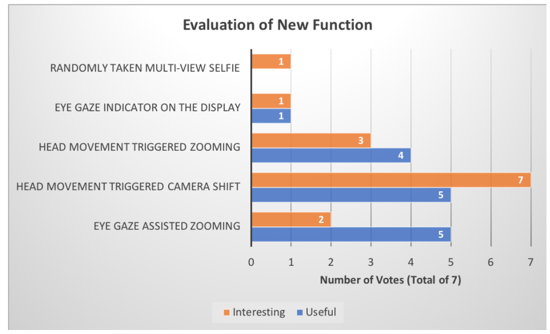


Figure 8: Evaluation of New Function



gap can be really huge (reducing 88% of the time) comparing to the traditional mirror. It can be concluded that the ECM is handy at tackling hard problems that traditional mirrors are facing. As users get adapted to the new ways of interaction, the improvement in efficiency becomes more obvious. On the other side, it cannot be ignored that some users were confused with the interaction due to the delay of view change with their action commands. They became a bit disappointed and impatient, and even stopped operating the system, which explains the grow in time for User 1 and User 4.

Qualitative. In order to evaluate the potential requirement of our ECM, participants were asked their normal ways of looking at blind spots, such as their back in front of a mirror. The statistics shows the majority of users (5 out of 7) preferred to turn their bodies to see their back, which is considered as the easiest and commonest way to interact with a traditional mirror. The potential problem is that under some circumstances, it could be difficult or even impossible for people to turn their bodies, e.g., when they are dying their hair and sitting in a chair.

Figure 7 shows the testees' evaluation of the usability of the system. Only one participant expressed his or her difficulty in using the system, while others all used it smoothly. The results are consistent with what the tester observed while participants were experiencing the new functions. We found that all the testees could operate the system properly at the end of the instruction and some of them became proficient in playing with it after a very short time. The results reveal that the ECM demands very low learning cost and would be accepted by most users that have a similar background with the participants.

In the survey, some qualitative questions were also designed to assess the system's most attractive parts. In Figure 8, it shows that all the participants found it interesting to switch view-angles with head movement. With this new type of interaction, users would not desperately twist their bodies to look at their back or sides, especially when they are unable to do so. This convenient action command also makes it possible to get multiple view-angles of a certain pose and users would not need other mirrors or advisors for help as before. Besides, Figure 8 also shows most users found it useful to use eye gaze assisted zooming to get a close-up view at where they were staring at. During the experiment, the testers were surprised to find some users were able to master this function unconsciously. When they were asked to read out the word on the paper, they switched the view quickly and accurately zoom in to the word area, even though the word was big enough to read in the normal display mode.

It is also observed that sometimes the system performed not as smoothly as expected. As a result, some participants thought the system failed to recognize their command and gave the same command several times, which led to a sequence of confusing view change. Moreover, the mis-recognition of users' unconscious actions could also trigger the respond of the system, which also annoyed some testees during the tasks.

The privacy issue is also considered as a problem in the experiment. Although all the participants were guaranteed to protect their personal information before the test, most of them (6 out of 7) still showed strong concerns about personal images leakage in a public environment. Fewer testees (4 out of 7) expressed the same concerns if they used this system privately.

At the end of the experiment, the testers found 3 participants out of 7 did not realize there was still a sticker on their back when they were leaving the room. It indicates that even the testees were told beforehand a paper was stuck on their back, the back area can also be easily omitted if they were doing other things at the same time, which was owing to the blind spot in front of a traditional mirror.

4 CONCLUSION

In this paper, we presented an innovative digital mirror: the ECM, which was designed to overcome several drawbacks of the conventional mirror. By using a new way of interaction, users are allowed to switch view-angles freely or zoom in to a specific point accurately by moving their heads or eye-gaze points in front of the mirror. Experiments have been conducted to prove the improvements it can bring to help users check the blind spots when adjusting appearance. Besides, it also demonstrates the system is easy and friendly for new users to experience.

The extension of the system could be done by incorporating a huge digital screen and more webcams to display more information simultaneously. For example, a bigger display area can show multiple view angles at the same time or use secondary screen mode to constantly show a fixed view angle at the corner while users are switching to other angles. Additionally, the movement detection algorithm we employ is a simple threshold based method, which may be oversensitive or invalid for certain people. We can also introduce the machine learning method to produce higher success rate to detect head movement. What is more, the cost for our produce is high due to the use of the gaze tracker as well as the processing center. If we want our product to be financially acceptable by the general public, the cost needs to be reduced by 60%.

ACKNOWLEDGMENT

The authors would like to appreciate all participants in our project. We would like to give special thanks to Prof. Sid Fels and our teaching assistant Ms Qian Zhou for their critical ideas and comments to our project. Also, we want to thank all who joined our user test for their valuable evaluations and suggestions.

REFERENCES

[1] X. Zhu and D. Ramanan, "Face detection, pose estimation, and landmark localization in the wild," in *Computer Vision and Pattern Recognition (CVPR), 2012 IEEE Conference on.* IEEE, 2012, pp. 2879–2886.

[2] H. Chennamma and X. Yuan, "A survey on eye-gaze tracking techniques," *arXiv preprint arXiv:1312.6410*, 2013.

[3] M. Minamoto, Y. Suzuki, T. Kanno, and K. Kawashima, "Effect of robot operation by a camera with the eye tracking control," in *Mechatronics and Automation (ICMA), 2017 IEEE International Conference on.* IEEE, 2017, pp. 1983–1988.

[4] C. Wirawan, H. Qingyao, L. Yi, S. Yean, B. S. Lee, and F. Ran, "Pholder: An eye-gaze assisted reading application on android," in *2017 13th International Conference on Signal-Image Technology Internet-Based Systems (SITIS)*, Dec 2017, pp. 350–353.

[5] A. Ishizuka, A. Yorozu, and M. Takahashi, "Motion control of a powered wheelchair using eye gaze in unknown environments," in *2017 11th Asian Control Conference (ASCC)*, Dec 2017, pp. 90–95.

[6] B. Velichkovsky, A. Sprenger, and P. Unema, "Towards gaze-mediated interaction: Collecting solutions of the "midas touch problem"," in *Human-Computer Interaction INTERACT 97.* Springer, 1997, pp. 509–516.

[7] E. Kowler, "Eye movements: The past 25 years," *Vision research*, vol. 51, no. 13, pp. 1457–1483, 2011.

[8] M. N. Sahadat, A. Alreja, and M. Ghovanloo, "Simultaneous multimodal pc access for people with disabilities by integrating head tracking, speech recognition, and tongue motion," *IEEE Transactions on Biomedical Circuits and Systems*, vol. 12, no. 1, pp. 192–201, Feb 2018.

[9] E. Murphy-Chutorian and M. M. Trivedi, "Head pose estimation in computer vision: A survey," *IEEE transactions on pattern analysis and machine intelligence*, vol. 31, no. 4, pp. 607–626, 2009.

[10] M. Ito, K. Sato, and M. Fukumi, "Optimization of categorizing driver's head motion for driving assistance systems," in *2012 Proceedings of SICE Annual Conference (SICE)*, Aug 2012, pp. 471–474.

[11] A. Caspi, P. E. Rosendall, J. W. Harper, M. P. Barry, K. D. Katyal, G. Dagnelie, and A. Roy, "Combined eye-head vs. head-only scanning in a blind patient implanted with the argus ii retinal prosthesis," in *2017 8th International IEEE/EMBS Conference on Neural Engineering (NER)*, May 2017, pp. 29–32.

[12] M. Boulanger and A. Lamontagne, "Eye-head coordination during overground locomotion and avoidance of virtual pedestrians," in *2017 International Conference on Virtual Rehabilitation (ICVR)*, June 2017, pp. 1–2.

[13] thecloudcasting, "iface digital mirror," 2018. [Online]. Available: http://www.thecloudcasting.com/iface-digital-mirror/

[14] Sharp, "Sharp magic mirror," 2018. [Online]. Available: http://retail-innovation.com/uniqlos-magic-mirror

[15] Z. Zhang, P. Luo, C. C. Loy, and X. Tang, "Facial landmark detection by deep multi-task learning," in *European Conference on Computer Vision.* Springer, 2014, pp. 94–108.

[16] D. E. King, "Dlib-ml: A machine learning toolkit," *Journal of Machine Learning Research*, vol. 10, no. Jul, pp. 1755–1758, 2009.

[17] X. P. Burgos-Artizzu, P. Perona, and P. Dollár, "Robust face landmark estimation under occlusion," in *Computer Vision (ICCV), 2013 IEEE International Conference on.* IEEE, 2013, pp. 1513–1520.

[18] C. H. Morimoto and M. R. Mimica, "Eye gaze tracking techniques for interactive applications," *Computer vision and image understanding*, vol. 98, no. 1, pp. 4–24, 2005.

[19] I. G. Tong, "Eye gaze tracking in surgical robotics," Ph.D. dissertation, University of British Columbia, 2017.

[20] B. Chapman, G. Jost, and R. Van Der Pas, *Using OpenMP: portable shared memory parallel programming.* MIT press, 2008, vol. 10.

[21] L. Dagum and R. Menon, "Openmp: an industry standard api for shared-memory programming," *IEEE computational science and engineering*, vol. 5, no. 1, pp. 46–55, 1998.