

A ROBOT ARM CONTROL SYSTEM FOR AMPUTEES USING EYE GAZING TECHNIQUES

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Abstract

Many people lose their limbs due to many reasons, like car accidents, wars, birth defects, etc., which makes doing their daily activities difficult or even impossible. The future technologies of the robot applications can be used to help those amputees' peoples. The robot controller is designed based on the eye gazing techniques, so it is possible for the robot to compensate the limbs in many of the jobs. In this paper, a robot controller is designed based on the direction of the eye gaze. In the proposed system, Industrial glasses are designed first to capture video for the eye, where this video is then analysed by the MATLAB software in order to track eye gaze towards the targets points. After that, the decision will be made, and then commands will be sent to the robot in order to achieve one of the functions of the limbs that will be performed by CS-113 ARM Robot. Several challenges are discussed and processed in order to solve the problem of eye structures differences and their effects on accuracy. The experimental results show the possibility of using the proposed system by the amputees.

Keywords: Amputees, ARM robot, Artificial limb, Eye gazing tracking, Machine vision, Robot controller.

1. Introduction

The robots have been widely deployed in all areas of life and have become remarkably active in industrial, military and even personal applications, making them an indispensable part of life. These robots are self-controlled robots or can be controlled by humans (wired or wireless), and there are hybrid control types that respond by both other types of control. The types of wired robots, wireless robots and even self-controlled robots are remotely controlled using a hand-based control panel. Therefore, amputees are deprived of the possibility of using these robots in personal tasks and cannot be used in applications mentioned earlier.

In recent decades, researchers developed eye-tracking methods that have become a good tool to help with different applications. The using of eye-tracking research is developed during three eras that summarize as follows: In the first interval (around 1879-1920), the discovery of key concepts of eye activity such as the suppression of saccadic, cumin latency, and the size of the period of perception. In the second interval, begin at around 1930 to 1958 characterized by more applied fields that employ an eye movement in experimental psychology. Based on studies by Rayner [1] and Nakazawa et al. [2], while in the third era (around 1970-1998), refinement eye-tracking methods led to becoming more interactive and could be used in more applications such as diagnostic or interactive applications.

The robustness of interaction between human and computers by interfacing methods led to using eye tracking as input tools for visual applications. An interfacing system must interact with the user based on observation of eye movements. Such interfacing systems can be categorized into two systems: selections system and gaze-contingent system. In selective system, using the gaze point as a pointing device like a mouse, while gaze-contingent systems employ the user's gaze knowledge to aperient the rapid rendering of complex displays (e.g., graphical environments) [3-5].

Biswas et al. [6] and Mason et al. [7] mentioned that the technologies of identifying eye gaze play an important role to extract information and features that help in the human-computer interaction (HCI) and machine smartness, in which, the researchers are interested with this topic while the accuracy of detecting and investigation of eye gaze play as an important role in the system performance. The intrusive techniques that used for extracted information with high accuracy from eye movements required equipment like electrodes, contact lenses, or head-mounted devices to physical contact with the user during the image acquisition [8-11]. While the nonintrusive technique used eye image captured by cameras for eye gaze estimation. The main four methods that used in nonintrusive techniques are the corneal reflex spots method, mapping function methods, artificial neural network, and projective geometry methods [12, 13].

There are two methods can be used for tracking eye gaze; the first one is dependent on corneal reflex spots, which can be achieved by analysing the IR spot reflected by the cornea. This method by Wang et al. [14] required complicated and expensive hardware; also, it is affected by sunlight and the type of glasses. The other method includes the principle of pattern recognition of eye based on image processing techniques, this method is starting with capturing video for eye and then analyse the video frames in order to extract the information required for recognition and then achieving tasks [15-18].

In this paper, the robot control system has been designed based on eye gaze to track points of targets in order to help amputees for achieving their tasks. The project

starting by implementing glasses having a camera, which uses to capturing video of eye gazing to the target points, then the captured video will be analysed by image processing technique in order to extract eye gazing features that used to identify and perform the tasks. There are several challenges are found through deriving the mathematical model, which required to obtain the gaze parameters and used to select the task, which should be performed. The challenges are represented by the structure of human eyeball and the structure of Glasses that used for this purpose. Several algorithms are used to achieve segmentation of frame extracted from the eye video. In addition, iris recognition has been performed to evaluate the iris deviation, in addition, a mathematical model is derived to evaluate the eye gaze direction based on iris deviation, which is used as stimuli for making decisions, and then generates parameters used to control ARM robot. The CS-113 ARM Robot is used to achieve several experiments that test this system. Experiments are starting by capturing video and using MATLAB to analyse this video (frame by frame), then using the extracted features for eye gazing in robot control tasks.

The paper is organized as follows: In Section 2, the methodology of eye gazing tracking has been introduced; in Section 3, the implementation control system of ARM robot is explained, in Section 4, several experiments are implemented, while the results have been discussed. Finally, in Section 5, the conclusions of the paper are drawn.

2. Tracking of Eye Gaze

In order to control the ARM robot, eye gaze tracking must be achieved. In the proposed system, the eye deviation and eyelash have been used as stimuli for this purpose. Figure 1 shows the comprehensive block diagram of the proposed system, which is describing the process of controlling the ARM robot. The sequence of the processes is starting by the real-time capturing video, which is read by a personal computer. The captured video is processed by MATLAB, which decision will be taken in order to produce the tasks that send to the controller box by RS232, which are used to control the ARM robot.

2.1. Monitoring eye in real-time

A video capturing system has been designed to monitor eyeball motion as shown in Fig. 2. The eyeball motion is affected by head movement due to the eye gaze is affected by the outside environment, so the industrial black glass is used to fixed the camera to the head, which reduces the effects of head movement on the eyeball motion.

Monitoring the eyeball motion needs to capture video in real-time. There are many types of cameras, which are categorized according to the resolution of the camera, snapshot speed (frame/s), zoom (lens size), and prices. Therefore, the features of the camera must be discussed in order to select a camera with optimum features for this task. Certainly, increasing the resolution of the camera will increase the performance of monitoring, but this required excellent microprocessor with high processing speed and big memory size. Snapshot speed should be selected suitable for the speed of the eyeball, in this work 30 frames/s or more is selected. Lens size is a very important factor because it effects on the camera resolution, which limits the distance between the camera and the eyeball (in this work the camera will be close to the eye). Finally, for more practical selection, the price of the camera should be appropriately chosen to be commercially accepted.

As shown in Fig. 2, high-definition (1080p) webcam has been used with 5x digital zoom, 24 bit/pixel, and 8.6447 frame rate. The camera must have fixed inside black isolated glasses in order to protect the video capture environment from affected by outside environment light, also, the normally distributed light inside video capture environment prevents the reflection of light spot by eye iris that will complicate the tracking of the eyeball and reduces the accuracy.

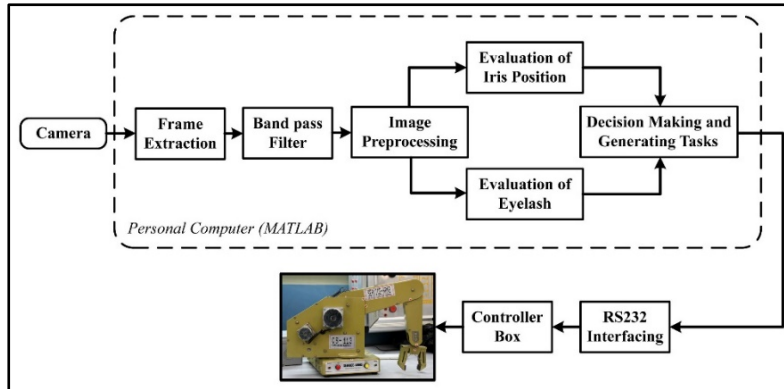


Fig. 1. Block diagram of the comprehensive ARM robot system controlled by tracking the eye gaze.



Fig. 2. Video capture system.

2.2. Video preprocessing

Real-time video is analysed by MATLAB in order to extract the information required for gaze tracking that will be converted to the decision process. A video analysing starting by video pre-processing, which the captured video will unzip into sequences of frames analysed separately by image processing. According to Rashid [19], each frame passes into a sequence of the image processing system in order to find the centre coordinate of iris; these processes are shown in Figs. 3(a) to (f).

The original image is shown in Fig. 3(a) has been converted to a grayscale image then manipulated by pixel intensity value to produce a binary image (see Fig. 3(c)), after that all bubbles in regions are filled to get solid regions in an image. Now the noise, which represented by unwanted small regions has been removed while only one region is passed from the high pass filter as shown in Fig. 3(d). This region is an iris,

which passes through a centroid algorithm in order to detect the centre of the region as shown in Figs. 3(e) and (f).

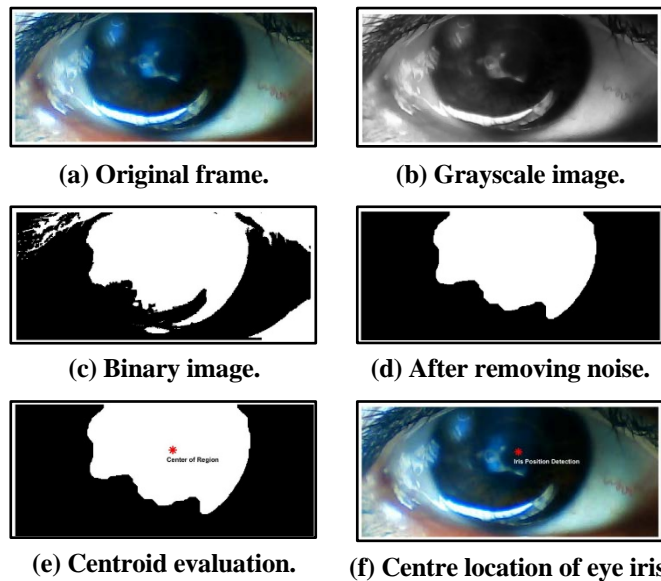


Fig. 3. Detection eye iris centre position by image processing.

2.3. Eye gaze estimation

In the previous subsection, the centre coordinate of iris has been detected, so the distance of iris deviation can be calculated when eye gaze is changed, and the accuracy of measurement is related to the image pre-processing quality, also the maximum distance of iris deviation can be calculated as shown in Fig. 4(a). The iris location at the eye centre representing the reference displacement ($x = 0$) while the displacement to right and left are x and $-x$ respectively. Figure 4(b) shows the displacement and direction of the camera lens with respect to the eye. The value of iris deviation angle from the camera side can be easily evaluated by

$$\varphi = \tan^{-1} \left(\frac{W_E}{2D} \right) \quad (1)$$

The value of φ can be used for camera snapping range, but the value of φ affected directly by value of iris displacement (x). Eye gaze estimation can be achieved based on the iris deviation distance and the gaze direction is the angle between the line of sight and the straight line between the camera lens and centre of eyeball [20]. But there are many challenges must be solved to get high accuracy measurements, these challenges represented by the difference of eyes structures from human being to another, which the eye structure effecting on the value of (D , W_E , and x) as shown in Fig. 5.

To solve this problem, the mathematical model for estimating the eye gaze based on the eyeball dimension and the iris diameter as shown in Fig. 6 is used. C_1 and C_3 are the start and endpoints of the iris plane when iris centre and a camera centre are located on the straight line (the iris deviation is zero ($x = 0$)).

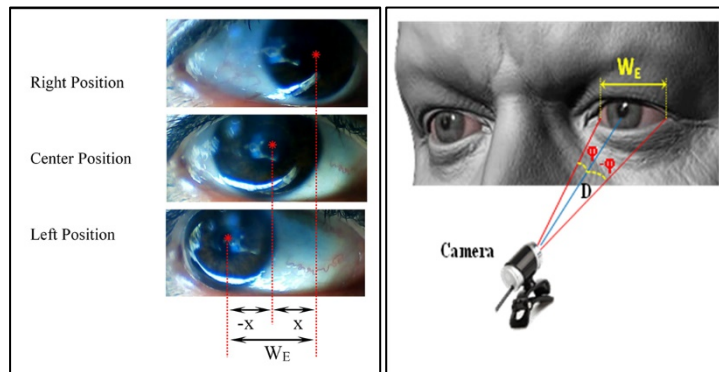
While B_1 and B_3 are the start and endpoints of the iris plane in the case of gaze to the target point. In this case, the value of iris deviation (x) can be calculated by the following Eq. [18]:

$$x = \overline{B_2 C_2} = \frac{Rd \cos \Phi \sin \theta}{d + R \cos \Phi - R \cos \Phi \cos \theta} \quad (2)$$

$$\Phi = \sin^{-1} \frac{r}{R} \quad (3)$$

where R is the eyeball radius, r is the iris radius, θ is the deviation angle from the eyeball side, and d is the distance between the eyeball and target point.

Gaze diagram in Fig. 6 shows that for increasing the tasks, which performed by eyeball motion, the number of target points must be increased, but there is a limitation for the number of target points, this limitation is the accuracy of tracking target points. To solve this problem the eyelash and gaze timing can be used to increase the number of tasks. Also, the distance between the eyeball and the camera lens (d) is an important factor related to the accuracy of evaluation eye deviation to the target point (see Eq. (2)). Increasing the distance (d) will increase the accuracy of tracking and controlling eyeball to target, but the distance is limited by the glasses, which is used for this purpose.



(a) Distance of iris deviation. (b) Angle of iris deviation.

Fig. 4. Maximum iris deviation.



Fig. 5. Different types of eye structure.

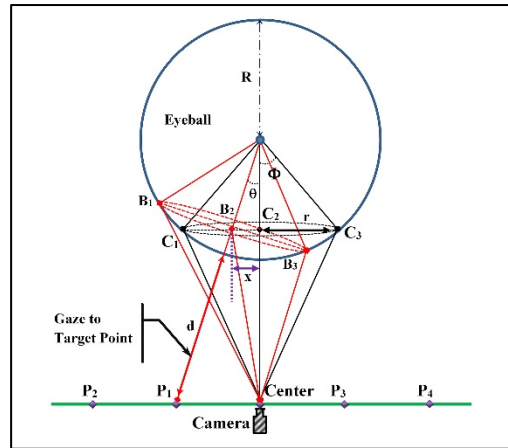


Fig. 6. Diagram of gaze direction.

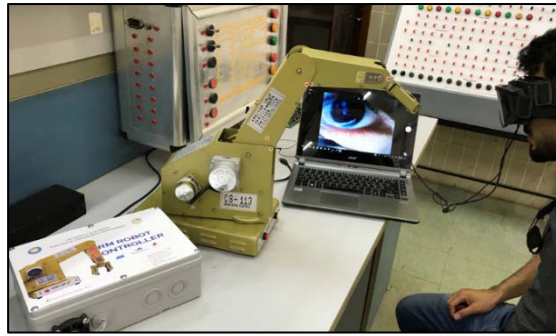
3. Implementing a Robot Control System

Many researchers have been using the microprocessor to implement the proposed control systems [21-26]. In this paper, CS-113 ARM robot will be used for testing the efficiency of the control system by eyeball. CS-113 ARM robot is designed to simulate industrial robot operation in laboratory, which controlled by a personal computer using a simple basic program while the main part of CS-113 is Z-80A microprocessor board. The CS-113 has been modified by replacing the Z-80A microprocessor mainboard by the ATmega2560 microcontroller board in order to be compatible with windows system, also it can be easily programmed by high-level languages like MATLAB, Visual studio dot net etc. The CS-113 ARM robot is shown in Fig. 7(a) while the schematic diagram is shown in Fig. 7(b), which its specifications are multi-jointed, metal-plate structure with six stepper motors, position precision is ± 0.9 mm, loading capacity is 0.5 kg (Max.), grasp of hand is 45 mm, movement speed is 300 mm/s (Max.), and progress of freedom is 5. The Rotation of range for each motor is shown in Table 1.

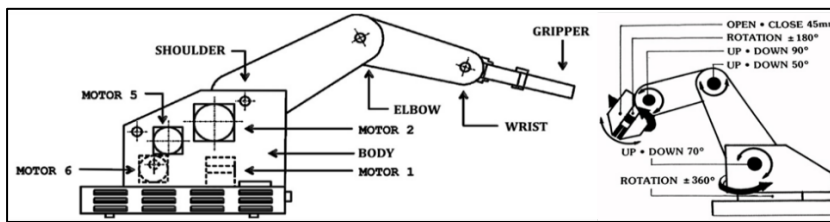
The motion control of CS-113 ARM robot is achieved by using six motors as shown in Fig. 7(b), therefore, eyeball motion will be employed for gazing to six target points in order to control the six motors and in addition to start/stop instruction will be achieved by an eyelash at the centre target point. To get more accurate results the target points will be placed on a curve instead of a straight line in order to achieve the same distance (d) between each target to the eyeball (see Fig. 8). The motor must be rotated in both directions, so the gazing to target point represents the value of rotation, while direction selection performed by an eyelash.

Table 1. Motor movement specification.

Joint name	Rotation range
Body	240° (right 120°, left 120°)
Shoulder	144° (up 72°, down 72°)
Elbow	100° (up 50°, down 50°)
Bending of wrist	180°
Rotation of wrist	360°



(a) CS-113 ARM robot.



(b) CS-113 ARM robot schematic diagram.

Fig. 7. ARM robot description.

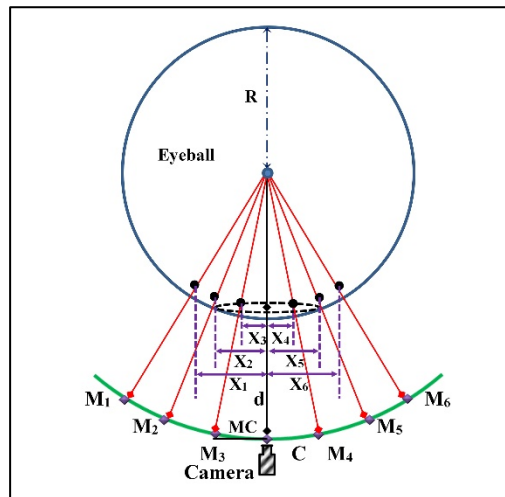


Fig. 8. Targets points diagram for CS-113 ARM robot controller.

4. Experiments and Results

The CS-113 ARM robot will be controlled based on eyeball motion in the horizontal axis, and the iris deviation is tracked by image processing. As mentioned in previous sections, there are many limitations in iris deviation traction, which is represented by eye type, so these limitations are evaluated based on Eq. (2).

In Fig. 9, the relation between the deviation angle (θ) and deviation distance (x) is evaluated at ($R = 12.5$ mm, $r = 6.5$ mm) for different values of eyeball to target distance (d). From which, we can be seen the value of deviation distance is affected by the distance of the camera with respect to the eye, especially when the camera is placed close to the eye, but after 60 mm the effective of the distance value (d) is starting to reduce. Figure 10 shows the effective of eyeball and iris radius. From this figure, it can see that the value of angle deviation is fixed to ($\pi/12$) and then the value of iris deviation is evaluated with respect to camera location for different values of eyeball and iris radius. As seen in Fig. 10, the value of iris deviation is affected by the size of eyeball and iris, so the human eye must be calibrated at the first step when using the system.

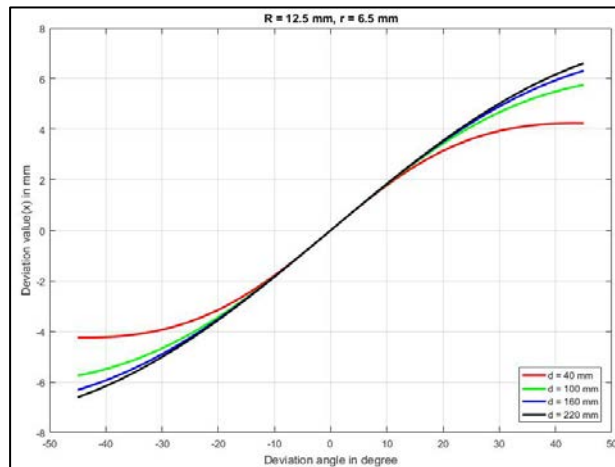


Fig. 9. Iris deviation (x) with respect to deviation angle (θ).

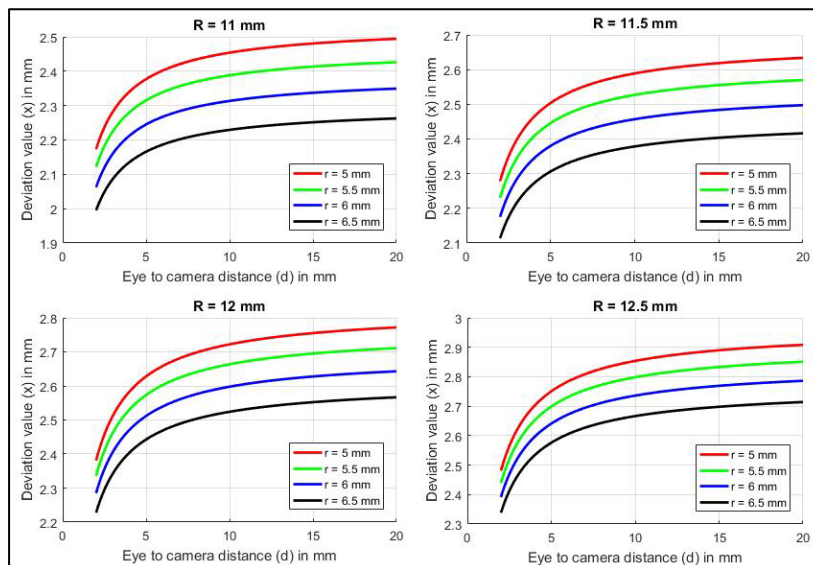


Fig. 10. Iris deviation (x) with respect to camera location (d).

In order to test the effectiveness of the designed system, several experiments have been performed and performance evaluation has been achieved. Iris deviation has been practically evaluated with respect to target points that are shown in Fig. 8. The angle deviation of each target point evaluated based on the following equation:

$$\theta = \tan^{-1} \frac{MC}{d + R} \tag{4}$$

These values are evaluated for an eye with ($R = 12.5$ mm, and $r = 6.5$ mm), and the camera is placed in the distance ($d = 40$ mm). In addition, the distance between each two target points is ($MC = 10$ mm). Figure 11 shows the comparison between simulation and practical results while the error value between simulation and practical results are listed in Table 2. These values of error are acceptable for system performance due to the gap between iris deviation values with respect to the error value.

The comprehensive system has been tested by experiment setup that emulates the task of ARM robot motion to achieve path planning. Figure 12 shows the prototype task of the industrial application represented by transfer products from point to the target place. The motion of robot ARM's joints is controlled by eye movements, which the angular displacement of each joint is specified by gazing time to target point in glasses. Figure 12 shows the relation between gazing time and angular displacement value for each tested joint.

Table 2. Comparison between simulation and practical values of iris deviation.

Target point	Deviation angle (degree)	x-coordinates of target points	Iris deviation distance x_s (simulation)	Iris deviation distance x_p (practical)	Error = $ x_s - x_p /x_s$
M1	-30	10 mm	-5.15 mm	-4.82 mm	0.068
M2	-20.85	20 mm	-3.5 mm	-3.23 mm	0.077
M3	-10.78	30 mm	-1.75 mm	-1.83 mm	0.045

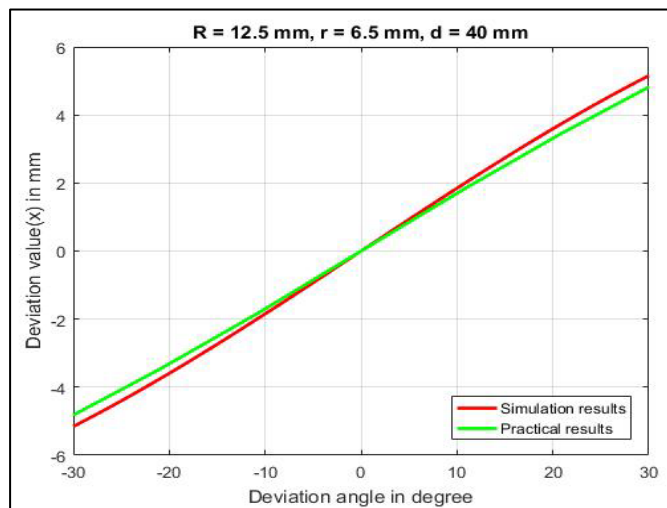


Fig. 11. Simulation and practical values of iris deviation with respect to deviation angle.

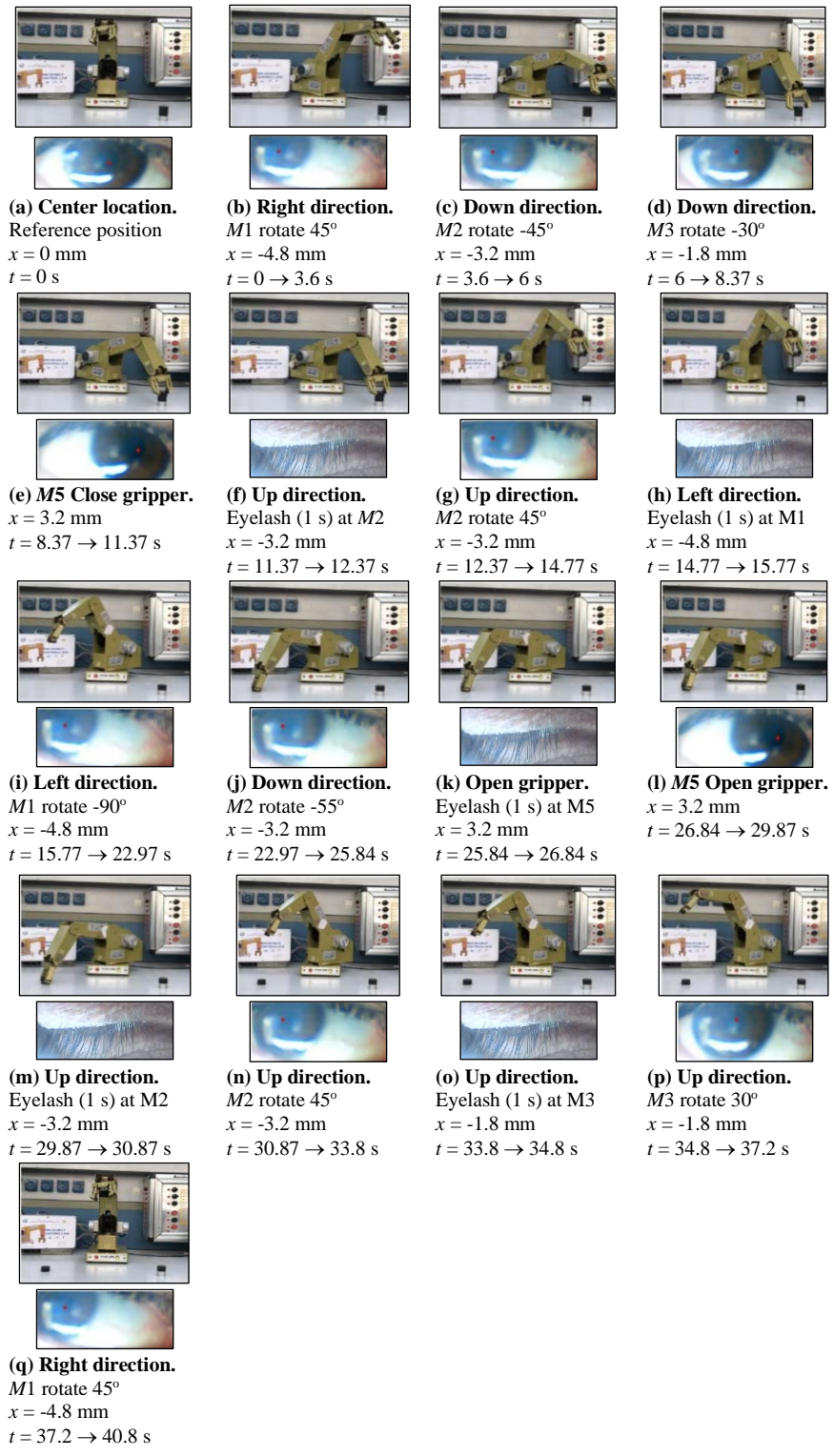


Fig. 12. CS-113 ARM robot controlled by eye gaze.

At this test, the robot ARM reaches the target position directly, but this status represented ideal state, normally the user needs more time for tuning position. The user needs to be trained on this system to reduce the time required for tuning position. For example, several persons with different ages tested the designed system by control robot motors to achieve ARM robot joint angle value. Figure 13 shows the number of trials to train with respect to personage, which these values are approximate values.

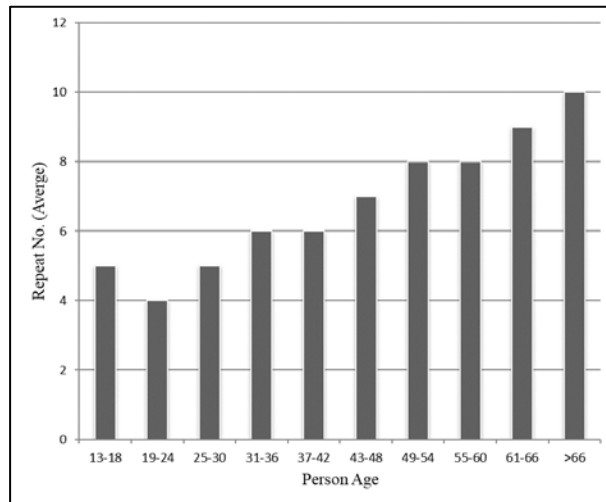


Fig. 13. Training test on motor no. 3.

5. Conclusions

In this paper, the robot controller based on tracking eye gaze has been achieved and the system is tested by performing several experiments using CS-113 ARM robot. During the emulate process of eyeball motion through gazing to target points, appeared several challenges represented by analysing capturing video by image processing and the structure of the human eye. Therefore, the iris location detection during eye gazing to target points fixed inside industrial glasses, while the difficulty through iris tracking appear when eyeball affected by an outside light spot, which this problem solved by using isolated black industrial glasses. The challenges of the human eye structure have been discussed, in which the effectiveness of eye structure parameters on the evaluation of iris deviation has been minimized during the eye is gazing to the target points. Eye-tracking system practically tested on the human eye with ($R = 12.5$ mm, $r = 6.5$ mm, $d = 40$ mm), in which, the results show the control system can track the iris deviation during gazing to the targets points. The ARM robot has been tested for the ability to employing it in the industrial application in real-time. In addition, the amputees must be trained in order to achieve the joint angle with good accuracy and suitable time.

References

1. Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, 124(3), 372-422.

2. Nakazawa, A.; Kato, H.; Nitschke, C.; and Nishida, T. (2017). Eye gaze tracking using corneal imaging and active illumination devices. *Advanced Robotics*, 31(8), 413-427.
3. Duchowski, A.T. (2002). A breadth-first survey of eye-tracking applications. *Behavior Research Methods, Instruments, & Computers*, 34(4), 455-470.
4. Jacob, R.J.K.; and Karn, K.S. (2003). Eye tracking in human-computer interaction and usability research: Ready to deliver the promises. *The Mind's Eye: Cognitive and Applied Aspects of Eye Movements*, 573-605.
5. Nouredin, B.; Lawrence, P.D.; and Man, C.F. (2005). A non-contact device for tracking gaze in a human computer interface. *Computer Vision and Image Understanding*, 98(1), 52-82.
6. Biswas, P.; Dutt, V.; and Langdon, P. (2016). Comparing ocular parameters for cognitive load measurement in eye-gaze-controlled interfaces for automotive and desktop computing environments. *International Journal of Human-Computer Interaction*, 32(1), 23-38.
7. Mason, M.F.; Hood, B.M.; and Macrae, C.N. (2004). Look into my eyes: gaze direction and person memory. *Memory*, 12(5), 637-643.
8. Duchowsky, A.T. (2007). *Eye tracking methodology: Theory and practice* (2nd ed.). London: Springer Verlag.
9. Hyoki, K.; Shigeta, M.; Tsuno, N.; Kawamuro, Y.; and Kinoshita, T. (1998). Quantitative electro-oculography and electroencephalography as indexes of alertness. *Electroencephalography and Clinical Neurophysiology*, 106(3), 213-219.
10. Babcock, J.S.; and Pelz, J.B. (2004). Building a lightweight eye tracking headgear. *Proceedings of the Eye Tracking Research and Applications Symposium*. New York, United States of America, 109-113.
11. Nguyen, B.L.; Chahir, Y.; and Jouen, F. (2009). Free eye gaze tracking using Gaussian processes. *Proceedings of the International Conference on Image Processing, Computer Vision, & Pattern Recognition*. Las Vegas, United States of America, 137-141.
12. Zhang, Y.; Zhao, X.; Fu, H.; Liang, Z.; Chi, Z.; Zhao, X.; and Feng, D. (2011). A time delay neural network model for simulating eye gaze data. *Journal of Experimental & Theoretical Artificial Intelligence*, 23(1), 111-126.
13. Xia, D.; and Ruan, Z. (2007). IR image based eye gaze estimation. *Proceedings of the Eighth ACIS International Conference on Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing (SNPD)*. Qingdao, China, 220-224.
14. Wang, Y.; Yuan, J.; Chang, S.; and Zhang, Y. (2002). Gesture labeling based on gaze direction recognition for human-machine interaction. *Optical Engineering*, 41(8), 1840-1844.
15. Rozado, D.; Moreno, T.; San Agustin, J.; Rodriguez, F.B.; and Varona, P. (2015). Controlling a smartphone using gaze gestures as the input mechanism. *Human-Computer Interaction*, 30(1), 34-63.
16. Zhu, Z.; and Ji, Q. (2004). Eye and gaze tracking for interactive graphic display. *Machine Vision and Applications*, 15(3), 139-148.

17. Colombo, C.; Comanducci, D.; and Bimbo, A.D. (2007). Robust tracking and remapping of eye appearance with passive computer vision. *ACM Transactions on Multimedia Computing, Communications and Applications*, 3(4), 1-20.
18. Wang, J.-G.; Sung, E.; and Venkateswarlu, R. (2005). Estimating the eye gaze from one eye. *Computer Vision and Image Understanding*, 98(1), 83-103.
19. Rashid, M.T. (2015). Modeling of self-organization fish school system by neural network system. *Basrah Journal for Engineering Sciences*, 15(1), 14-19.
20. Zhang, W.; Zhang, T.-N.; and Chang, S.-J. (2011). Eye gaze estimation from the elliptical features of one iris. *Optical Engineering*, 50(4), 047003.
21. Zungeru, A.M.; Mangwala, M.; Chuma, J.; Gaeboloe, B.; and Basutli, B. (2018). Design and simulation of an automatic room heater control system. *Heliyon*, 4(6), 1-17.
22. Aldair, A.; and Wang, W.J. (2010). Adaptive neuro fuzzy inference controller for full vehicle nonlinear active suspension systems. *Proceedings of the 1st International Conference on Energy, Power and Control (EPC-IQ)*. Basrah, Iraq, 97-106.
23. Li, D. (2016). Smart home system implementation based on ARM microprocessor. *Proceedings of the 6th International Conference on Electronic, Mechanical, Information and Management Society*. Shenyang, China, 1152-1156.
24. Aldair, A.A.; Alsaedee, E.B.; and Abdala T.Y. (2019). Design of ABCF control scheme for full vehicle nonlinear active suspension system with passenger seat. *Iranian Journal of Science and Technology, Transactions of Electrical Engineering*, 43(1), 289-302.
25. Lachin, V.I.; Solomentsev, K.Y.; and Demidov, O.Y. (2016). Microprocessor instrumentation and control systems for power generating objects' parameters. *Proceedings of the 2nd International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM)*. Chelyabinsk, Russia.
26. Nefed'ev, A.I.; and Sharonov, G.I. (2016). Development of microprocessor-based car engine control system. *Procedia Engineering*, 150, 1341-1344.