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Robot Control Systems Using Bio-Potential Signals

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Abstract. Robot control systems via human bio-potentials, such as electroencephalography (EEG), electrooculography (EOG), and electromyography (EMG) signals offers unlimited opportunities to stakeholders. Research and development of the technology essential for estimating and identifying the usable biological signals through sensors and signal processing techniques, as well as their conversion into control scheme has been carried out in the recent past. The need for bio-signal control is heightened by elderly and disabled people who through myriad of happenstances have lost control of the environment. To promote quality of life and self-reliance, biotechnology joined with Man-Machine interfaces are a promising undertaking. In this research, we utilize EOG, EMG and eye related information to control a robot in 3D environment. By mapping gaze motions to corresponding inverse kinematics, the operator can control a robot arm through his eye movements and facial muscles. The results prove the workability of the concept which on further improvement, would avail a dynamic 3D bio-signal control system.

INTRODUCTION

In modern Japan, as the population is aging, dysfunctions related with senility and the like are on the rise. On the other hand, disabilities stemming from traffic and occupational accidents have a potential to change the lives of individuals from self-reliance to dependents. The reality is that, the numbers of such people who need constant nursing care are increasing. To this end, support for restoration of control to individuals, restoration of independence in career, reduction of the caregivers' burden, etc. are issues that cannot be wished away. In the recent past, research in human-machine interface using biomedical signals that are extended to people with disabilities have gained traction for enhancing self-reliance of the elderly and persons with disabilities and towards reducing burden on the nursing persons.

As mentioned above, bio-signal technology paired with a support equipment and or communication schemes can handle or lessen the severity of the challenges experienced by the elderly and disabled. Bio-signals are present in any human being in varying forms e.g. electromyography (EMG) [1], electroencephalography (EEG) [2], and electrooculography (EOG) [3] to list but a few. EOG focuses on the potential resulting from the movement of the eyes. In this technique, EOG signal waveform that is generated when the subject is looking upwards, downwards, left or right is interfaced with a computer system which associates the eye potential with the viewing angle. EMG on the other hand deals with the signal generated by contraction of muscles.

EOG signals have been implemented in various research areas. In [4], EOG was applied to control mouse functions. Gadget control by classifying EOG with Deterministic Finite Automata was introduced by [4]. EOG signal was used in wheelchair control to help disable people [5]. The authors reported an accuracy of approximately ±2°. In [6], an improvement system of automatic wheelchair with EOG signal was developed with PIC microcontroller.

In [7], research to combine EOG and two degrees of freedom robot manipulator was introduced. EOG signal was grouped by four positive thresholds and four negative thresholds for both vertical and horizontal gaze motions. The

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values of thresholds are varied among persons. These thresholds were used to control velocity of robot. Blink was used if the robot reached a target. In [8], a 2-dof planar robot was controlled by gaze motions. EOG signals were controlled by creating vector equations between horizontal and vertical signals. Blink was also used to operate this system.

This study is centered on the man-machine interface system using EOG and EMG as applied in a manipulator control system. In this work, the EOG signals are used to move the joint angles whereas EMG is used for grasping objects using the manipulator end-effector. Discrimination of meaningful EOG and EMG signals is required prior to the application of the signal in the control scheme. To this end, motion of the joints of the manipulator are determined by EOG discrimination where the polarity of the gaze determines the direction of motion. EMG discrimination method is used to control the arm gripper to grasp and release the target object.

Additionally, the motion-and-grasp task is extended to cover a 3D workspace. For the system, two cameras are integrated in the setup to give front and top view of the target. The EOG signal is thereby divided in to two; blink and gaze. The gaze, which translates to the point in space where the user is looking at, provides coordinates that moves the robot. The linear relationship between the EOG signal and gaze motion was determined by affine transform. Blink, on the other hand, switches the camera from side to top as need arise. The system could discriminate between voluntary and involuntary blinks. Camera switch was performed by flip-flopped based system using voluntary blink only.

Further, a man-machine servo interface was developed using EOG and EMG bio-potential signals for controlling one-axis positioning system. The relationship between the force generated by chewing and the resulting EMG signal was linear whereas EOG signal is proportional to the acceleration of the eye movement. EMG signal was employed in switching while time integral of EOG signal with a threshold was used for servo motor input signal.

CONTROL SYSTEM BASED ON ELECTROOCULOGRAPHY AND ELECTROMYOGRAM

In this research, four electrodes are connected as shown in Figure 1 to record EOG signal using custom made bio-amplifier circuit. The signal was recorded using NI USB 6008 for A/D conversion. We managed to record and distinguish four eye movements from two EOG signals that obtained from specific electrode positions as shown in Figure 1 below. The eye movements are used as the gaze to control the direction of the robot. The EOG signals produced was converted to pixel units by using the linear relationship between EOG signals and gaze motion distances. Affine transformation method is utilized to derive actual target from gaze information. Further details can be found in [9] and [10].

We utilized EMG signal recorded from masseter muscle with a bipolar electrode positioning to get bite muscle activity. We utilized the amplitude of the EMG to infer bite strength. In this way, the EMG is used as a gripper force. We distinguished the EOGs and EMGs into 5 patterns as described in Fig.2 below.

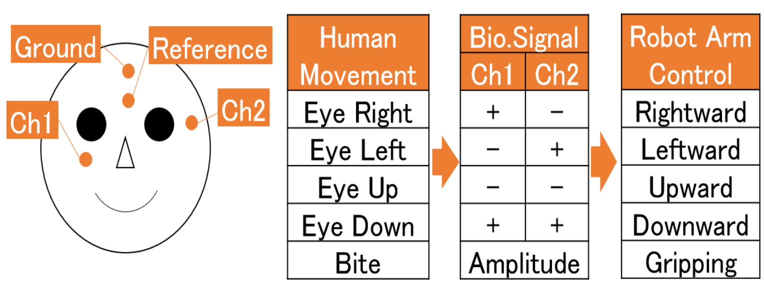
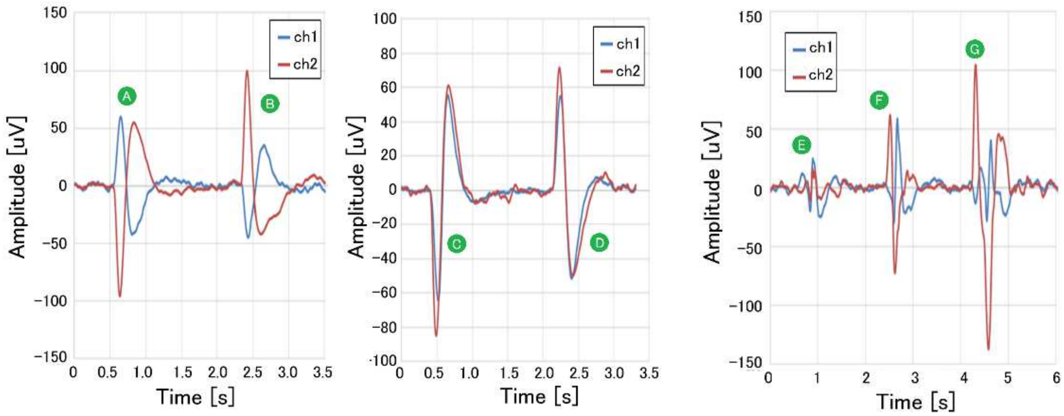


FIGURE 1. Control System based on EOG and EMG.



a) EOG b) EMG

FIGURE 2. a) EOG signals for movement control: A- Left eye movement B - Right Eye movement C - Look up D - Look down. b) EMG signals for bite strength Control: E - Soft bite, F - Normal bite, G - Strong bite

CONTROLLING 3-D MOVEMENT OF ROBOT MANIPULATOR USING EOG

In this study, EOG signal was used to translate gaze information to object positions in a 3D workspace. Two cameras were used to give front and top view information of the target object. Affine transform method was applied to generate the relationship between gaze motion and EOG signal. This research combines three building blocks to implement a robot manipulator control; EOG signal acquisition and processing, target display system and robot control bloc. Each of this block was performed by designated computer as shown in Fig. 3 below. The first part was the EOG signal acquisition and analysis. The signal acquired was classified either as gaze motion or eye blink. Eye blinks were used to switch the active display of computer 2. The block utilized two cameras for side view and top-view of the manipulator workspace. Computer 2 gave visual feedback of the target. Switching between displays of either front camera top camera gave the user perspective of the target position. Operators moved their eyes to the targets on the monitor display.

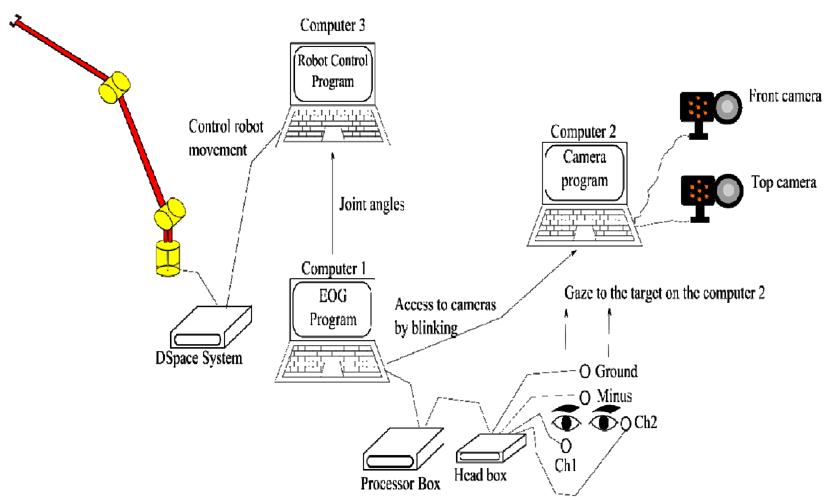


FIGURE 3. Environmental experiment.

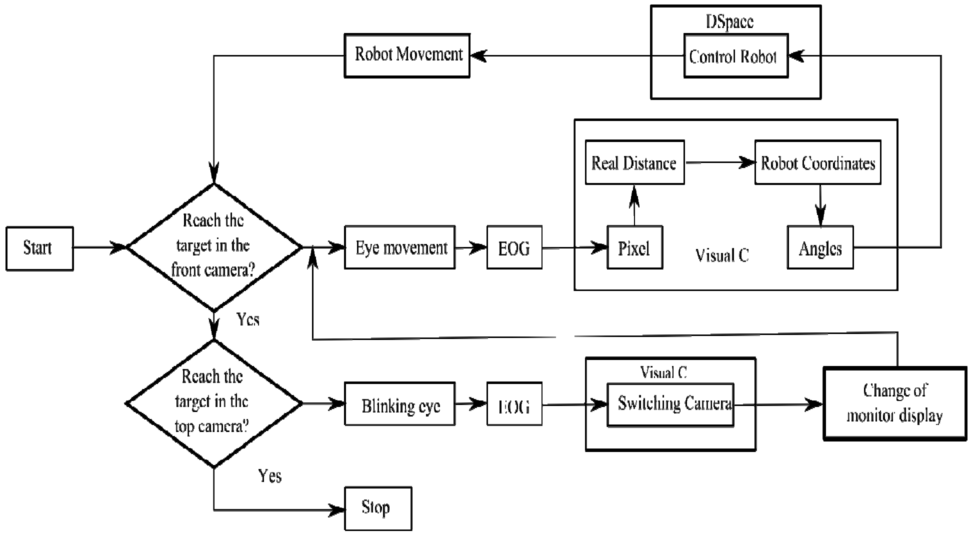


FIGURE 4. Process of using EOG signal to control robot manipulator in 3-dimension.

The last building block was the robot control system. dSPACE® environment was used to interface between the robot and generated joint angles. Gaze motion was used to guide the robot arm to a target position. The target position in pixels was converted into real world distance units. The distances were transformed to the robot coordinates based on the correlation between cameras and robot position. Once the target position in the robot coordinates were established, joint angles were calculated using inverse kinematics. Figure 4 illustrates the process of eye movements to control robot.

RESULTS AND DISCUSSIONS

Figure 5 below describes the physical setup with two target used to evaluate the system. Figure 6(a) shows front view and Figure 6(b) shows the top view of the setup with robot arm current position marked with a green circle. The performance of tracking the target position using EOG system is evaluated with real positions. Evaluation was on the performance of the transform function of the EOG gaze to pixels. From transformation algorithm, affine transform showed an accurate performance in tracking objects with an error of approximately 0.86˚± 0.67˚ in the horizontal and 0.54˚ ± 0.34˚ in the vertical.

Eye blink information was utilized as a switching mechanism between the two cameras. Our proposed system availed such mechanism to user with great discrimination between voluntary and involuntary blinks. The key was how the affine transform rotate the pixel rotation based on a reference line from each area [11]. Accessing the camera using blinking EOG was successfully done in this research. The ratio was determined from [12] which varied among the operators.

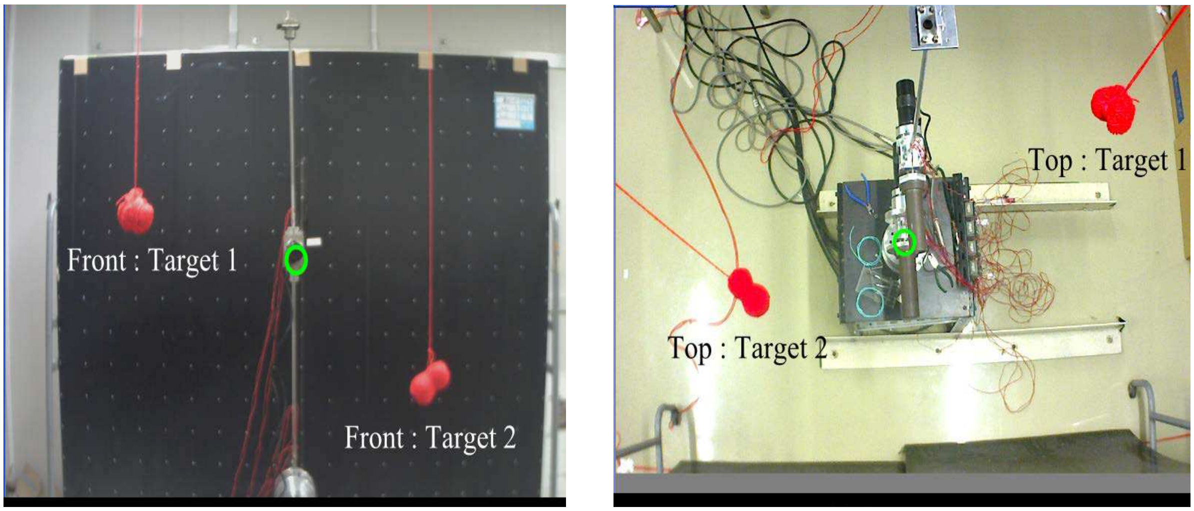
The tables 1 and 2 below gives the physical positon and the perceived positioning of targets 1 and 2 as interpreted by the camera and EOG systems. This are the calculations done by distinct system blocks as described in section 3 above.

TABLE 1. Perceived location of target (x, y, z).

	Pixel size	
	Target 1	**Target 2**
Real	(315, 219, 78)	(−295, 110, −235)
EOG	(298, 190,70)	(−275, 95, −240)

TABLE 2. Real location of target (x, y, z).

	Distance in cm	
	Target 1	**Target 2**
Real	(50, −75, 136)	(−45, −50, 91)
EOG	(48, −73, 137)	(−44, −48, 93)



a) Front view b) Top view

FIGURE 5. Target positions in a monitor from a) Front camera and b) Top camera

From the result, a methodology of calculating target object position in 3D using EOG systems is plausible to be explored as an alternative in object tracking and its related applications. This study only focused on voluntary blinks, as such, failure in camera switches was inevitable in cases of fatigue and or visual strains.

CONCLUSION

Nowadays, many machines are being produced to improve the quality of human life. To address the challenges that elderly and disabled people encounter in day-to-day lives, concerted efforts as well as new inquiry areas will need be revisited. With every rise in technological advancement, Human-Machine interfaces are providing a pipeline for development of new health industry and promote wellbeing of citizens.

One of the readily available bio-signal that is used in neuroscience is electrooculography (EOG). From this, gaze motions and blink information can be harnessed to provide a control scheme as developed and discussed in the paper. EOG signal compared to electromyography (EMG) and electroencephalography (EEG) has a linear relationship with gaze motion distance, relatively high amplitude and is easily detected, EOG has a bright future to be investigated to develop the proportional bio-signal control.

REFERENCES

1. A. B. Barreto, S. D. Scargle, and M. Adjouadi, "A practical EMG-based human-computer interface for users with motor disabilities.," *J. Rehabil. Res. Dev.*, vol. 37, no. 1, pp. 53–63.
2. J. R. Wolpaw, D. J. McFarland, G. W. Neat, and C. A. Forneris, "An EEG-based brain-computer interface for cursor control," *Electroencephalogr. Clin. Neurophysiol.*, vol. 78, no. 3, pp. 252–259, Mar. 1991.

3. E. Magosso, M. Ursino, A. Zaniboni, and E. Gardella, "A wavelet-based energetic approach for the analysis of biomedical signals: Application to the electroencephalogram and electro-oculogram," *Appl. Math. Comput.*, vol. 207, no. 1, pp. 42–62, Jan. 2009.
4. M. Sasaki and K. ho Choi, "Communications with a Brain-Wave Bio-Potential Based Computer Interface," pp. 438–438, 2002.
5. C. Castellini and P. van der Smagt, "Surface EMG in advanced hand prosthetics," *Biol. Cybern.*, vol. 100, no. 1, pp. 35–47, Jan. 2009.
6. H. Harun and W. Mansor, "EOG signal detection for home appliances activation," in *2009 5th International Colloquium on Signal Processing & Its Applications*, 2009, pp. 195–197.
7. M. B. I. Raez, M. S. Hussain, and F. Mohd-Yasin, "Techniques of EMG signal analysis: detection, processing, classification and applications.," *Biol. Proced. Online*, vol. 8, pp. 11–35, 2006.
8. C. K. Ho and M. Sasaki, "Mental tasks discrimination by neural networks with wavelet transform," *Microsyst. Technol.*, vol. 11, no. 8–10, pp. 933–942, Aug. 2005.
9. M. S. A. bin Suhaimi, K. Matsushita, M. Sasaki, and W. Njeri, "24-Gaze-Point Calibration Method for Improving the Precision of AC-EOG Gaze Estimation," *Sensors*, vol. 19, no. 17, p. 3650, Aug. 2019.
10. M. Rusydi, M. Sasaki, and S. Ito, "Affine Transform to Reform Pixel Coordinates of EOG Signals for Controlling Robot Manipulators Using Gaze Motions," *Sensors*, vol. 14, no. 6, pp. 10107–10123, Jun. 2014.
11. R. Barea, L. Boquete, M. Mazo, and E. López, "Wheelchair Guidance Strategies Using EOG," *J. Intell. Robot. Syst.*, vol. 34, no. 3, pp. 279–299, 2002.
12. E. Iáñez, J. M. Azorín, E. Fernández, and A. Úbeda, "Interface based on electrooculography for velocity control of a robot arm," *Appl. Bionics Biomech.*, vol. 7, no. 3, pp. 199–207, Sep. 2010.