DESIGN AND IMPLEMENTATION OF AN EYE-BLINK CONTROLLED WHEELCHAIR FOR PERSONS WITH SEVERE MOTOR IMPAIRMENT

A Project Report carried out at the **Atal Tinkering Lab**

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Bhubaneswar, Odisha

2018

ABSTRACT

A significant minority of people who require a powered wheelchair cannot operate the hand joystick with which such chairs are supplied. For individuals with high cervical spinal cord injury, motor neurone disease or late-stage neuromuscular conditions, voluntary control of the eyelid frequently survives long after control of the hand, neck and respiratory musculature has been lost, yet the available alternative drive controls, chiefly sip-and-puff systems and head arrays, still demand residual respiratory or cervical function and remain expensive. This report describes the design, construction and demonstration of a low-cost wheelchair control interface operated entirely by voluntary eye blinks. Two infrared reflectance sensor modules mounted on a spectacle frame, one before each eye, detect eyelid closure; their digital outputs are transmitted over a short-range radio link to a microcontroller on the chair, which decodes blink sequences into drive commands and actuates the motors through an H-bridge driver. A discrete command vocabulary separates intentional blinks from involuntary ones by duration and by which eye is closed, allowing the system to be armed, steered and halted without any limb, neck or respiratory movement. The interface was implemented on a downscaled chassis from commodity components and was demonstrated to execute the designed command set. The report closes with an assessment of the approach's limitations, of which the discrimination of intentional from involuntary blinking and the absence of independent emergency braking are the most significant.

Keywords: assistive technology, powered wheelchair, alternative drive control, infrared reflectance sensing, blink detection, human–machine interface, Arduino, embedded systems.

ACKNOWLEDGEMENTS

We thank Mr. Tanmay Kumar Nayak for his guidance throughout this project, and the Atal Tinkering Lab at DAV Public School, Unit-VIII for providing the workspace, tools and components without which the prototype could not have been built. We are grateful to the school administration for its support of the Lab and of student-led project work.

1 Introduction

1.1 Background and Motivation

A powered wheelchair is conventionally driven by a proportional hand joystick, an interface that presupposes controlled movement of the fingers, wrist and forearm. This assumption does not hold for a substantial group of users. In a clinical survey of practitioners who prescribe and train users on powered mobility, approximately 9 to 10 percent of patients receiving powered wheelchair training were reported to find the chair extremely difficult or impossible to use for activities of daily living; asked specifically about steering and manoeuvring, that figure rose to 40 percent. Eighty-five percent of the clinicians surveyed reported encountering, each year, patients who could not use a powered wheelchair at all owing to insufficient motor skill, strength or visual acuity [1, 2].

For this population a range of alternative drive controls exists, principally sip-and-puff tubes, head arrays, chin joysticks and proximity switch arrays. Each requires some residual voluntary function outside the hand: breath control, cervical movement, or the ability to hold the head against a switch. Where the underlying pathology has progressed beyond those capabilities, or where the cost of a specialist control package places it out of reach, the user is returned to dependence on an attendant.

The oculomotor system is comparatively resilient. In high cervical spinal cord injury the cranial nerves controlling eye and eyelid movement are spared entirely, and in progressive neuromuscular disease ocular function is typically among the last capabilities lost. Voluntary blinking therefore offers a control channel that remains available when almost every other voluntary movement has ceased.

1.2 Problem Statement and Objectives

The problem addressed is the absence of an affordable wheelchair drive control requiring no limb, cervical or respiratory function. The interface must be built from components available in the general electronics market, must be fittable to an existing chair rather than requiring a purpose-built one, and must be maintainable by a general electronics technician rather than a specialist supplier. The objectives follow directly:

(i) to design a head-worn sensing unit detecting voluntary eyelid closure independently for each eye, using low-cost non-contact sensors;

(ii) to define a command encoding that distinguishes deliberate control blinks from spontaneous blinking and maps blink patterns to drive commands;

(iii) to implement a wireless link between headset and chair, so the user is not tethered to the chassis;

(iv) to build and demonstrate a prototype on a downscaled chassis, and to identify the engineering and safety work required before such a system could be used by a person.

2 Related Work

Interfaces deriving control from the eye fall into three families. **Electrooculography (EOG)** exploits the standing corneo-retinal potential, measured by skin electrodes around the orbit. Barea et al. demonstrated an assisted mobility system guiding a powered wheelchair from EOG-derived eye movements, establishing the feasibility of ocular control for mobility [3]. EOG offers good angular resolution but requires adhesive electrodes in contact with the face, is sensitive to electrode drift and skin impedance, and needs amplification and filtering hardware that raises cost and complexity. **Video-oculography** uses a camera and image processing to recover gaze direction. It avoids skin contact and can give continuous proportional input, but requires a camera, a processing platform able to run the vision pipeline, and controlled illumination; Simpson's review documents several such efforts alongside voice and head-gesture control and notes how few reached clinical deployment [2]. **Electroencephalography** is the most general approach, requiring no peripheral motor function at all; Tanaka et al. demonstrated EEG-based direction control of an electric wheelchair [4], though such systems remain costly, need extended user training, and deliver low information transfer rates.

The present work takes a deliberately narrower and more economical position. Rather than recovering gaze direction, it treats the eyelids as a pair of independent binary switches and derives commands from the pattern in which those switches are operated. This reduces the sensing requirement to two infrared reflectance detectors and the processing requirement to a timing routine on an eight-bit microcontroller, at the cost of the continuous proportional control that gaze-based systems can in principle provide.

3 System Design

3.1 Architecture

The system is divided into two physically separate units joined by a one-way radio link. The head-worn unit carries only sensing and transmission; all decoding and actuation is performed on the chair. This keeps the headset light and free of the battery mass a processing load would demand, and ensures that loss of the radio link leaves the chair's controller in a known state rather than an undefined one.

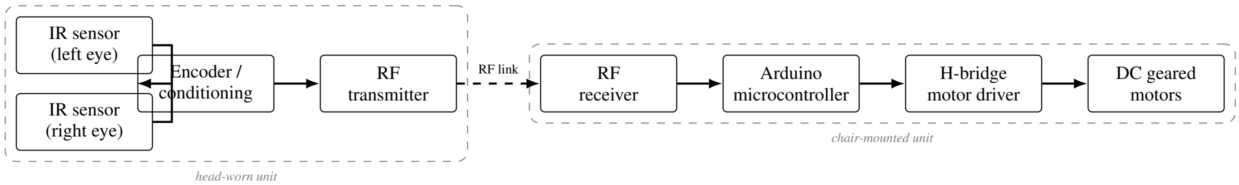

Figure 1: System block diagram. Sensing and transmission are carried on the spectacle frame; decoding, power and actuation are carried on the chassis.

3.2 Sensing Principle

Each sensor module comprises an infrared emitter and a phototransistor mounted side by side and directed at the eye region from the inner face of the spectacle frame. The sclera and the closed eyelid differ appreciably in infrared reflectance, so phototransistor current changes when the lid closes. The module's onboard comparator compares this against a threshold set by a trimmer potentiometer and produces a clean digital output, obviating analogue signal processing on the host. Because the two eyes are instrumented independently, the subsystem yields two binary channels rather than one. This doubles the command alphabet available for a given sequence length and, more usefully, allows left and right steering to be mapped to the corresponding eye, which is intuitive and lowers the cognitive load of operation.

3.3 Command Encoding

Spontaneous blinking occurs involuntarily at roughly fifteen to twenty times per minute, with a typical duration well under half a second. Any usable encoding must reject that involuntary population while accepting the deliberate one. Two discriminants are used: *duration*, since a deliberately held blink is markedly longer than a spontaneous one, and *laterality*, since deliberate unilateral closure is rare in spontaneous blinking, which is overwhelmingly bilateral.

Input	Condition	Action
Long (held) blink, both eyes	system disarmed	Arm the system; motors enabled
Double blink, left eye only	system armed	Turn left
Double blink, right eye only	system armed	Turn right
Long (held) blink, both eyes	system armed	Halt motors; disarm the system
Short blink, either or both	any	Ignored (treated as involuntary)

Table 1: Primary command set. The arming state ensures the chair cannot be set in motion by blinking that occurs before the user intends to drive. The encoding is extensible: further two- and three-blink sequences across the two channels remain unassigned and can be mapped to additional functions.

3.4 Hardware

Component	Function
Infrared reflectance sensor module (×2)	Detects eyelid closure, one per eye
Spectacle frame with head strap	Carries the sensors at a fixed eye-relief
RF transmitter module	Sends sensor states to the chair
RF receiver module	Recovers sensor states on the chair
Arduino microcontroller board	Decodes blink sequences; issues drive commands
Dual H-bridge motor driver module	Switches motor current under logic control
DC geared motors (×2)	Differential drive of the two wheels
Rechargeable battery packs	Independent supplies for headset and chassis

Table 2: Principal components, all sourced from the general hobby-electronics market.

4 Implementation

4.1 Head-Worn Unit

A pair of wraparound safety spectacles was chosen as the carrier for the sensing hardware, in preference to a purpose-fabricated headband, because the frame already provides a stable and repeatable geometry relative to the eyes and because it is a familiar and unremarkable object to wear. The two sensor modules were mounted on the inner face of the frame, one before each lens, with their standoff adjusted so that the emitter-detector pair was directed at the lid without obstructing the visual field. A padded strap was added across the temples to prevent the frame shifting, since the detection threshold is sensitive to sensor-to-eye distance. Sensor outputs and the transmitter were wired along the frame and secured with tape; the assembly is powered by a small battery pack carried on the strap.

4.2 Chair-Mounted Unit

The receiving side was implemented on a downscaled chassis rather than a full-size wheelchair. The chassis was fabricated from aluminium flat bar, with two independently driven wheels on a common axle at the rear and a castor at the front, giving a differential drive with a zero turning radius. Receiver, microcontroller, motor driver and battery were mounted on the deck between the side frames, with a flat seat panel fixed above them to represent the seating position.

This reduction in scale was deliberate. A full-size chair carrying a person introduces mass, braking and structural safety requirements outside the scope of a first prototype, and testing an unproven control scheme on such a chair would be irresponsible. The downscaled build exercises the control logic, the radio link and the command encoding in full while confining the consequences of a control failure to the model itself.

4.3 Control Logic

The microcontroller maintains a state machine with two states, DISARMED and ARMED, and a timer for each input channel. On each channel transition the firmware records the time and the channel identity. A closure whose duration exceeds a long-blink threshold is classified as a hold; two closures on the same channel falling within a defined inter-blink window, with the opposite channel inactive, are classified as a unilateral double blink. Closures shorter than a minimum duration are discarded as involuntary. Decoded commands are dispatched to the motor driver only in the ARMED state; in DISARMED the motor outputs are held inactive regardless of sensor activity.

5 Results and Observations

The assembled system was demonstrated end to end. With the headset worn and the chassis powered, a held bilateral blink armed the system, unilateral double blinks produced the corresponding left and right turns, and a second held bilateral blink halted the motors and returned the machine to the disarmed state. Commands issued over the radio link were executed by the chassis with no wired connection between the two units, confirming the viability of the split architecture.

It must be stated plainly that these are qualitative functional observations and not a characterisation of performance. The following were *not* measured, and no claim is made regarding them: the false-positive rate, that is, the frequency with which involuntary blinking is misclassified as a command, whether at rest or in motion; the false-negative rate; the latency between completion of a blink sequence and the motor response; the sensitivity of the detection threshold to ambient infrared illumination, chassis vibration or displacement of the frame on the face; and performance with any user other than the developers, in particular with a user having the motor impairments the system is intended to serve. The system was operated only by its designers, who knew the command vocabulary and could blink deliberately and with exaggerated duration. This is the least demanding possible test condition, and the observations above should be read accordingly.

6 Limitations

Discrimination of intentional from involuntary blinking. This is the central difficulty of the approach and the present design does not solve it. The signal and the noise are the same physical event, separated only by duration and laterality thresholds. Setting those thresholds conservatively suppresses false commands but forces the user into uncomfortably long blinks; setting them permissively risks unintended motion. The correct values are likely to be user-specific and to require individual calibration.

The control channel and the visual channel are the same organ. Every command requires the user to close their eyes, and so to lose sight of where the chair is going at precisely the moment they are commanding it to move. This is inherent to blink-based control rather than a defect of implementation, and it places a ceiling on how much of the driving task should be assigned to this interface.

Absence of independent emergency braking. There is no stopping mechanism independent of the sensing chain. If the headset is displaced, the battery fails or the radio link is lost, no separate path exists by which the chair can be halted. Any system intended for a person requires a fail-safe that stops the chair on loss of signal, together with an attendant-operated override.

Environmental sensitivity. Infrared reflectance sensing is affected by ambient infrared, including sunlight and incandescent lighting, and by the reflectance properties of the individual user's eye and skin. Spectacle wearers, users with ptosis and users with involuntary eyelid movement present further difficulties not investigated here.

Scale and structural validation. The prototype is a downscaled model. No load-bearing structure, braking system, seating or stability analysis has been undertaken, and no aspect of the build has been assessed against any medical device or wheelchair safety standard.

7 Future Work

1. **Quantitative characterisation.** Measure false-positive and false-negative rates across varied ambient lighting and with the chassis in motion. This is the most important outstanding task, since it determines whether the approach is viable at all.
2. **Per-user calibration.** A short guided routine that establishes each user's spontaneous blink duration distribution and sets the classification thresholds from it, rather than relying on fixed values.
3. **Fail-safe design.** A watchdog halting the motors on loss of the radio link or on sensor timeout, plus an independent attendant override.
4. **Obstacle detection.** Because the interface is inherently low-bandwidth and occupies the user's vision, the chair should assume more of the driving task. Ultrasonic or infrared proximity sensing with automatic stopping would considerably reduce the consequence of a misclassified command.
5. **Evaluation with intended users.** Testing with people who have the impairments the system addresses, with appropriate supervision and consent, is required before any claim of clinical usefulness can be made.

8 Conclusion

A wheelchair control interface operated entirely by voluntary eye blinks has been designed, constructed and demonstrated. Two infrared reflectance sensors mounted on a spectacle frame detect eyelid closure independently for each eye; blink sequences are transmitted over a radio link to a microcontroller on the chassis, which decodes them into drive commands through a state machine separating deliberate from spontaneous blinking by duration and laterality. The command set was demonstrated in full on a downscaled differential-drive chassis assembled from commodity components.

The contribution of the work is a demonstration that a usable command channel can be derived from the eyelid alone, using hardware costing a small fraction of a commercial alternative drive control. Its principal limitation is equally clear: the reliability with which deliberate blinks can be separated from involuntary ones has not been measured, and until it has, no statement about the safety or practical usefulness of the interface is warranted. Establishing that figure, and designing the fail-safe behaviour that must accompany it, are the necessary next steps.

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