Title	Design and Test of a Headset Activation Platform Controlled by Eye Gaze Tracking
Authors(s)	Lambe, Eoin, Cuffe, Paul
Publication date	2019-10-17
Publication information	Lambe, Eoin, and Paul Cuffe. “Design and Test of a Headset Activation Platform Controlled by Eye Gaze Tracking.” IEEE, October 17, 2019. https://doi.org/10.1109/IECON.2019.8927716.
Conference details	IECON 2019, 45th Annual Conference of the IEEE Industrial Electronics Society (IES), Lisbon, Portugal, October 14-17 2019
Publisher	IEEE
Item record/more information	http://hdl.handle.net/10197/10983
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Publisher's version (DOI)	10.1109/IECON.2019.8927716

Design and Test of a Headset Activation Platform Controlled by Eye Gaze Tracking

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Abstract— **For years, eye tracking technology has been making huge improvements and has become very popular in the robotics industry. This paper covers a new concept resulting in the creation of a fully functioning prototype utilising eye tracking technology that can aid with such things as improved visibility or better communication for people in the workplace or at home. The concept involves a portable headset that can track the user's gaze direction and accurately point an illumination source at the point of eye fixation. Use cases for such a device could include assisting people working in low light conditions by directing a beam of light in the gaze direction or for people living with disabilities that possess substandard verbal communication skills, by acting as an eye-controlled laser pointer. The prototype uses digital servo motors, a 3D printed pan-tilt platform, a microcontroller, an illumination source and off-the-shelf eye-tracking glasses. The result is a responsive and accurate device that could potentially be transformative for many people around the globe.**

I. INTRODUCTION

Viewing and analysing the movement of human eyes has been a topic of investigation for over a century. Many different methods of measuring this movement have been used over this time. This has ranged from direct observation to the use of mirrors, magnifying lenses and telescopes to newer and more advanced methods [1]. The most common method of eye-tracking used in most modern devices is video-oculography which is non-invasive and usually gives high levels of accuracy and good sampling rates [2]. This involves recording the eye position with video cameras which can be implemented using several techniques – the most common of which is dark or bright pupil with corneal reflection which involves contrasting the amount of infrared light reflected by different sections of the eye [3].

Off-the-shelf eye-tracking equipment is becoming quite accessible: for instance, the *Pupil* glasses are a wearable, non-invasive gaze tracking solution that are affordable and customisable [4]. They offer good levels of precision (0.08°) and accuracy (0.6°) and use a completely open-source software framework [5]. This is a much cheaper alternative to other high-end devices which can cost upwards of hundreds of thousands of dollars [6].

Potential use-cases for the completed device require the cost to be as low as possible. Use-cases include assisting people working in low light conditions by focusing a beam of light in the gaze direction. The device could eventually be used in different activities such as running at night, rock climbing or even scuba diving in future iterations. The headset could also be used to help people living with disabilities. People living with motor neuron diseases such as amyotrophic lateral sclerosis or people living with cerebral palsy can have hindered communication which can even lead to the inability to speak [8], [9]. This device could potentially assist these people and act as an eye-tracking laser pointer that could direct other people's attention towards the users point of gaze. Current solutions to this include the Eye Transfer (ETRAN) board and eye-tracking communication devices (ETCDs). The commonly used ETRAN board involves the user gazing at a particular letter, word or symbol on a transparent board and the caregiver attempting to decode the gaze direction [10]. The more advanced ETCDs can allow for vocal synthesis, internet connection and access to social networks. An obvious drawback of these high-tech systems is that they can cost upwards of €20,000 [10], [11].

The gaze-tracking illumination headset would be a clear and obvious upgrade to the ETRAN board. It would involve very little effort from the caregiver and could be used in a huge number of areas. The current ETCDs are very advanced and appears to improve the quality of life of people living with motor neuron disease dramatically [12]. The advantage the gaze-tracking illumination headset holds is that it would cost a fraction of the price. Eventually, as eye-tracking becomes more common and the headset becomes more robust, it could be combined with an ETCD for an even better overall experience for the user.

The author will first discuss how the gaze-tracking illumination headset was designed and built. Following this section, testing and validation results will be shown. Finally, discussion and conclusions will be drawn.

II. METHODOLOGY

This section will describe the design process for prototyping the headset activation platform. Due to the many different use-cases available, some design decisions were made to accommodate as many of these use-cases as possible. The five following subsection describe how each component of the headset was designed.

A. Pan-Tilt Platform

A way of rotating an illumination source about two axes rapidly and accurately is needed. A platform is rotated here instead of a fixed illumination source so that different illumination sources can be attached at this early development stage. A combination of digital servo motors and 3D printed components are used to achieve this.

The servo motor requirements were compactness, quickness, accuracy and cost. To choose an appropriate servo motor, the characteristics of human eye movement must also be considered. The human eye has four different types of movements – saccades, smooth pursuit movements, vergence movements and vestibulo-ocular movements [13]. Saccades are rapid, ballistic movements which abruptly change the point of fixation. Smooth pursuit movements are slower, tracking movements that keep a moving stimulus in sight. Vergence movements align both eyes in order to see objects at different distances whereas vestibulo-ocular movements compensate for head movements. Saccades are the quickest of the movements – they can reach up to 900 °/s – so the pan-tilt platform must be able to reach close enough to these speeds to eliminate any noticeable lag [14]. The pan-tilt platform must also have a relatively short deadband so it can follow the smoother eye-movements more effectively (a servo motor deadband can be described as a range in wherein no action will occur [15].) The chosen digital servo motor is the *Futaba S3776SB Micro-Servo* whose specifications are given in Table I.

TABLE I. FUTABA S3776SB MICRO-SERVO SPECS

Price	€ 45
Weight	10 g
Angle of Rotation	120 °
Torque	2 kg-cm (0.2 N-m)
Speed	500 °/s (84 RPM)
Deadband	0.4 °

The different components of the pan-tilt platform were designed in *Solidworks* and printed using *Onyx* – a nylon print reinforced with carbon fibre to increase strength [16]. The rotating rig can be assembled without adhesive using only nuts and bolts which was a design decision so assembly and disassembly can be performed with ease. Some insight into the design choices for this pan-tilt platform are listed below and labelled in Fig. 2.

a) This section fastens the pan-tilt platform to the helmet. It utilises a *GoPro* helmet mounting kit so it can be rotated, removed and replaced very easily [17]. The two prongs slip into a set of three prongs and are tightened together with a screw.

b) This section holds the horizontally rotating servo motor in place. There is clearance for accessing and tightening the bolts as well as a gap for the wires to come out of.

c) This section holds the vertically rotating servo motor in place. The servo motor body will be rotated by the other servo motor. There is clearance allowed for accessing and tightening the bolts and it is measured so that all parts rotate about their centre axis ensuring maximum accuracy when moving.

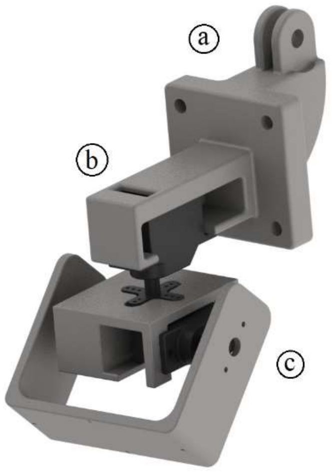

Fig 1. Labelled rendered image of pan-tilt platform

Some of the more intricate details of the design can be seen from an exploded view in Fig. 3:

a) This section splits into two parts so it can be bolted to a flat surface for testing purposes.

b) This section has an indent of the supplied servo motor horn. This allows for added stability as the motor rotates.

c) This pin uses a *"tight-fit"* joint – it is pushed through the body of the device and out through to the rotating platform. This pin can be pushed back out when disassembling with ease.

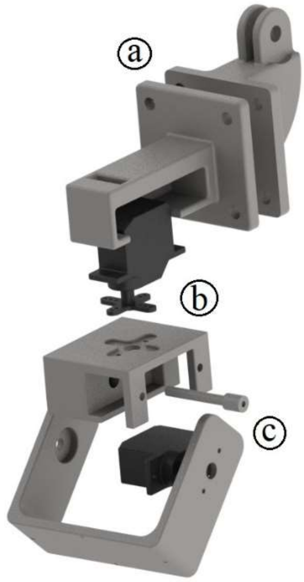

Fig 2. Labelled exploded pan-tilt platform

B. Controller

The chosen controller will need to be able to generate an accurate *pulse-width modulation* (PWM) signal to control the servo motors in the pan-tilt platform depending on the user's gaze position. There is a wide range of controllers on the market today to do this.

There is a useful comparison provided in [18] between five popular controller boards: the *Raspberry Pi, Arduino Uno, BeagleBone Black, Phidgets and Uddo*. The comparison is made under four different headings: *Size and Cost, Power* *and Memory, Flexibility, Communication and Operating Systems and Programming Languages*. This comparison gives a great overall feel for different devices and concludes that the Raspberry Pi is the *"perfect platform for interfacing with many different devices and using in wide range of applications"* [19]. The Raspberry Pi also has a huge number of peripherals to choose from known as *HAT*s (Hardware Attached on Top). Included in these is the *Raspberry Pi PWM Servo Hat Development Board* from *Adafruit* which communicates with the Raspberry Pi over one General Purpose Input/ Output (GPIO) pin and generates an extremely precise and accurate PWM signal.

The chosen microcontroller chosen for the present usecase is the *Raspberry Pi 3 Model B+*. This is a affordable, lightweight and high-performance micro-computer that would be perfect for this scenario when using the PWM Servo Hat. This model contains a processor which is a 64-bit BCM2837B0, Cortex-A53 System-on-chip, it has 1GB RAM, 40 GPIO pins and many methods of connectivity including USB 2.0 and HDMI.

C. *Eye Tracker*

Both accuracy and precision are metrics used to define the correctness of eye-gaze data[5]. These can be respectively defined as *"The spatial difference between the true and the measured gaze direction"* and *"How consistently calculated gaze points are when the true gaze direction is constant"* [3].

The levels of precision and accuracy are both very important in choosing equipment. The pan-tilt platform will add a degree of error, so the coordinates given to this platform must be as accurate as possible. Precision could be even more important for the development of this headset as if the user's gaze is constant, the illumination source should be fixed – otherwise the headset could be very distracting to the user. Of the most common, feasible headsets on offer (as described in the iMotions study [7]), the Pupil has the superior level of precision (0.08 Deg) while still maintaining a sufficient level of accuracy (0.6 Deg) [3], [4]. A study conducted by iMotions - a software developer for eye-tracking partnering large companies such as Tobii, SMI and Gazepoint - shows that the Pupil is the only wearable device on the market today under the $10,000 price point [7].

The Pupil eye tracking glasses were used for this device with the high-speed world camera attachment as well as the 200 Hz monocular eye camera [4]. The open-source software framework can be used on a mobile computer and the glasses will connect through USB. Users can choose to run the software from source and make alterations directly, design a plugin that can manipulate data inside the application or subscribe to the data and process it elsewhere. The Raspberry Pi can then connect to the mobile computer through an ethernet connection and subscribe to the eye gaze data for real-time manipulation. The software system that the Pupil uses is publically available on GitHub. Summary technical specifications for the glasses are provided in Table II.

TABLE II. THE *PUPIL* TECHNICAL SPECS

Gaze Accuracy	0.60 degrees
Gaze Precision	0.08 degrees
Pupil Tracking Technology	Dark pupil with 3d model
Sampling Frequency Eye Camera	200hz @200x200px
Sampling Frequency World Camera	30hz@1080p/60hz@720p /120hz@vga

Fig 3. The Pupil eye tracking glasses: image from [22]

D. *Software Design*

All software for the device is written in Python [23] and run on the Raspberry Pi. The eye tracking glasses are connected to a laptop through USB and the Pupil-Labs Capture software should be running. The Raspberry Pi opens a TCP connection with the laptop using an ethernet cable using ZeroMQ [24]. ZeroMQ is a high-performance messaging library built on TCP which utilizes sockets for different messaging patterns targeted for use in concurrent applications.

The Pupil-Labs Capture software uses the *IPC Backbone* as their PUB-SUB (Publisher – Subscriber) messaging bus. Different applications can then subscribe to the particular message topics on the IPC Backbone depending on the use-case. For this use, gaze positions and world camera video frames are subscribed to. The gaze positions are used to move the individual servo motors and the world video frames are used for facial recognition – if a face is recognized, the illumination source should be switched off as to not dazzle onlookers. The gaze coordinates arrive to the Raspberry Pi as normalized positional data ranging from [0,0] indicating the bottom left of the world camera frame to [1,1] indicating the top right of the world camera frame. The world camera frame has an Angle of View (AOV) of 60° in both horizontal and vertical axes. This normalized data can then be converted into an equivalent PWM signal to be sent to each individual servo motor. On the vertical axis, computer vision control techniques were chosen to avoid distance parallax effects caused by the displacement between the pan-tilt platform and the eye tracking glasses.

A joystick was added to the headset assembly so the user can calibrate the pan-tilt platform in relation to the eye tracker calibration. When first wearing the headset, the user should focus their gaze on a point and use the joystick to move the pan-tilt platform to the exact point of gaze, as perceived by them. The user can then click down on the joystick and this will store two offset variables which will then be used for the rest of the session. A Python function was also implemented to switch on and off the headset if a blink sequence is recognized. Each gaze coordinate arrives with a *"confidence"* value between 0 and 1 indicating how confident the eye tracking software is about the pupil position. If an extremely low value arrives (~0), this indicates that the eye tracker does not recognize the pupil in the eye. If successive low confidence coordinates arrive, this indicates that the eyes are closed, or the glasses have been removed. The pan-tilt platform and illumination source can then be switched off if a blink lasts between 1-2 seconds.

E. *Headset Build*

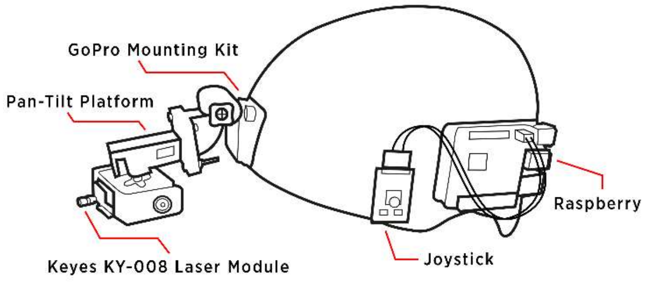

Fig 4. Schematic representation of the gaze-tracking headset activation platform

Both the Raspberry Pi and pan-tilt platform are mounted on a protective skateboarding helmet. This type of helmet was chosen for the first prototype as it has a plain, smooth surface area that can be used for easily mounting different components. It also stays very still in the same position on the head when the user is moving. The pan-tilt platform is mounted using a *GoPro* helmet mounting kit and the Raspberry Pi is mounted using a 3M VHB adhesive pad. The Raspberry Pi connects to a laptop running the Pupil-Labs Capture application via ethernet (communication) and USB (power). The Pupil glasses are then connected to the laptop via USB.

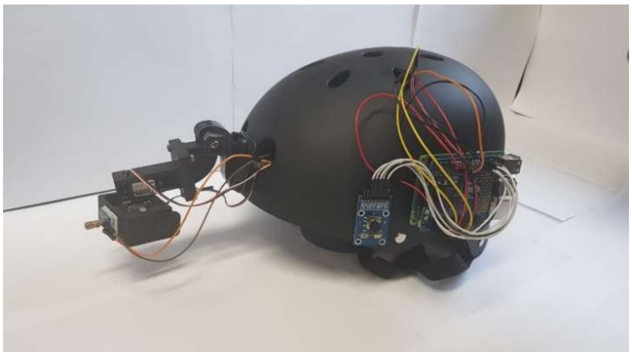

Fig 5 The gaze-tracking headset activation platform, as built

III. RESULTS

Performance testing began on the device as an eye tracking laser pointer. The testing plan worked as follows – the user will stand at a distance away from a plane containing a number of targets. In this case, the targets will contain a centre target, one to either side of the centre target, and one above and below the centre target. This will test each calibration area of the eye tracking glasses. The user will then try to hit each target, one after another, and the maximum distance to each target will then be recorded. This will give a measured value for the headset accuracy. A visual representation of the headset performance testing can be seen in Fig 6.

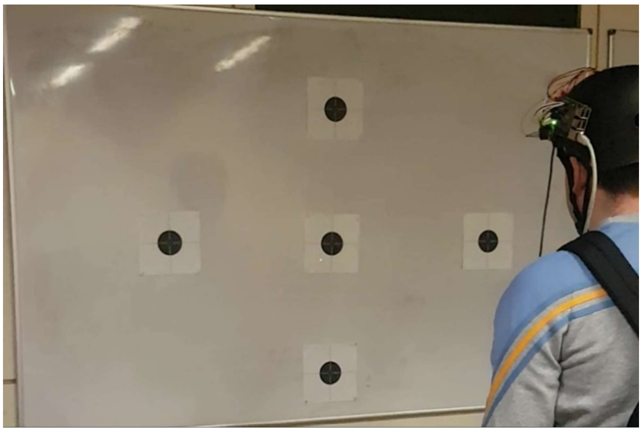

Fig 6. Headset testing using laser pointer

The results for this test were impressive. With the user standing a distance of 2m away from the targets, the laser pointer consistently kept within at least half the width of an A4 page away from the target (105 mm). Using the cosine rule, this gives a worst-case headset accuracy of 3°. Two remarks that can be drawn from this testing are:

- Accuracy is largely dependent on the quality of calibration performed on the eye tracking glasses. When the distance to the targets is known, the user should attempt to calibrate the glasses at a similar distance to the computer screen to optimise performance.
- Accuracy is optimised in the centre of the user's field of view and diminishes gradually as the user's gaze position moves from this. This is caused by two factors – the eye tracking glasses perform best at the centre of the user's field of view and the headset is calibrated at this centre. A potential method of improving the accuracy at points outside the centre of the field of view would be to calibrate the headset at different points – including the centre – and finding an average value for the x and y offset values. This, however, would diminish accuracy closer to the centre of the field of view which is the most important area for the user. A decision was then made to keep headset calibration at the centre of the user's field of view.

The headset was then tested as a gaze tracking headlamp. A similar testing plan was conducted as shown in Fig 7.

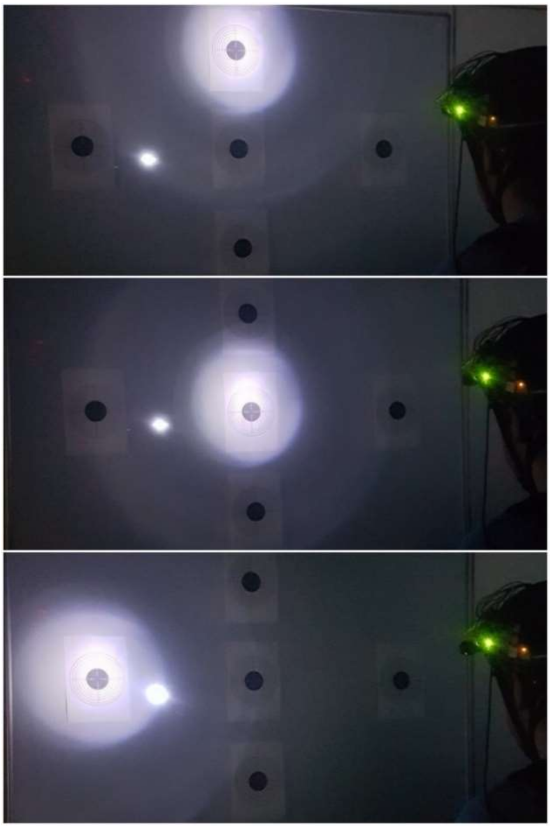

Fig 7. Headset testing using LED lamp

The results from this testing were very promising. The error of 3° while using an LED headlamp with a beam angle of approximately 12° is barely noticeable. Blink detection in the dark is not as seamless as when using the headset in brighter conditions as the pupil is more difficult to detect. A moving average filter – acting as a low-pass filter – was then placed on the output coordinates of the pan-tilt platform which removed a significant amount of noise received from the eye-tracking glasses and negated a large amount of the jitter on the light illuminating the users' gaze direction. The gaze-tracking illumination headset, when used as a moveable headlamp performs very well and is already a useful and helpful device.

IV. DISCUSSION

The final headset performs very well and would suit many of the different use-cases available. A point to be made is that the Pupil eye tracking glasses can be purchased with a second 200 Hz eye camera for the user's other eye which measures eye vergence. As mentioned above, eye vergence movements involve both eyes moving in opposite directions in order to view objects at different distances. If this distance measurement was readily available from the eye tracking glasses, this could effectively eliminate any parallax error caused by the distance between the glasses and the pan-tilt platform and increase accuracy of the overall device. For an effective eye-tracking laser pointer, this addition would play a huge role in making it an extremely effective piece of equipment, especially over short distances. From the Pupil-Labs team – *"the vergence measurement is working very well over distances of 0.5-2m"*. The parallax error is greatest over short distances, especially in this range. The added eye camera would reduce this error by a large amount but would also increase the cost of producing the device considerably.

This error of parallax reduces over large distances. As an eye tracking headlamp, the second eye camera would most likely not be needed, especially as the cone of illumination from a torch light is much wider than a laser pointer. This device could work as a useful and functional moveable head lamp that would suit many different use cases in sports and work activities.

Currently there are no micro-computers on the market today powerful enough to run the Pupil-Labs Capture software efficiently, as well as small enough to be mounted on a helmet. In the future, a usable device could be released, and this headset could become even more portable. Efforts could also be made to strip down the Pupil-Labs Capture software so that only the vital elements are running, making the process more efficient and allowing it to run on less powerful devices such as the Raspberry Pi. In saying this, carrying a laptop in a backpack is quite common and not an insurmountable problem for many people. This headset could make huge improvements in future iterations and has a clear onward trajectory.

V. CONCLUSIONS

The gaze-tracking illumination headset is a new and exciting device that could potentially help many people around the globe. It has a huge range of use-cases including helping people in their everyday work environments to creating a new method of communication for people who need assistance. Some very notable progress was made on a usable and high-performance device that was designed and constructed and has produced some encouraging results. There is some clear capacity for future work on subsequent iterations of the device with distinct areas that can definitely be improved on. Future design efforts will continue in order to create a new, exciting and helpful device.

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