Horizontal Gaze Nystagmus Transmission Interlock System

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***Abstract*—Driving while intoxicated continues to be a morbid issue in the United States, responsible for causing approximately one-third of all fatal car crashes, claiming 11,000 victims each year. Psychological studies have shown that those who drive under the influence are likely to be repeat-offenders. The objective of this project is to remove human error from the equation by building a technological solution to address the needs specified by the Department of Transportation. While incorporating physiological analysis to determine sobriety based upon a passive HGN test, if an individual is attempting to drive while intoxicated, a personalized machine-learning algorithm will be calibrated to said individual to test their sobriety while protecting their privacy. The result of the sobriety test will determine if the individual is able to operate the vehicle, immobilizing the vehicle temporarily, if the driver is intoxicated. We show through our results that our system can identify whether or not a driver is impaired with a clear distinction in a very short amount of time without compromising on the user's privacy.**

***Index Terms*—Driving while Intoxicated (DWI), passive test, Horizontal Gaze Nystagmus, Machine Learning, Security & Privacy, Cryptography**

I. Introduction

Drinking and driving has been and continues to be a serious problem. In 2020, there were more than 11,654 deaths from alcohol related crashes in the United States [1]. Great strides have been made since the 1980s since Mothers Against Drunk Driving (MADD) [2] started advocating for stricter laws. Drinking and driving was criminalized and laws were passed based on a deterrent model of swift, certain, and severe punishment [3]. The number of alcohol related traffic fatalities decreased substantially from the 1980s to the late 1990s and then become constant with 20 percent of all traffic fatalities caused by drivers with a blood alcohol content of 0.08 or above [4]. Behavioral changes have had a significant impact on reducing the incidence of drinking and driving. To further reduce or eliminate drinking and driving a technological solution is needed.

Breathalyzers have been available since the 1950s and for the last couple of decades have been available as hand held devices and as ignition interlocks in cars [5]. These devices require the driver to breath into the device and it then measures the drivers blood alcohol and can prevent the car from starting with the blood alcohol content is too high [6]. When installed in vehicles the breathalyzer is a deterrent but it will also pick up alcohol in the air from other passengers. It also fails in cold conditions as moisture in ones breath will crystallize and freeze.

Law enforcement officers commonly use field sobriety tests, such as the, Horizontal Gaze Nystagmus (HGN) to determine probable cause for an arrest and then testing with a breathalyzer to determine the blood alcohol content of the driver. An HGN measures the physiological response in the eye that is present when under the influence of a substance. Using an ocular-graphic techniques, we can determine the type of nystagmus being exhibited, whether it be pendular (sinusoidal) or jerk (fast, sudden corrections). The latter of these is more common in people who are under the influence of alcohol, known as a vestibular nystagmus. We have built a device that can inexpensively be installed in vehicles and capable of detecting this in a matter of seconds, temporarily immobilizing the vehicle, and preventing a driver from driving the vehicle. The device encrypts information to prevent access to failed tests by others.

The remaining of this paper is organized as follows. Section II covers the background on the topic. Section III discusses the related work and literature review. Section IV details our methodology and the system components. We present our results in Section V and we conclude the paper in Section VI.

II. Background

A. Previous Legislation

After the lifting of Prohibition, nearly all states established a drinking age in the U.S. of 21 years old in order to restrict youth access to alcohol. In the 1970s, however, many states chose to lower their minimum legal drinking age. This resulted in a dramatic increase in alcohol-related crashes, as well as other drinking-related deaths [7]. A backlash followed and states began passing laws aimed at reducing the incidence of drinking and driving. The legal age for drinking was increased to 21 in all states by 1988, 40 states implemented mandatory license suspensions for DWI offenses, zero tolerance for underage drinking and driving became the law in all states by 1998, and legal blood alcohol content for conviction was reduced from 0.10 to 0.08 in all states by 2005 [8]. Mothers Against Drunk Driving (MADD) is an advocacy non-profit that was founded in 1980, with the goal of educating and protecting the public from drinking drivers. Since their founding, alcohol-related deaths have decreased by more than 50 percent, and according to MADD, more than 370,000 lives have been saved [2]. In the past twenty years, however, fatal crashes as a result of drinking drivers has plateaued, implying that social and legal interventions are no longer resulting in behavioral changes. A more innovative solution is required to address the problem and further decrease the number of deaths related to drinking and driving.

B. Public Interest

Studies have shown that much of the behavior of drinking and driving is attributed to one's environment. According to a survey conducted in 1993, these people often drink and drive repeatedly before being arrested [9]. In Fell et al. [10] the authors claim that checkpoints and arrests work in reducing drinking and driving by acting as a deterrent. Since the likelihood of being caught varies widely (from 1 in 50 to 1 in 2000), many believe that their chances of getting caught are quite low, and are willing to take the risk for the immediate gratification of getting to their destination [11]. Most people are deterred due to the safety risk itself, although the statistics resonate with people in different ways. Thirty percent of all fatal car accidents involve a DUI, and that is often enough of a deterrent in itself, yet this is clearly not the case for thousands of Americans [11].

C. Law Enforcement Practices

Over the years there have been a variety of different tactics employed by law enforcement in order to determine if someone is under the influence of alcohol. They are known as field sobriety tests. These ways are not forms of technology that are able to give you an exact reading, but instead a set of physical and mental tasks that the person in question must complete in order to prove that they are not impaired or intoxicated. There are three main field sobriety tests, and they are as follows; the one-leg stand test, the walk-and-turn test, and the horizontal gaze nystagmus test. While these tests can be useful in catching someone in the act of a DWI, hopefully resulting in a behavioral change, they can also be used to criminalize substance abuse. We intend to avoid this by encrypting all of the data collected by this system, making it private to the user only. These impairment checkpoints are also only effective if the person is caught in time by the officer, and many times they are not. This device would take a proactive approach, as opposed to the reactive approach of using law enforcement.

III. Related Work

Several studies have researched the idea of using a technological solution to create a prevention system for drinking and driving. In [12], Sudiksha introduces a technological solution composed of hardware and software components which allows ignition interlocking if an impaired driver is detected. The author shows through simulations that their system is fast in detecting impaired driving behaviour with high success rate. The system was not fully implemented and only simulation results were presented. and it also depends on a breathalyzer to be installed which is not suitable for cold regions with temperatures below freezing. Rahim et al. [13] explore the complexities of the breath alcohol ignition interlock device, commonly referred to as a breathalyzer. This device requires the driver to breath into it before they may start their engine. If the BAC in the breath is detected to be over a predetermined limit, the car will not start. While it does serve its purpose, a passive, more discrete device is preferred for long-term, daily usage.

Barba-Mata et al. [14] introduce an ignition interlock system that depends on the use of a breathalyzer to detect if the driver is intoxicated and prevents the car from starting. The system also utilizes GPS and GSM modules to send a signal regarding the car's location. The system was implemented in 5 vehicles and test results shows good performance overall. Roshan et al. [15] explains the complexities of conducting impairment screening in the field, and suggests a technology as a means to remove subjectivity from the process. This paper also addresses the use of machine learning algorithms in impairment detection for both drug and alcohol use. After the study was conducted, it was found that the horizontal gaze nystagmus test has 88 percent accuracy when run against the algorithms.

We separate ourselves from the previously mentioned solutions and other similar work in that our proposed solution is passive, does not prevent the vehicle from starting for a failed test, and it does not have the issues associated with devices that require certain temperatures to function properly such as is the case with breathalyzers.

IV. Methodology

A. Horizontal Gaze Nystagmus

Horizontal Gaze Nystagmus (HGN) is a term used to describe repetitive oscillatory movement of the eye, that, based on frequency and amplitude, can be used to determine an individual's sobriety. As blood alcohol content increases, so does the alcohol concentration within other bodily fluids, including that which can be found in the inner ear [16]. The inner ear system, or the vestibular system, acts as an accelerometer for your brain, helping to determine your body's orientation the surrounding environment. While this function prevents us from getting dizzy on a day-to-day basis, those who consume enough alcohol will be familiar with the disorienting effects of the substance, causing balancing issues, and even escalating to nausea. These side effects are a direct result of the chemical change in this fluid. As a result, your eyes will react to your body's change in speed and direction with "jerking" eye movements, as it searches for objects to orient itself. The same phenomenon can be observed after spinning in circles.

Our device is designed to measure this oscillation, which is known to occur and progressively increase in intensity beginning at a BAC of 0.05. Currently in the state of Virginia, the BAC limit that is considered to be driving while intoxicated corresponds to a BAC of 0.08. When conducted in the field, police officers have approximately 70 percent accuracy with this test. This requires observing a frequency of 3-4 Hz and an amplitude of 2-3 degrees. The test, conducted 12 inches from the subject's face, measures these parameters by graphing the gaze over time as a position function, and analyzing the reaction in the eyes at either horizontal extreme. This is because a vestibular nystagmus will present as jerking horizontal movements until the 45 degree point from the center line of the gaze, and as it is moved further to the corners of the eyes, the nystagmus will present itself as a vertical jerking.

B. System Overview

Once the driver takes their position and attempts to start the vehicle, the visor goes down revealing a camera and an LED display screen. First the camera sends a snap image of the driver to a Single Board Computer (SBC) which identifies the driver and loads their baseline data gathered during an initial one-time training phase. The baseline data is compared to the results of the HGN test to determine their sobriety. The test is performed by displaying a dot on an LED screen attached to the car visor on the driver's side. The dot moves horizontally across the display while the camera records the eye movement during the HGN test. Once the test is completed, the recordings are sent to the SBC for analysis issuing a signal to allow the transmission of the vehicle to function normally in case of a passed test or a signal to lock the transmission in case of a failed test. An illustration of our system is shown in Fig. 1 The

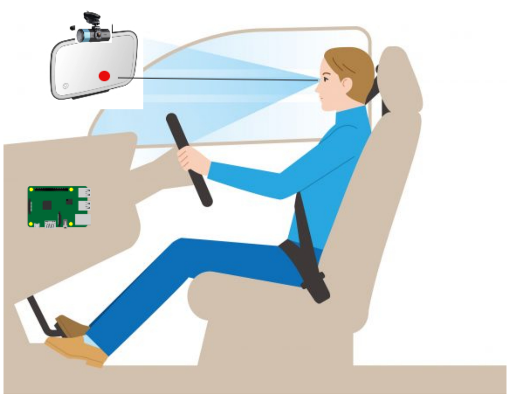


Fig. 1: Illustration of Our Drinking and Driving Prevention System

test is conducted by keeping an individual's head stationary, for the average person the ability to track an object smoothly it must move under 60 degrees per second. The average person has a field of view of 120 degrees. The object must pass through the field from one extreme to the next, with the goal being for the whole test and analysis to be conducted in under 10 seconds.

1) Hardware: The primary computing unit of our device is a Raspberry Pi (RPi) 4 Model B single-board computer running Raspbian. The RPi utalizes a 1.5GHz quad-core Broadcom BCM2711 Cortex-A72 (ARM v8) 64-bit CPU, 8GB LPDDR4-3200 SDRAM, and support for dual-band 802.11ac wireless networking, Bluetooth 5.0, and Gigabit Ethernet.

We attach a 7-inch touch screen display to the RPi's Display Serial Interface (DSI) connector in order to communicate with it. The user may interact with the device by selecting options and entering data using the touch screen.

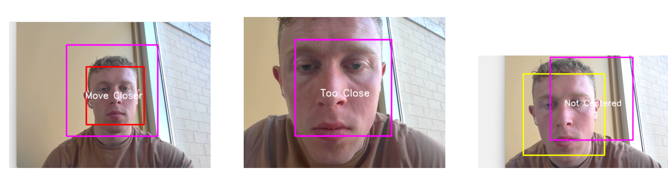
As part of the HGN test, we additionally record the subject's eye movements using a RPi Camera Module V2 module which is connected to the RPi's Camera Serial Interface (CSI) port. The camera has an 8-megapixel sensor and supports 1080p30, 720p60, and VGA90 video modes. We use this model because it provides high resolution video capture while keeping the system compact and it is also easy to mount.

We also use a 4-pin relay, which is a simple relay with a solenoid and a switch, to control the opening and closing of the break-transmission circuit switch which we explain in details the following subsection. The excess wires used ranged from gauges: 18-22.

Overall, our hardware arrangement is made to be portable, small, and simple to put together, allowing for a wide range of applications for our device.

2) Software: The software process we have developed involves several major stages, each of which plays a crucial role in ensuring the accuracy and reliability of the final test results. These stages are pretest face positioning, identification, dot simulation, head movement detection, and eye gaze tracking, respectively.

a) Pretest Face Positioning: The first stage involves positioning the user's face in a precise and optimal manner for the testing process. To achieve proper positioning we created a python script that utilizes the OpenCV library and is supplemented by a Haar Cascades xml file [17]. This face recognition system places a box around the user's face on the projection screen. In case the user's face is not in the ideal position for testing, visual cues are displayed on the screen in the form of text and changing colors to guide the user towards the correct positioning as shown in Fig. 2. The ideal positioning places the user's face at approximately 12 inches away from the camera and centered within the field of view for the camera. We ensure the location of the user's face by referencing the moving average of the x and y coordinate pixels of the face recognition box. Likewise, the distance to the camera is determined by the moving average of the length and width pixels of the face recognition box. Once our system has verified the user has positioned themselves correctly, the live feed disappears and the pretest face positioning stage is completed.

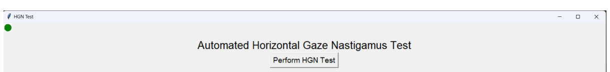


(a) Too Far (b) Too Close (c) Not Centered

Fig. 2: Guiding Squares and Messages to Position the Face

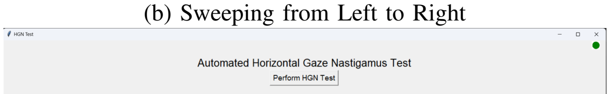
b) Identification: The Identification stage is conducted in order to give users a reference score for whenever they complete a successful test attempt. A user's reference score is derived from their profile's unique scores during their training phase and a typical acceptable score among the average individual. If it is a user's first time attempting a test and they have not created a profile, then a separate one-time training phase will be executed. This training phase involves adding their face to the system's unique face recognition model and having the user complete 3 passing HGN tests to create their reference score. From there, a user can take a test and compare their current score to their reference score, giving them a sense of their current physiological state.

c) Dot Simulation: The dot simulation stage involves recording a video of the user's face while they participate in the dot simulation. This process is accomplished using a Python script that accesses the connected webcam using the OpenCV library and projects a Graphical User Interface (GUI) using the tkinter library [18]. With the standard screen being 12 inches in width and the user's face positioned 12 inches from the camera, the dot simulation achieves an angle that places the dot near the user's peripheral vision, activating a user's HGN. The test begins with a dot holding its position at the left edge of the screen for two seconds, after which it traverses horizontally across the screen for four seconds, until it reaches the right edge. The dot then holds its position for two more seconds until the test ends, after which the webcam stops recording and saves the video to memory. The illustration for the dot simulation in different positions can be shown in Fig. 3



(a) Left Position

(b) Sweeping from Left to Right

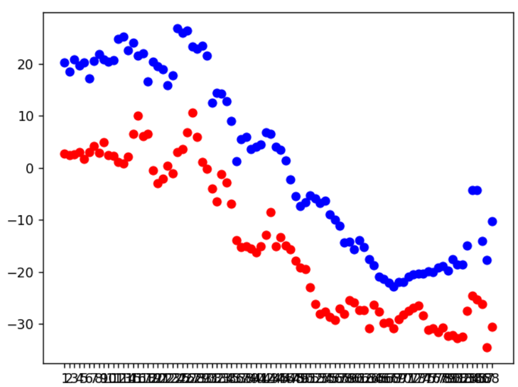


(c) Right Position

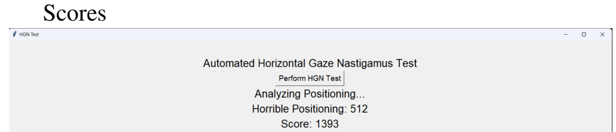
Fig. 3: Positions of the Dot During the HGN Test

d) Head Movement Detection: The head movement detection stage ensures that the user's head stays positioned throughout the dot simulation, which is paramount for creating HGN and establishing accurate scoring. Our solution involves analysing the recorded video with a Python script and using the same face recognition system as the pretest face positioning phase. The script takes the size and position of the face recognition box over multiple frames throughout the video. The positioning coordinate values are then analyzed by their variance to determine if there was significant change among them. The variance value is then displayed to the user to reflect if their position was satisfactory during the testing phase.

e) Eye Gaze Tracking: The final stage is the eye gaze tracking stage where we determine if the user exhibits HGN by scoring the facial landmarks of the user's gaze with a statistical model. The process starts by having the recorded video of the user's face during the test be processed by OpenFace [19] Feature Extraction. The OpenFace software analyzes each frame of the video and returns a spreadsheet of facial landmark values, including the x coordinate of each eyes' gaze. From there, our model makes use of the spreadsheet to determine if the user's eyes were following the dot adequately. Our overall model accounts for the three separate sections during the dot simulation (left, sweeping, and right) and two eyes, so six separate univariate linear regression models are created. The linear regression line for each eye and section is made from the x coordinate gaze values found within the spreadsheet from OpenFace. From each of the linear regression models, we determine a mean squared error and record the slope of the line. If the slope of the models is not near zero for the stable sections or a negative slope for the sweeping sections, we immediately return a failing score of 500 for the section as shown in Fig. 4. However, if the slope of the models is adequate, we return the mean squared error as the score as shown in Fig 5. Once all three sections for both eyes are scored, the final score returned is the sum of the best scoring eye from each of the three sections as shown in Table I and Table II .



(a) Graph for Left Eye (Red) and Right Eye (Blue) Scores

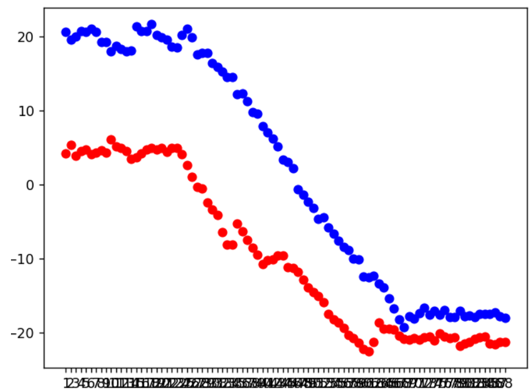


(b) Message Displayed when a Test is Failed

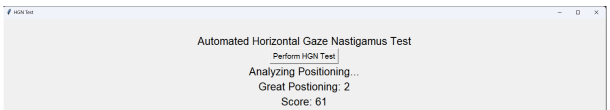
Fig. 4: Illustration of a Failed Test

TABLE I: Example of a User's Scores for Each Eye and the Final Score for Failed Test

Eye	Left Section	Sweeping Section	Right Section
Left Eye	**715**	**178**	**500**
Right Eye	807	318	652
Final Score	**1393**		



(a) Graph for Left Eye (Red) and Right Eye (Blue) Scores



(b) Message Displayed when a Test is a Success

Fig. 5: Illustration of a Passed Test

TABLE II: Example of a User's Scores for Each Eye and the Final Score for Passed Test

Eye	Left Section	Sweeping Section	Right Section
Left Eye	122	**13**	29
Right Eye	**31**	41	**17**
Final Score	**61**		

C. Vehicle Modification

The transmission interlock system by which we are immobilizing the vehicle is unique to our system. This feature allows for intoxicated individuals to use life-saving features in the vehicle, such as electricity, temperature control, etc., while inside their vehicle. This is because the test begins upon the start of the engine, yet the car will not be removed from park (the lowest gear), until the sobriety test is passed.

In order to do this, our team members followed wiring diagrams published by the vehicle manufacturer to determine where to find the brake pressure switch to disable the shifting mechanism. The brake pressure switch sends a signal to the vehicles computer, indicating that the brake pedal has been depressed. In a vehicle with an automatic transmission, a driver is not able to shift a vehicle out of the parking gear without pressing the brake pedal. Using a digital multi-meter (DMM) and testing for resistance between various points on the wires, we were able to identify and label them, as well as trace the wires through the vehicle. This allowed us to determine where to install our device so that it results in the correct response when the test is complete. By adding our system and a relay in this location we are able to control if the switch can be activated or not based upon the driver's test results. If the driver passes the HGN test, then a signal will be sent to the relay, closing the circuit, allowing for the brake pressure switch to be activated. Once the brake pressure switch is activated, the car is able to move from park. If the driver fails the test, the switch does not receive the necessary voltage to close the opened circuit thus immobilizing the vehicle. The immobilizing systems is illustrated in Fig. 6

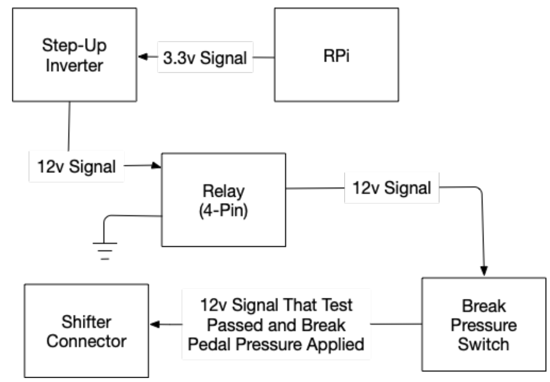


Fig. 6: Block Diagram for the Immobilization Mechanism

D. Security and Privacy

Our intention is not to criminalize the users utilizing our system or make their data available as evidence to their driving habits to affect their car insurance policy. We simply want to give drivers a mean to asses their ability to drive safely and for these reasons we add necessary security measures to protect the user's data and privacy. All identifiable data collected to create user profiles or during an HGN are encrypted using the secret-key cipher Advanced Encryption Standard in Galois Counter Mode (AES-GCM) [20]. We use the AES in GCM mode as, in addition to confidentiality, it also ensures authentication and integrity of the data. Additionally, we want to minimize the delay caused by the HGN test and AES authenticated encryption modes were shown to have minimal effect on the performance of applications running on lightweight platforms such as the RPi [21].

To create a user's profile in our system, the camera takes 150 pictures for the user to ensure accurate identification. There pictures are converted into arrays of bytes and then encrypted used AES-GCM and the originals are destroyed. Every time an HGN test is conducted, the user's identification data are decrypted and compared against the images gathered during the identification phase. This way we make sure that we load the baseline data for the correct user while protecting their privacy.

V. Results and Analysis

Three different types of tests were performed by the 6 users to test the efficiency of the system. The first set of tests established a baseline score for an individual where each user took the standard HGN test under normal sober conditions. The next set of tests performed used a modified version of the standard HGN test. The modified version of the test only differed in the behavior of the dot during the simulation. When the dot was present on the screen, it would flicker left and right erratically, while still moving in the general movement of the original dot's path. With the user following the flickering location of the dot, this effect emulates nystagmus in a user's eye to further show that the system can detect these minute eye movements. The last set of tests was performed using the standard HGN test. However, before users began each test they were spun around for 30 seconds in order to simulate the disorientation of intoxication. We conducted each of the 3 tests for each user 10 times and record the minimum, maximum and average score for each user in Table III, Table IV, and Table V.

TABLE III: Baseline Test Scores for Different Users

User	Min Score	Max Score	Average Score
User 1	95	183	135
User 2	62	167	103
User 3	69	116	78
User 4	101	143	126
User 5	98	152	124
User 6	340	451	396

TABLE IV: Flickering Test Scores for Different Users

User	Min Score	Max Score	Average Score
User 1	205	367	263
User 2	147	177	164
User 3	189	261	212
User 4	142	199	161
User 5	160	212	198
User 6	405	546	435

TABLE V: Spinning Test Scores for Different Users

User	Min Score	Max Score	Average Score
User 1	473	563	515
User 2	568	996	821
User 3	478	706	558
User 4	159	210	178
User 5	221	336	267
User 6	420	674	579

It can be shown from the test results for each user that there is a clear distinction between the scores in their normal state and when they are spun or following the flickering dot. This distinction allows the system to distinguish between a user's normal state and impaired state allowing it to send the correct signal to the vehicle immobilizing system when needed.

VI. Conclusion

In this paper we introduced a passive transmission interlock system that utilizes the HGN test to determine a driver's impairment state. Our system is unique in that it does not prevent the vehicle from starting but only immobilizes it making all functionalities such as heating, cooling and charging available to the vehicle riders. The test results show that our system can identify an impairment state for different users.

For future work, we would like to conduct more test cases on a wider range to train the system with difference face and eye shapes allowing for more universal usage. We believe that our system can help in the protection from the dangers of driving while intoxicated.

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