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Development and Implementation of Smart Glasses for Drowsiness Detection: Cutting-Edge Technology for a Safer Driving Experience

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Expression of Gratitude

At the outset, I begin by expressing my profound gratitude to God Almighty for His guidance and blessing during this long and wonderful journey. It is because of His mercy and care that we have achieved this milestone.

I also express my deepest gratitude to my dear parents who have always been by my side. Their unconditional support and encouragement have been a great help to me.

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Thank you all for this incredible journey, and I look forward to sharing more milestones and memories in the near future."

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Summary

The project focuses on developing smart glasses with advanced sensors designed to detect driver drowsiness. Using eye-tracking technology, the glasses continuously monitor the driver's eye movements. When a sign of drowsiness is identified (eye closure for specific periods of time), the glasses send signals to a controller, which activates an alert system to warn the driver. In critical cases where drowsiness persists despite the alert, the controller communicates with an external device via radio frequency to apply the brakes, addressing safety concerns associated with driver fatigue and preventing potential accidents. This technology represents a significant advancement in road safety by providing early warnings of fatigue-related incidents and effective intervention to minimize risks, thereby improving road safety for all motorists

Résumé

Le projet se concentre sur le développement de lunettes intelligentes dotées de capteurs avancés conçus pour détecter la somnolence du conducteur. Grâce à la technologie de suivi des yeux, les lunettes surveillent en permanence les mouvements oculaires du conducteur. Lorsqu'un signe de somnolence est identifié (fermeture des yeux pendant des périodes spécifiques), les lunettes envoient des signaux à un contrôleur, qui active un système d'alerte pour avertir le conducteur. Dans les cas critiques où la somnolence persiste malgré l'alerte, le contrôleur communique avec un dispositif externe par radiofréquence pour freiner, répondant ainsi aux problèmes de sécurité liés à la fatigue du conducteur et prévenant les accidents potentiels. Cette technologie représente une avancée significative en matière de sécurité routière, car elle permet d'alerter rapidement le conducteur en cas d'incidents liés à la fatigue et d'intervenir efficacement pour minimiser les risques, améliorant ainsi la sécurité routière pour tous les automobilistes.

ملخص

يركز المشروع على تطوير نظارات ذكية مزودة بأجهزة استشعار متقدمة مصممة للكشف عن نعاس السائق. وباستخدام تقنية تتبع العين، تراقب النظارات باستمرار حركات عين السائق. عندما يتم تحديد علامة النعاس(إغلاق العين لفترات محددة)، ترسل النظارة إشارات إلى وحدة تحكّم، والتي تقوم بتفعيل نظام تنبيه لتحذير السائق. وفي الحالات الحرجة التي يستمر فيها النعاس على الرغم من التنبيه، تتواصل وحدة التحكم مع جهاز خارجي عبر التردد اللاسلكي لتطبيق المكابح، مما يعالج مخاوف السلامة المرتبطة بإرهاق السائق ويمنع وقوع حوادث محتملة. وتمثل هذه التقنية تقدماً كبيراً في مجال السلامة على الطرقات من خلال توفير إنذارات مبكرة للحوادث المرتبطة بالإرهاق والتدخل الفعال للحد من المخاطر، وبالتالي تحسين السلامة على الطرقات لجميع سائقي السيارات

General Introduction

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General Introduction

Road safety is a major concern for all countries around the world, whether they are developed or developing. Road accidents pose a significant economic, social, and public health problem.

In Algeria, road accidents remain a major challenge. Despite the development of infrastructure and a symbol of economic and social progress, the level of insecurity on the roads remains high, and even disturbing. Each year, the number of accidents continues to rise, with more than 4,000 deaths, 45,000 injuries and significant material damage recorded in 2015 [1].

According to Ministry of Interior data, in 2021, more than 22,000 accidents occurred in Algeria, resulting in 3,061 deaths. [2]

In 2023, these figures increased further, with 59,000 incidents, 1836 deaths and nearly 79,000 injuries recorded, according to civil security data [3].

The consequences of road accidents go beyond pain and suffering, causing enormous economic losses to the country. Insurance companies pay millions of dinars to victims and their beneficiaries, while incurring substantial expenses for specialized care for the injured and indirect losses, such as lost working days.

Driver fatigue and drowsiness are common issues that compromise driver safety. Long hours of driving, monotonous conditions, and inadequate rest can all contribute to fatigue, affecting drivers' cognitive functions, reaction times, and decision-making abilities.

Public authorities must intervene to reduce the number of fatal accidents by implementing appropriate policies and laws, while also raising awareness and educating the public about road safety, as well as striving to ensure the means to improve road safety. In this context, we have developed smart glasses to detect driver drowsiness, incorporating advanced technologies to alert drivers when fatigued.

When signs of drowsiness are detected, such as prolonged eye closure or erratic eye movements indicative of fatigue, the smart glasses will initiate a series of proactive interventions to alert the driver and prevent potential accidents. Integrated with a sophisticated alert system, the glasses will provide timely notifications to the driver, encouraging them to take necessary precautions and breaks to combat fatigue.

Furthermore, in critical situations where the driver does not respond to initial alerts and drowsiness persists, our system will utilize advanced connectivity features, such as RF technology, to communicate with the vehicle's onboard systems and activate emergency braking mechanisms. By seamlessly integrating with the vehicle's infrastructure, our solution aims to provide an additional layer of safety to prevent accidents and mitigate the impact of driver drowsiness.

Our manuscript is structured into three distinct chapters:

In the first chapter, we will delve into detail about accidents caused by driver drowsiness, providing a comprehensive overview and relevant statistics on this phenomenon.

In the second chapter, we will discuss the different components used in the realization of our project. The final chapter is divided between the design and implementation. Finally, we conclude our thesis with a summary of the various stages of our project and discussing future prospects.

Chapter I: Accidents due to Driver Drowsiness “Overview and Statistics"

1. Introduction

Roads around the world are subject to a serious public safety problem, causing heavy human and material losses, namely, traffic accidents caused by the driver ' s sleep. Driver fatigue and sleepiness are among the most important factors contributing to traffic accidents, and this is a major challenge that requires effective action to reduce their impact.

The effects of traffic accidents on the driver ' s sleep range from serious injuries to human and material losses to psychological and economic impacts on society. Tiredness and sleep during driving lead to loss of attention and focus, which increases the likelihood of traffic accidents and exacerbates the resulting injuries.

In Algeria, as in many countries of the world, driving accidents caused by driver's sleep represent a major challenge to public safety and the national economy. There is an increasing need to understand the scope of the problem and its impact on society, to take preventive and remedial action to reduce it and to maintain road safety and society.

In this context, we will talk about the frightening statistics of traffic accidents in general, caused by driver's sleep, especially the most important technology proposed in the world, to conclude with our technology.

2. Prevalence of Accidents Due to Driver Drowsiness

2.1 Statistics on accidents caused by drowsy driving

Drowsy driving is a perilous combination of operating a vehicle while feeling sleepy. It typically occurs due to insufficient sleep, untreated sleep disorders, or shift work. Additionally, prescription and over-the-counter medications can induce drowsiness, and alcohol can exacerbate this condition. Falling asleep at the wheel is undoubtedly dangerous, but even being sleepy affects your ability to drive safely, even if you manage to stay awake. Here are some key statistics related to drowsy driving .

Prevalence:

In a CDC survey, approximately 1 in 25 adult drivers (aged 18 years or older) reported having fallen asleep while driving. [4]

Adult drivers who snore or usually sleep 6 or fewer hours per day were more likely to report falling asleep while driving than those who sleep 7 or more hours per day .[4]

Accidents and Fatalities:

In 2017, drowsy driving was involved in 91,000 crashes, resulting in 50,000 injuries and nearly 800 deaths. [5]

In 2020, there were 633 deaths based on police reports. However, these numbers are underestimated, and over 6,000 fatal crashes each year may involve a drowsy driver. [6]

Risk Factors:

Teen and young adult drivers, especially those on the road between midnight and 6 a.m. or in the later afternoon, are at greater risk.

Commercial truck drivers, those working night shifts or long shifts, and individuals with untreated sleep disorders (such as sleep apnea) are also vulnerable.

Medications that induce sleepiness further contribute to the risk [7].

2.2 Factors contributing to driver drowsiness

Sleep Deprivation: When a driver hasn't had enough rest, drowsiness can set in. Lack of adequate sleep impairs alertness and responsiveness, making it a significant risk factor for drowsy driving. [4]

Fatigue: Fatigue can lead to lapses in attention, slower reaction times, and impaired decision-making. These effects increase the likelihood of accidents on the road. [8]

Medications: Both prescription and over-the-counter medications can cause drowsiness. If a driver is taking such medications, it's essential to be aware of their potential impact on alertness while driving. [9]

Alcohol Interaction: Alcohol can exacerbate sleepiness, leading to impaired cognitive function and increased drowsiness. Combining alcohol with existing sleepiness can significantly affect driving performance [10].

Driving Time: Prolonged driving time is strongly associated with drowsiness development. As the hours behind the wheel accumulate, the risk of feeling drowsy increases. [11]

Personal Characteristics: Certain personal aspects influence susceptibility to drowsiness. Being older, male, and having robustness are factors that make a participant less prone to getting drowsy. [12]

2.3 Impact of driver drowsiness on road safety

1. *Increased Accident Risk:*
    - Drowsy driving significantly raises the risk of accidents. Fatigue impairs cognitive function, attention, and reaction time, leading to poor decision-making and decreased awareness of surroundings.
    - Drowsy drivers are more likely to drift out of their lanes, miss traffic signals, and collide with other vehicles or objects.

2. *Severity of Accidents:*
    - Accidents caused by drowsy driving tend to be more severe. When a fatigued driver is involved in a crash, the impact is often greater due to reduced responsiveness and inability to take evasive actions.
    - High-speed collisions can result in serious injuries or fatalities.
3. *Challenges in Detection:*
    - Identifying drowsy driving as the cause of an accident can be challenging. Unlike alcohol-impaired driving, there is no straightforward test (such as a breathalyzer) to measure drowsiness.

- Police reports may not always capture drowsiness accurately, leading to underreporting of its role in accidents.

4. *Economic Costs:*
    - Accidents due to drowsy driving impose substantial economic costs. These include medical expenses, property damage, lost productivity, and legal fees.
    - The financial burden affects individuals, insurance companies, and society as a whole.
5. *Emotional Impact:*
    - Victims of accidents caused by drowsy driving experience emotional trauma. Survivors may suffer from anxiety, depression, and post-traumatic stress disorder.[13]
    - Families who lose loved ones endure grief and long-lasting emotional pain.
6. *Preventive Measures:*
    - Public awareness campaigns, education, and legislative efforts are crucial for preventing accidents related to drowsy driving.
    - Encouraging responsible sleep habits, promoting rest breaks during long trips, and addressing work-related factors can mitigate the risk.

3. Consequences of Accidents Due to Driver Drowsiness

Drowsy driving is a serious and often overlooked issue that can lead to devastating consequences. From physical injuries and fatalities to economic costs and emotional trauma, the impacts of drowsy driving accidents can be far-reaching. This document will explore the various consequences of these types of accidents and examine the methods and technologies available for detecting and preventing drowsy driving.

3.1 Physical injuries and fatalities

Drowsy driving is dangerous and causes serious accidents and even fatalities every year as we see in Figure 1.1 and Figure 1.2.

According to a study by the AAA Foundation for Traffic Safety, an average of 328,000 motor vehicle accidents occur each year that involve drowsy drivers. Nearly 109,000 of those crashes result in injuries, and 6,400 of them end in fatalities. [13]

Shockingly, one out of every 25 drivers have admitted to driving while drowsy. The National Safety Council (NSC) purports that fatigued drivers are three times more likely to be in a car accident. Driving tired puts everyone on the road at risk. [14]

It is estimated that driver drowsiness is a primary contributing factor in approximately 750 deaths and over 20,000 injuries involving commercial motor vehicles (CMV; Advocates for Highway and Auto Safety, 2001). Therefore, any increase in our understanding of such incidents is likely to greatly benefit public safety). [15]

Traffic accidents are considered one of the seventh causes of death in the world. In Algeria, more than 22,000 accidents were recorded in 2022, leaving more than 3,000 dead and 30,000 injured. [16]

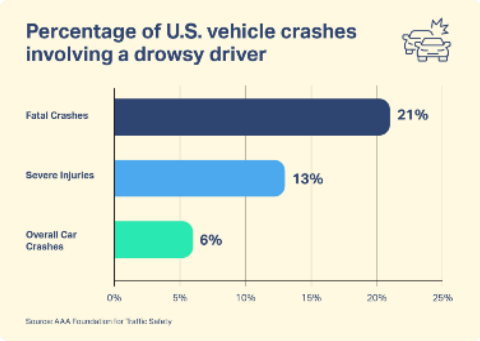


Figure 1.2 *USA vehicle crashes [18]*

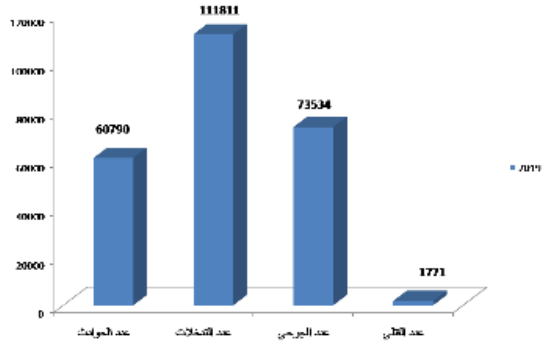


Figure 1.1 *INJURIES AND FATALITIES IN ALGERIA [17]*

3.2 Economic costs of accidents caused by drowsy driving

In addition to physical injuries, drowsy driving causes property damage and other costs to society. The Sleep Foundation estimates that between hospital admissions, property damage, and other costs, drowsy driving costs society between $12.5 billion and $109 billion each year. The physical and financial costs of drowsy driving are tremendous [19].

Standards of international bodies estimate the economic losses resulting from traffic accidents at between 1 and 3 percent of each country's gross national income, a cost that for Algeria represents an amount of approximately 200 billion dinars, equivalent to about 1.5 billion dollars [20].

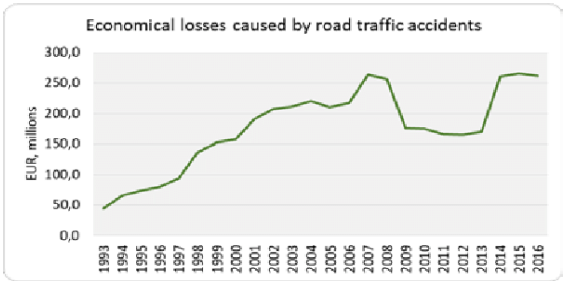


Figure 1.3 *economical losses [21]*

3.3 Psychological and emotional impact on victims

Traffic accidents can have profound psychological effects on affected individuals, and sleep may have an impact on such effects.

1. PTSD: Some people who have experienced traffic accidents suffer from PTSD. Symptoms can include rehearsals, nightmares, constant anxiety, and stress.

2. Depression and anxiety: persons affected by traffic accidents may suffer from depression and anxiety. These situations can affect their ability to work and social interaction.

3. Fear of leadership: Some people may face fear of driving after a traffic accident. They may avoid the roads or sites that remind them of the incident.

4. Guilty: If the incident resulted in injury or death, those affected may feel guilty and

responsible.

It is important to recognize that the psychological effects of traffic accidents can be long-term and may require professional intervention such as psychological treatment or social support to overcome them. Prevention and traffic awareness play an important role in reducing the incidence and psychological effects of these incidents.



Figure 1.4 *emotional impact on victims [22]*

4. Drowsiness detection technologies: infrared technology

Driver drowsiness detection is a car safety technology which helps prevent accidents caused by the driver getting drowsy. Various studies have suggested that around 20% of all road accidents are fatigue-related, up to 50% on certain roads. [23]

Some of the current systems learn driver patterns and can detect when a driver is becoming drowsy.

4.1 Technologies and methods for detecting drowsy driving

Various technologies can be used to try to detect driver drowsiness

Steering pattern monitoring: Primarily uses steering input from electric power steering system. Monitoring a driver this way only works as long as a driver actually steers a vehicle actively instead of using an automatic lane-keeping system [25].



Figure 1.5 *Steering pattern monitoring [24]*

Vehicle position in lane monitoring: Uses a lane monitoring camera. Monitoring a driver this way only works as long as a driver actually steers a vehicle actively instead of using an automatic lane-keeping system [25].

Physiological measurement: Requires body sensors to measure parameters like brain activity, heart rate, skin conductance, muscle activity, head movements etc...

Driver eye/face monitoring: Uses computer vision to observe the driver's face, either using a built-in camera [26] or on mobile devices.[27]



Figure 1.6 *Driver eye/face monitoring [28].*

4 .2 infrared technology

Infrared Radiation is an integral part of the electromagnetic spectrum, consisting of waves with a wavelength of between 0.7 and 300 micrometers, roughly equivalent to the frequency range between 1 and 400 terahertz These rays have a longer wavelength than visible light, but are shorter than the radiation waves of the Terahertz, making them invisible to the human eye, but their temperature can be felt. [29]

Infrared radiation is used in a wide range of applications, including night vision, communications, remote sensing and spectral analysis, as well as for military and civilian purposes. In the context of the drowsiness detector, this technique is used to determine the eye movements of drivers, which helps to reduce sleepy road accidents during drive.

4.3 Exploitation of Infrared Technology: Effective Transformation

Infrared technology in drowsiness detectors offers a set of advantages that make it an extremely effective tool, including:

Detection Accuracy: Infrared rays are characterized by their ability to monitor the precise movements of the driver's eyes, allowing for accurate determination of the driver's alertness levels. [29]

Lighting Independence: Since infrared rays do not rely on visible light, drowsiness detectors operate efficiently even in low or no light conditions. [29]

Climate Conditions Flexibility: Infrared technology reduces the impact of environmental factors such as fog and rain, ensuring high performance continuity of the detectors in various conditions.[29]

Material Penetration 'Vision': Infrared rays can penetrate some materials, allowing for the detection of objects even if they are partially covered.[29]

Multiple Applications: In addition to drowsiness detectors, infrared is used in various fields such as night vision and thermal imaging, indicating its versatility and effectiveness. [29]

These characteristics make infrared technology an ideal choice for developing advanced drowsiness detectors that can be relied upon to enhance road safety.

5. Conclusion

Traffic accidents resulting from driver fatigue are a serious problem that threatens public safety and affects health and life. In this chapter, we have provided a comprehensive overview of the impact of driver fatigue on traffic accidents by highlighting available statistics and data. Car accidents caused by a driver's tiredness have proved to be a serious threat to public safety, resulting in serious injuries and severe human and material losses, thus prompting serious and direct reflection on effective measures and solutions to address this problem.

Thus, focusing on the development of fatigue detection techniques is not just a choice but also an imperative, we explored deeper infrared technology and its role in detecting driver fatigue and improving road safety. In the next chapter, we will provide more points and research on the technological components of our project.

Chapter II: Exploring Project Tools: Hardware Essentials

1.Introduction

After discussing in the first area a glimpse and statistics about the serial killer in the roads and the difficult problem of the driver's drowsiness and sleep while driving and the resulting human and material losses are terrifying, especially since the biggest sufferers of these conditions are those who transport long-distance travelers or transport important goods to public and private companies.

We welcome you in the second area where we will talk about the components of our system and ways of integrating and communicating between devices to ensure effectiveness and stability under all conditions experienced by the driver.

2.Processing units (Arduino)

Arduino is an open-source platform used to design electronic circuits in which microcontrollers play an essential role. Arduino consists of two main parts: the board containing the hardware, and the software in which the programming processes are performed.

Arduino is mainly used in the design of interactive electronic projects, such as those that use sensors to measure temperatures, humidity, light, pressure and others. Arduino can be connected to different software on the computer, and its programming is based on the open-source language Processing, which is similar to the programming language C and is one of the easiest languages used to write accurate controllers' software.

2.1Arduino nano

Definition

The Arduino Nano is an open-source breadboard-friendly microcontroller board based on the Microchip ATmega328P microcontroller (MCU) and developed by Arduino.cc and initially released in 2008. It offers the same connectivity and specs of the Arduino Uno board in a smaller form factor.

The Arduino Nano is equipped with 30 male I/O headers, in a DIP-30-like configuration, which can be programmed using the Arduino Software integrated development environment (IDE),

which is common to all Arduino boards and running both online and offline. The board can be powered through a type-B mini-USB cable or from a 9 V battery.

Technical specifications

Microcontroller: Microchip ATmega328P.

Operating voltage: 5 volts

Input voltage: 5 to 20 volts

Digital I/O pins: 14 (6 optional PWM outputs)

Analog input pins: 8

DC per I/O pin: 40 mA

DC for 3.3 V pin: 50 mA

Flash memory: 32 KB, of which 2 KB is used by bootloader

SRAM: 2 KB

EEPROM: 1 KB

Clock speed: 16 MHz

Length: 45 mm

Width: 18 mm

Mass: 7 g

USB: Mini-USB Type-B

ICSP Header: Yes

DC Power Jack: No

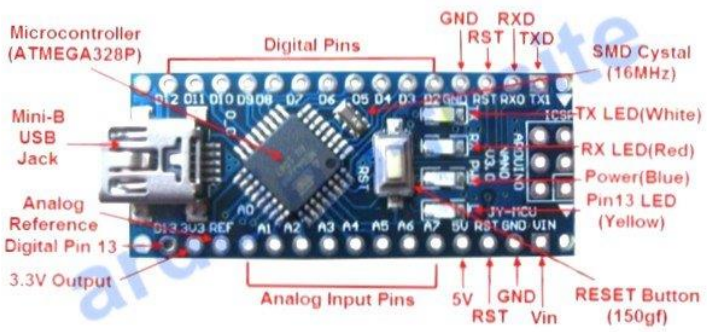


Figure 2.1 *Arduino Nano [30]*

2.2Arduino Uno

Definition

The Arduino Uno is an open-source microcontroller board based on the Microchip ATmega328P microcontroller (MCU) and developed by Arduino.cc and initially released in 2010.[31] The microcontroller board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. The board has 14 digital I/O pins (six capable of PWM output), 6 analog I/O pins, and is programmable with the Arduino IDE (Integrated Development Environment), via a type B USB cable. It can be powered by a USB cable or a barrel connector that accepts voltages between 7 and 20 volts, such as a rectangular 9-volt battery. It has the same microcontroller as the Arduino Nano board, and the same headers as the Leonardo board. The hardware reference design is distributed under a Creative Commons Attribution Share-Alike 2.5 license and is available on the Arduino website. Layout and production files for some versions of the hardware are also available.

Technical specifications

Microcontroller (MCU):

IC: Microchip ATmega328P (8-bit AVR core)

Clock Speed: 16 MHz on Uno board, though IC is capable of 20 MHz maximum at 5 Volts

Flash Memory: 32 KB, of which 0.5 KB used by the bootloader

SRAM: 2 KB

EEPROM: 1 KB

USART peripherals: 1 (Arduino software default configures USART as a 8N1 UART)

SPI peripherals: 1

I²C peripherals: 1

Operating Voltage: 5 Volts

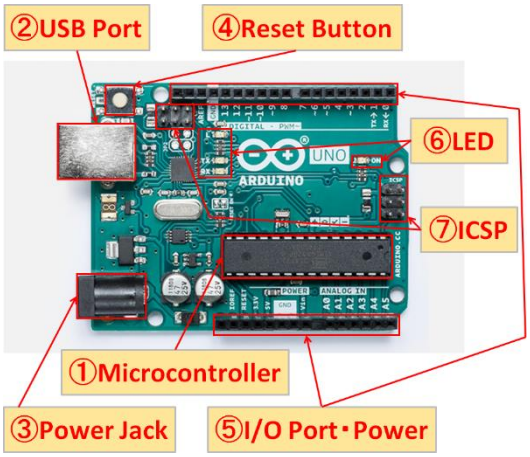


***Figure 2.2** ARDUINO UNO*

Digital I/O Pins: 14

PWM Pins: 6 (Pin 3, 5, 6, 9, 10 and 11)

Analog Input Pins: 6

DC Current per I/O Pin: 20 mA

DC Current for 3.3V Pin: 50 mA

Size: 68.6 mm x 53.4 mm

Weight: 25 g

ICSP Header: Yes

Power Sources:

- USB connector. USB bus specification has a voltage range of 4.75 to 5.25 volts. The official Uno boards have a USB-B connector, but 3rd party boards may have a miniUSB / microUSB / USB-C connector.
- 5.5mm/2.1mm barrel jack connector. Official Uno boards support 6 to 20 volts, though 7 to 12 volts is recommended. The maximum voltage for 3rd party Uno boards varies between board manufactures because various voltage regulators are used, each having a different maximum input rating. Power into this connector is routed through a series diode before connecting to VIN to protect against accidental reverse voltage situations.
- VIN pin on shield header. It has a similar voltage range of the barrel jack. Since this pin doesn't have reverse voltage protection, power can be injected or pulled from this pin. When supplying power into VIN pin, an external series diode is required in case barrel jack is used. When board is powered by barrel jack, power can be pulled out of this pin.

3. Communication unit

3.1 RF 433 MHz

The 433MHz band is widely used for various wireless applications, including:

Remote controls: Garage door openers, car alarms, and other remote-control devices often operate in this frequency range.

Wireless sensors: Temperature sensors, motion detectors, and other environmental sensors often transmit data using 433MHz.

Home automation: Smart home devices like light switches, thermostats, and security systems can communicate wirelessly using 433MHz.

Radio-controlled toys: Many RC cars, boats, and airplanes use 433MHz for control signals.

RFID tags: Passive RFID tags operating at 433MHz are used for asset tracking and identification.



Figure 2.3 *Module RF 433 MHz [32]*

3.2 Technical Aspects of 433MHz RF Communication

Frequency range: 433.050 MHz to 434.790 MHz (varies slightly depending on region).

Wavelength: Approximately 70 cm.

Modulation: Amplitude-shift keying (ASK) is the most common modulation scheme used.

Data rates: Typically range from 1 kbps to 10 kbps.

Range: Up to 100 meters in open areas, but can be significantly reduced by obstacles.

Power output: Limited to 10mW in most countries.

3.3 Advantages of 433MHz RF Communication

Low cost: 433MHz modules and antennas are readily available and inexpensive.

Simple to implement: The technology is relatively straightforward, making it accessible to hobbyists and beginners.

Good range: The frequency offers a reasonable range for many applications.

Low power consumption: 433MHz devices are energy-efficient, making them suitable for battery-powered applications.

Widely available components: A vast selection of modules, antennas, and development tools are available from various manufacturers.

4.Infrared sensor

4.1 Definition

An infrared detector is a detector that reacts to infrared (IR) radiation. The two main types of detectors are thermal and photonic (photodetectors).

The thermal effects of the incident IR radiation can be followed through many temperatures' dependent phenomena. Bolometers and microbolometers are based on changes in resistance. Thermocouples and thermopiles use the thermoelectric effect. Golay cells follow thermal expansion. In IR spectrometers the pyroelectric detectors are the most widespread.

The response time and sensitivity of photonic detectors can be much higher, but usually these have to be cooled to cut thermal noise. The materials in these are semiconductors with narrow band gaps. Incident IR photons can cause electronic excitations. In photoconductive detectors, the resistivity of the detector element is monitored. Photovoltaic detectors contain a p-n junction on which photoelectric current appears upon illumination.

An infrared detector is hybridized by connecting it to a readout integrated circuit with indium bumps. This hybrid is known as a focal plane array.

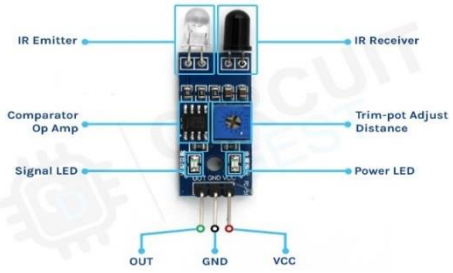


Figure 2.4 *IR-Sensor-Description.[33]*

4.2 Infrared sensor application

Proximity and presence detection: Infrared sensors can detect the presence or absence of an object by emitting infrared radiation and measuring the reflection or interruption of the emitted signal. They are often used in automatic faucets, hand dryers, and occupancy detection systems.

Motion detection: Infrared motion sensors use passive infrared (PIR) technology to detect changes in infrared radiation caused by moving objects. They are commonly found in security systems, lighting control, and automatic doors.

Temperature measurement: Infrared sensors can measure the temperature of objects without direct contact. These sensors are used in thermometers, industrial process control, and HVAC systems for temperature monitoring and control.

Night vision: Infrared sensors are utilized in night vision devices to detect and capture infrared radiation emitted by objects in low-light or no-light conditions. They convert the infrared radiation into visible images, allowing users to see in the dark.

Gas and flame detection: Infrared sensors can detect the presence of certain gases or flames by measuring the absorption of infrared radiation at specific wavelengths. They are commonly used in gas leak detectors, fire alarm systems, and industrial safety applications.

5. Relay

5.1 Definition

A relay is an electrically operated switch. It consists of a set of input terminals for a single or multiple control signals, and a set of operating contact terminals. The switch may have any number of contacts in multiple contact forms, such as make contacts, break contacts, or combinations thereof.

Relays are used where it is necessary to control a circuit by an independent low-power signal, or where several circuits must be controlled by one signal. Relays were first used in long-distance telegraph circuits as signal repeaters: they refresh the signal coming in from one circuit by

transmitting it on another circuit. Relays were used extensively in telephone exchanges and early computers to perform logical operations.

The traditional electromechanical form of a relay uses an electromagnet to close or open the contacts, but relays using other operating principles have also been invented, such as in solid-state relays which use semiconductor properties for control without relying on moving parts. Relays with calibrated operating characteristics and sometimes multiple operating coils are used to protect electrical circuits from overload or faults; in modern electric power systems these functions are performed by digital instruments still called protective relays or safety relays.

Latching relays require only a single pulse of control power to operate the switch persistently. Another pulse applied to a second set of control terminals, or a pulse with opposite polarity, resets the switch, while repeated pulses of the same kind have no effects. Magnetic latching relays are useful in applications when interrupted power should not affect the circuits that the relay is controlling.

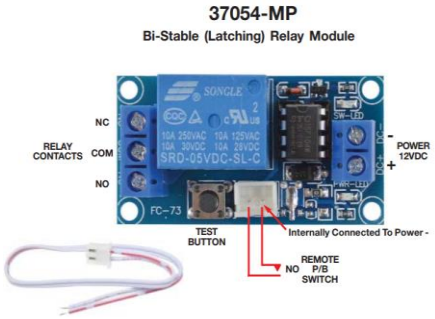


***Figure 2.5** RELAY MODULE [34]*

5.2 Types of Electromagnetic Relays

Attracted Armature Relay: Uses an armature that is pulled towards the coil when the magnetic field is generated, breaking contact when the current is off. [35]

Induction Type Relay: Utilizes a disc that rotates in response to the electromagnetic field, engaging the switch to control the circuit.[35]

Latching Relay: Maintains its position even after the actuating current is removed, useful where a constant signal is not possible. [35]

5.3 Applications

Industrial Controls: They are used to safely operate heavy machinery by isolating control circuits from the machine power supply. [35]

Automotive Systems: In vehicles, electromagnetic relays control electrical systems such as headlights, blinkers, and other components. [35]

Telecommunication Equipment: Relays help manage and switch between communication lines in complex telecommunication systems. [35]

Protection of Electrical Equipment: They provide over/under current and voltage protection for various AC and DC equipment. [35]

Differential Protection: Employed in electrical systems to detect differences in current or voltage that may indicate a fault. [35]

Auxiliary Relays: Used within the contact systems of protective relay schemes to enhance the functionality of the main relays. [35]

6.Motor

6.1 Gearmotor (type)

Definition:

A gearmotor is a mechanical device that combines an electric motor with a gearbox. The motor generates rotational power, which is then managed by the gears to achieve the desired speed and force. This integration allows gearmotors to efficiently perform tasks that require high torque at low speeds. [36]

Advantages of Gearmotors:

Increased Torque Output: Gearmotors can increase torque while reducing speed through the gearbox, making them suitable for applications that need a lot of force to move heavy objects.[36]

Compact Size: The integrated design of gearmotors allows them to be more compact and space-efficient than separate motor and gearbox units.

Enhanced Durability: Gearmotors tend to have fewer moving parts, which reduces the likelihood of mechanical failures and extends the lifespan of the device.

Integrated Motor + Gearbox Solution: This all-in-one solution simplifies design and installation processes, making gearmotors a convenient option for many mechanical systems.

Energy Efficiency: Gearmotors are often more energy-efficient compared to using separate otors and gearboxes, which can lead to cost savings over time.

Reduced Maintenance: With fewer moving parts and connections, gearmotors typically require less maintenance, further reducing long-term costs.

These features make gearmotors a versatile and essential component in various industrial and commercial applications. They are particularly useful when high torque is needed in a limited space.



Figure 2.6 *GEAR MOTOR [37]*

6.2 JGB37-545 (the used module)

Definition

A JGB37-545 is a type of DC gearmotor, which is essentially a normal DC motor paired with a gear reduction box. This combination provides the motor with a significant increase in torque at the expense of reducing the maximum rotational speed of the output shaft.

Specifications

Gear Ratio: 168:1 (motor shaft rotates 168 times for one gearbox revolution) . [38]

No-load Current: 200Ma. [38]

Maximum Load Current: 5. [38]

No-load Speed: 30 RPM. [38]

Maximum Load Speed: 24 RPM. [38]

Rated Torque: 21 kg·cm . [38]

Maximum Torque: 84 kg·cm . [38]

Gearbox Length (L): 26.5mm . [38]

Gear Ratio: 1:56. [38]

Weight: About 265 g. [38]

Features

- Available in a wide variety of motor speeds, selectable based on project needs.
- Suitable for applications requiring high torque at low speeds.
- Compact design integrates the motor and gearbox, saving space and simplifying installation.
- The gearmotor's high torque output makes it ideal for robotics, automation, and other industrial applications.

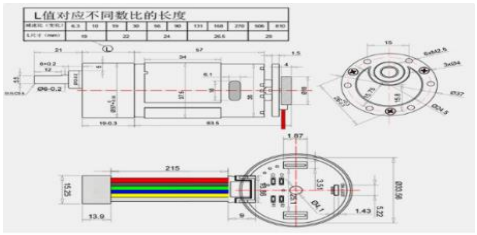


***Figure 2.7** JGB37-545 MODULE*

7.Rechargeable battery

7.1 Definition

is a type of electrical battery which can be charged, discharged into a load, and recharged many times, as opposed to a disposable or primary battery, which is supplied fully charged and discarded after use. It is composed of one or more electrochemical cells. The term "accumulator" is used as

it accumulates and stores energy through a reversible electrochemical reaction. Rechargeable batteries are produced in many different shapes and sizes, ranging from button cells to megawatt systems connected to stabilize an electrical distribution network. Several different combinations of electrode materials and electrolytes are used, including lead–acid, zinc–air, nickel–cadmium (NiCd), nickel–metal hydride (NiMH), lithium-ion (Li-ion), lithium iron phosphate (LiFePO4), and lithium-ion polymer (Li-ion polymer).

Rechargeable batteries typically initially cost more than disposable batteries but have a much lower total cost of ownership and environmental impact, as they can be recharged inexpensively many times before they need replacing. Some rechargeable battery types are available in the same sizes and voltages as disposable types, and can be used interchangeably with them. Billions of dollars in research are being invested around the world for improving batteries as industry focuses on building better batteries.[39][40]



Figure 2.8 *12V Rechargeable battery*

7.2 Applications

Devices which use rechargeable batteries include automobile starters, portable consumer devices, light vehicles (such as motorized wheelchairs, golf carts, electric bicycles, and electric forklifts), road vehicles (cars, vans, trucks, motorbikes), trains, small airplanes, tools, uninterruptible power supplies, and battery storage power stations. Emerging applications in hybrid internal combustion-battery and electric vehicles drive the technology to reduce cost, weight, and size, and increase lifetime.

Older rechargeable batteries self-discharge relatively rapidly[vague] and require charging before first use; some newer low self-discharge NiMH batteries hold their charge for many months, and are typically sold factory-charged to about 70% of their rated capacity.

Battery storage power stations use rechargeable batteries for load-leveling (storing electric energy at times of low demand for use during peak periods) and for renewable energy uses (such as storing power generated from photovoltaic arrays during the day to be used at night). Load-leveling reduces the maximum power which a plant must be able to generate, reducing capital cost and the need for peaking power plants.

According to a report from Research and Markets, the analysts forecast the global rechargeable battery market to grow at a CAGR of 8.32% during the period 2018–2022.[41]

Small rechargeable batteries can power portable electronic devices, power tools, appliances, and so on. Heavy-duty batteries power electric vehicles, ranging from scooters to locomotives and ships. They are used in distributed electricity generation and in stand-alone power systems.

8.Buzzer (HBE12)

8.1 Definition

The HBE12 buzzer is a commonly used component in various electronic projects and devices. It is an active buzzer, which means it has a built-in oscillating source, allowing it to produce sound when powered by a DC voltage, typically around 6V. Active buzzers like the HBE12 are widely used in applications such as alarms, timers, and notification systems due to their simplicity and ease of use.

8.2 Features and Specifications

- Rated Voltage: 6V DC
- Operating Voltage: 4-8V DC
- Rated Current: Less than 30mA
- Sound Type: Continuous beep
- Resonant Frequency: Approximately 2300 Hz
- Compact and easy to integrate with breadboards and perf boards .[42]

8.3 Applications

- Alarming Circuits: Used to alert users about various conditions.

- Communication Equipment: Provides audio signals for notifications.
- Automobile Electronics: Used in car alarms and indicator systems.
- Household Appliances: Common in devices like microwave ovens and washing machines.
- Portable Devices: Ideal for small gadgets due to its compact size and low power consumption . [42]

9.Conclusion

In conclusion, of this chapter, we have presented the various components, boards, and software used for the design of smart glasses for drowsiness detection.

This comprehensive presentation of components, boards, and software provides a solid foundation for the design and implementation of our project. In the next chapter, we will delve into the design and implementation in detail, integrating these components to create an automated and efficient system capable of detecting driver fatigue and applying automatic braking techniques, if necessary, thereby contributing to improving road safety.

Chapter III: Design and Practical Construction of the Driver's Drowsiness Detection System

1.Introduction

After a thorough discussion of the traffic accidents resulting from the driver's drowsiness in the first chapter and a glimpse of the significant impacts of this problem on individuals and society and the discussion of the electronic components used in our second area, now is the time to move to the practical and structural side. In this third area, we will address the basic steps needed to design and build the prototype of the driver drowsiness detection system and activate automatic braking using the components we talked about such as Arduino, RF modules, and motors.

This chapter aims to provide a structured and comprehensive approach that combines electronic engineering and software to achieve an effective and reliable system that can improve road safety and reduce traffic accidents. We will start by reviewing how to assemble different components, then move to electronic circuit design and the required mechanical mechanism. Next, we will cover system programming using Arduino IDE development environment, and we will explain how software integrates with devices to achieve perfect performance.

The assembly and integration steps between different components will also be reviewed, followed by the testing and evaluation stages to ensure that the system works efficiently under different conditions. This methodological approach will ensure that the prototype we develop is not only effective but also stable and reliable in real-world environments.

In the end, we will discuss the results obtained from the tests, and we will make recommendations for future improvements and possible developments for the project. We look forward to providing a prototype that effectively contributes to improving road safety and reducing traffic accidents caused by the driver's drowsiness.

2. Electronics Assembly

2.1 Components List

System section	Section units	Module names	Module Spec	Module pictures
Glasses Section	Processing units	Arduino nano	*Small size *Powerful processor "ATmega328" *14 digital I/O ports	 *Figure 3-1 ARDUINO NANO*
	Sensor Unit	IR Sensor (Flying Fish)	*Detection range (2....30) *Cheap and practical	 *Figure 3-2 IR SENSOR (FLYING FISH)*
	Alarm Unit	Buzzer	*Loud sound *Low power consumption *Small size	 *Figure 3-3 The used buzzer*
	Communication unit	RF433MHz (Transmitter)	*Reliable in data transmission *Low power consumption *Advanced Interference Minimization Techniques	 *Figure 3-4 RF TRANSMITTER*
Braking Section	Processing units	Arduino Uno	*Powerful processor "ATmega328P" *Secondary power input to 12V	 *Figure 3-5 THE USED ARDUINO UNO*
	Mechanical unit	Dc motor	* High torque and low rpm * Strong and sturdy structure *Low power consumption	 *Figure 3-6 Gear motor*
	control unit	Relay	*Mechanical switch mechanism	 *Figure 3-7 1-Channel RELAY*
	Power Supply unit	Battery	*Rechargeable battery	 *Figure 3-8 Rechargeable battery*
	Communication unit	RF433MHz (Receiver)	*Reliable in data transmission *Low power consumption *Advanced Interference Minimization Techniques	 *Figure 3-9 RF433 MHz RECEIVER*

Table 1.1 List of our project components

2.2 Glasses section

Connect the Arduino Nano:

Connect the Arduino to power

Connect the IR sensor:

To connect the IR sensor, begin by attaching the sensor wire to pin 2 on the Arduino Nano. Then, connect the sensor's power (VCC) wire to the 5V pin on the Arduino Nano. Finally, link the sensor's ground (GND) wire to the GND pin on the Arduino Nano. We ensure all connections are secure and properly fastened to ensure reliable operation of the sensor.

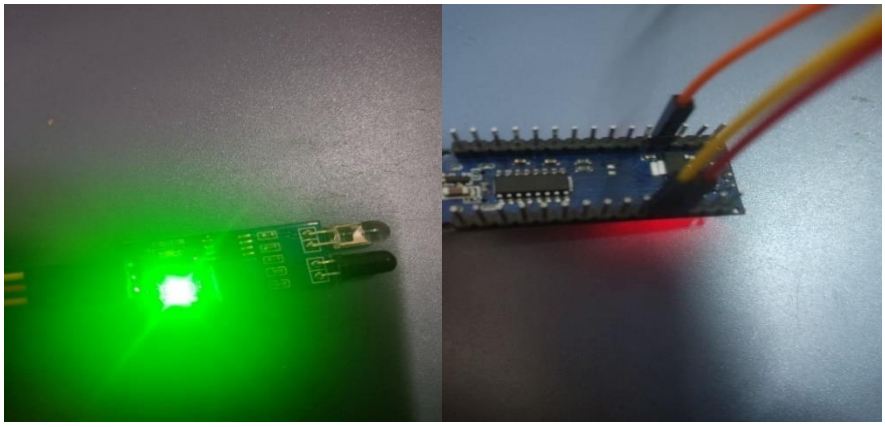


Figure 3-10 *Infrared Sensor Wiring*

Connect the RF433 MHz transmitter module:

To connect the transmitter, begin by attaching the data wire to pin 10 on the Arduino Nano. Then, connect the transmitter's power lead (VCC) to the 5V pin on the Arduino Nano. Finally, connect the transmitter's ground wire (GND) to the GND pin on the Arduino Nano. We ensure all connections are secure and properly fastened to guarantee the transmitter functions correctly.

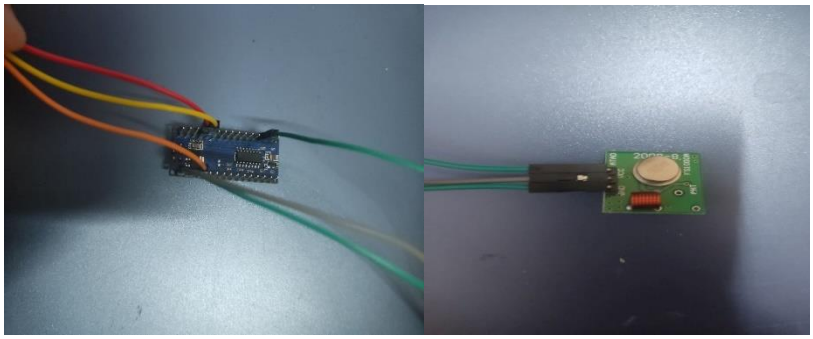


Figure 3-11 *RF433 MHz Wiring*

Connecting the buzzer:

To connect the buzzer, start by attaching the buzzer wire to pin 9 on the Arduino Nano. Next, connect the buzzer's power (VCC) wire to the 5V pin on the Arduino Nano. Finally, connect the buzzer's ground (GND) wire to the GND pin of the RF module. We ensure that all connections are secure and properly fastened to guarantee the buzzer operates correctly.

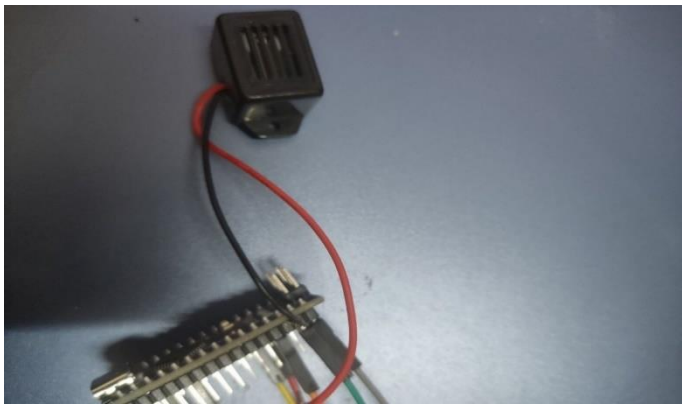


Figure 3-12 *Buzzer Wiring*

2.3 Motor section

Connect the RF433 MHz receiver:

To connect the receiver module, start by attaching the data wire to pin 4 on the Arduino Uno. Next, connect the receiver's power lead (VCC) to the 5V pin on the Arduino Uno. Finally, connect the receiver module's ground wire (GND) to the GND pin on the Arduino Uno. We ensure that all connections are secure and properly fastened to guarantee the proper operation of the receiver module.

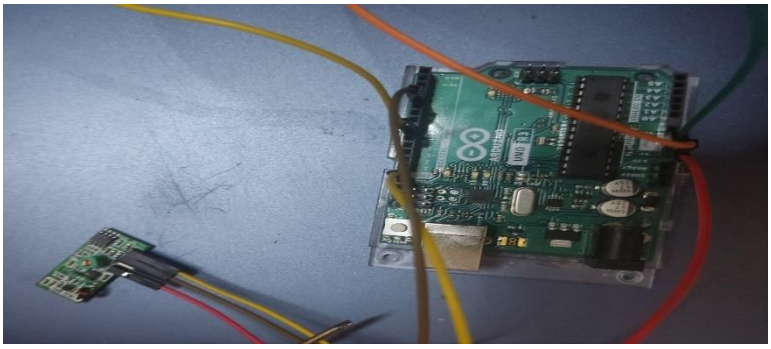


Figure 3-13 *Rf 433MHz Wiring*

Connecting the relay:

To connect the battery to the relay, first attach the positive (+) pin of the battery to the positive (+) input of the relay (VCC port). Next, connect the negative (-) pin of the battery to the negative (-) input of the relay (GND port). Finally, connect the control input of the relay to pin 8. we Ensure all connections are secure and properly fastened to guarantee the relay operates correctly.

Connecting the motor:

Connect the positive (+) motor pin to the open (NO) port on the relay.

Connect the negative (-) motor pin to the negative (-) battery input.

Connecting the battery:

Connect the battery to the system. Make sure the terminals are connected correctly: The positive (+) terminal to COM and the motor negative (-) terminal to negative (-) pin.

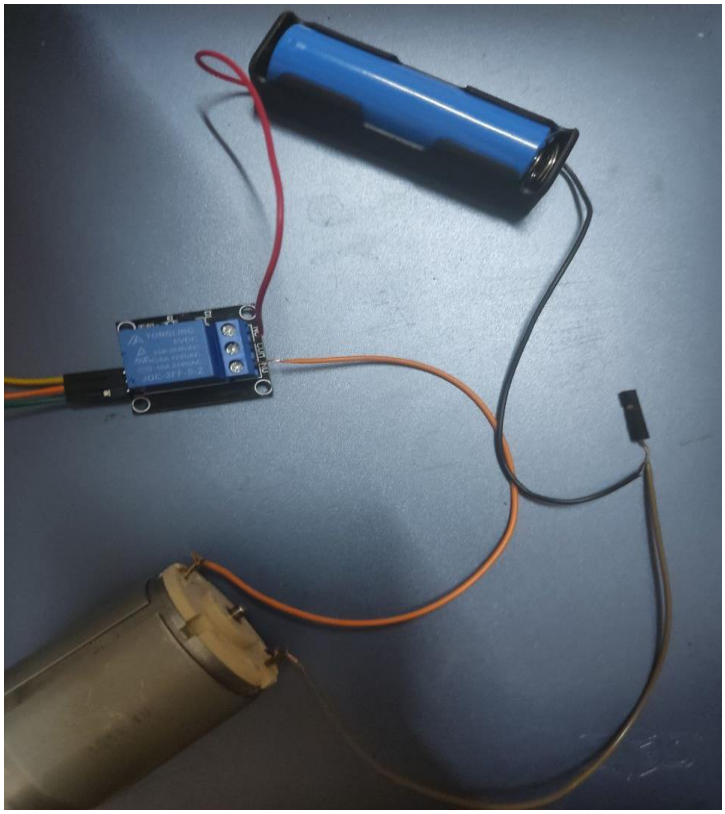


Figure 3-14 *The relay, motor and battery wiring*

3.Programming and testing

3.1 Braking program

To program the Arduino Uno to receive the signal and start the motor, begin by configuring the pins on the Arduino to read the signal from the receiver and control the relay connected to the motor. Figure 3.10 illustrates the detailed steps of this setup, including connecting the receiver to the Arduino, making the necessary electrical connections, and initializing the program to interpret the received signal and activate the relay, which in turn starts the motor.

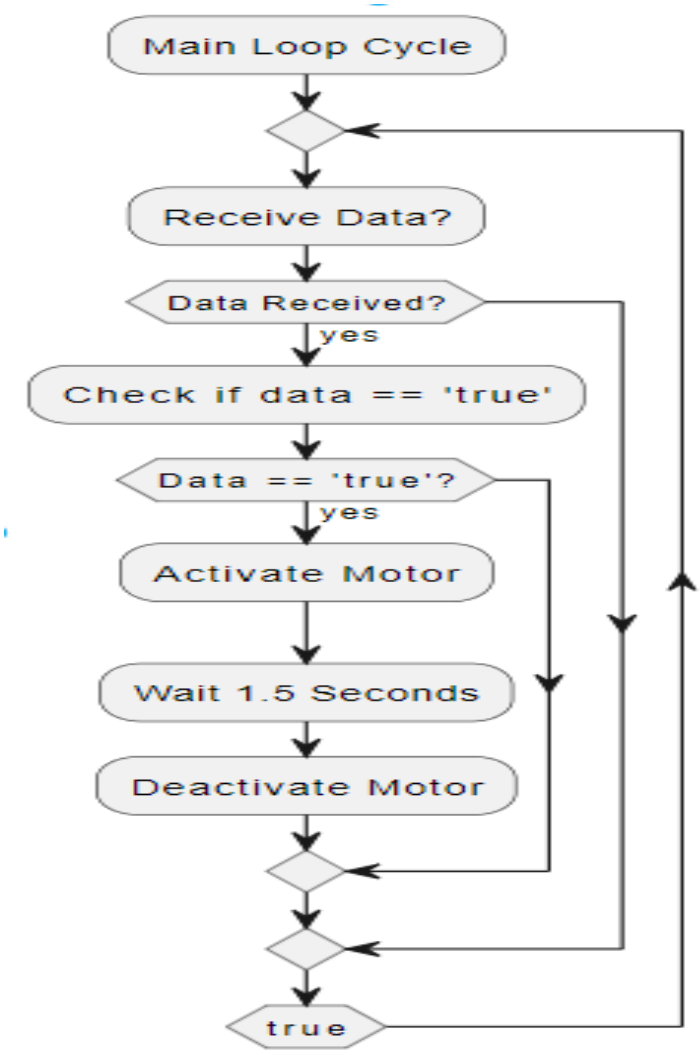


Figure 3-15 *BRAKING SYSTEM DIAGRAM*

3.2 Detection program

The operating principle of this system involves programming the Arduino Nano to read sensor data, trigger the buzzer when driver drowsiness is detected, and send a signal using the RF433Mhz module. see figure 3.11.

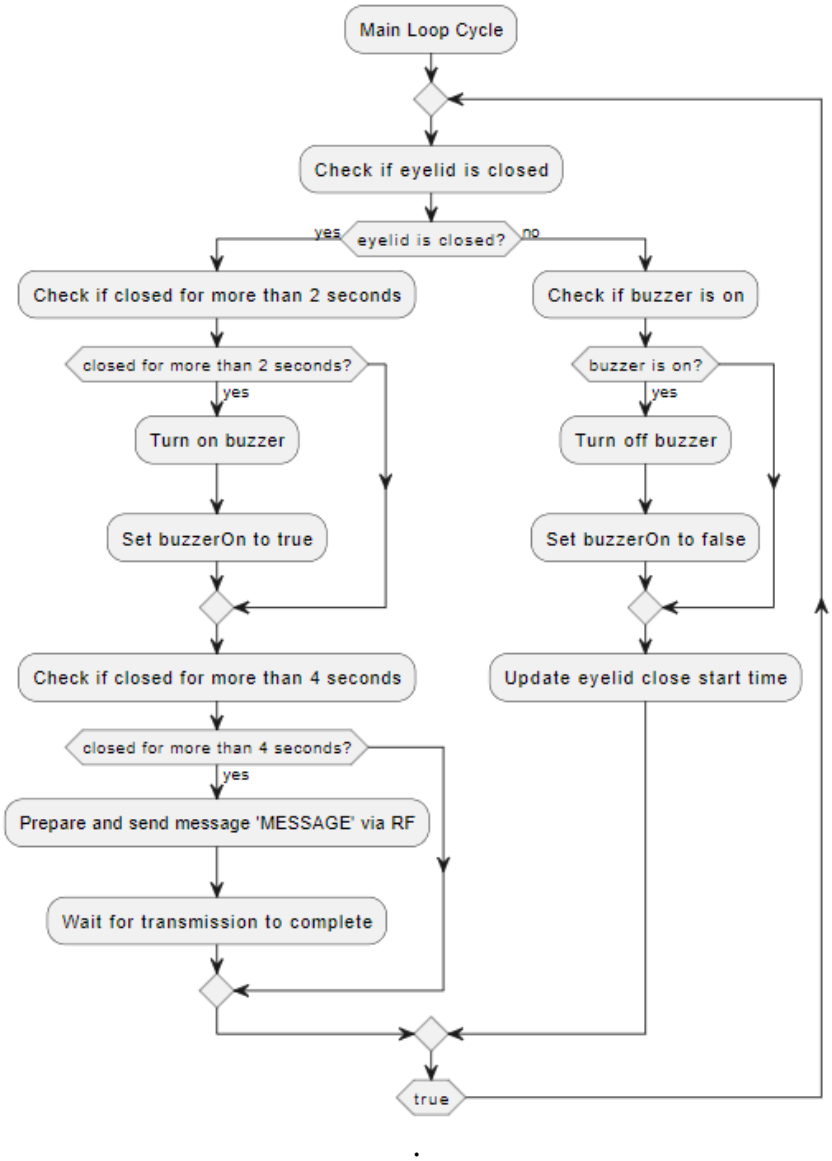


Figure 3-16 DETECTION SYSTEM DIAGRAM

4. Simulation and design of the circuit

4.1 Glasses part

Figure 3.12 illustrates the simulated circuit of the glasses part

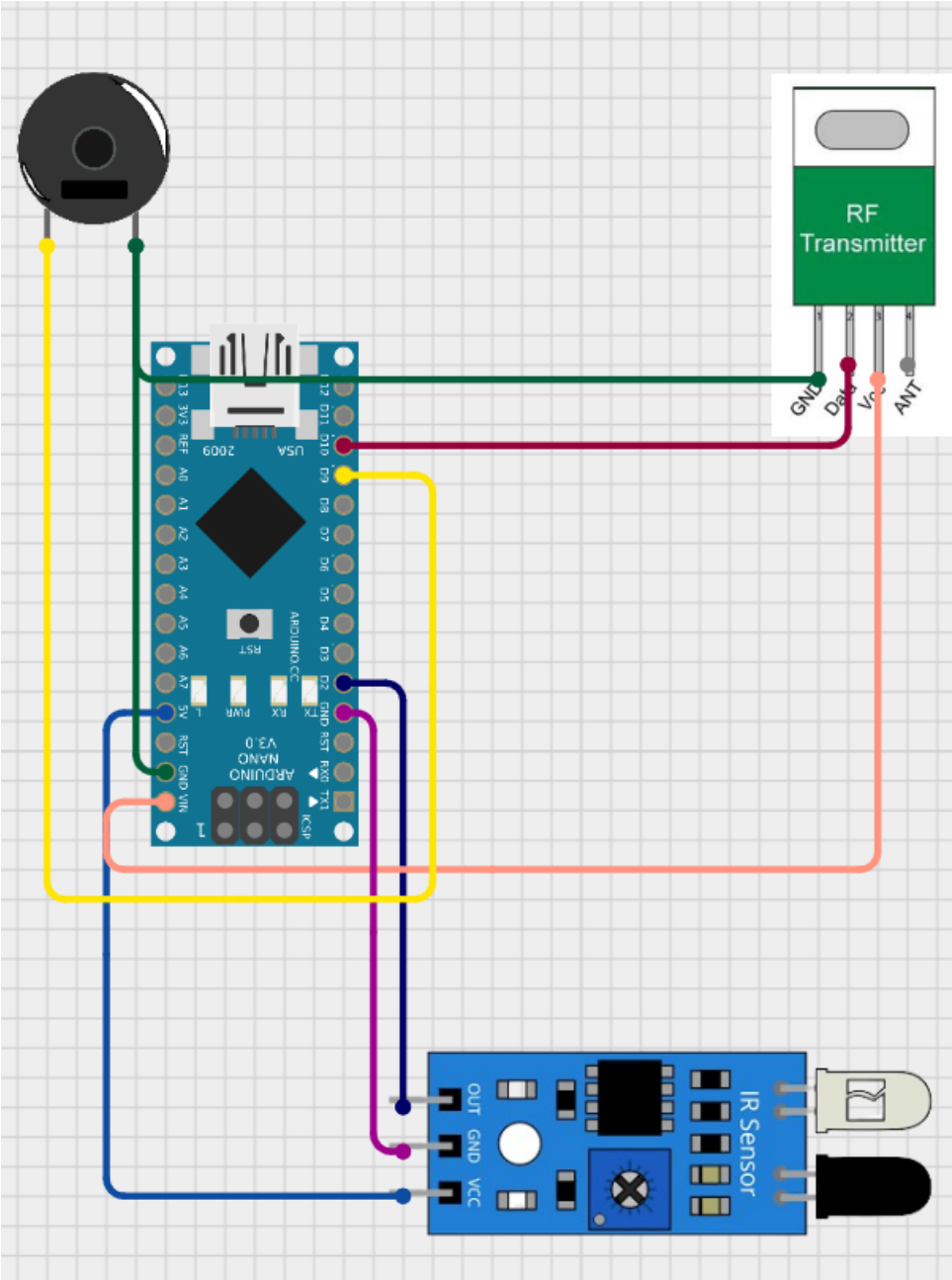


Figure 3- 17 GLASSES CIRCUIT

4.2 Motor part

Figure 3.13 depicts the simulated circuit of the braking system.

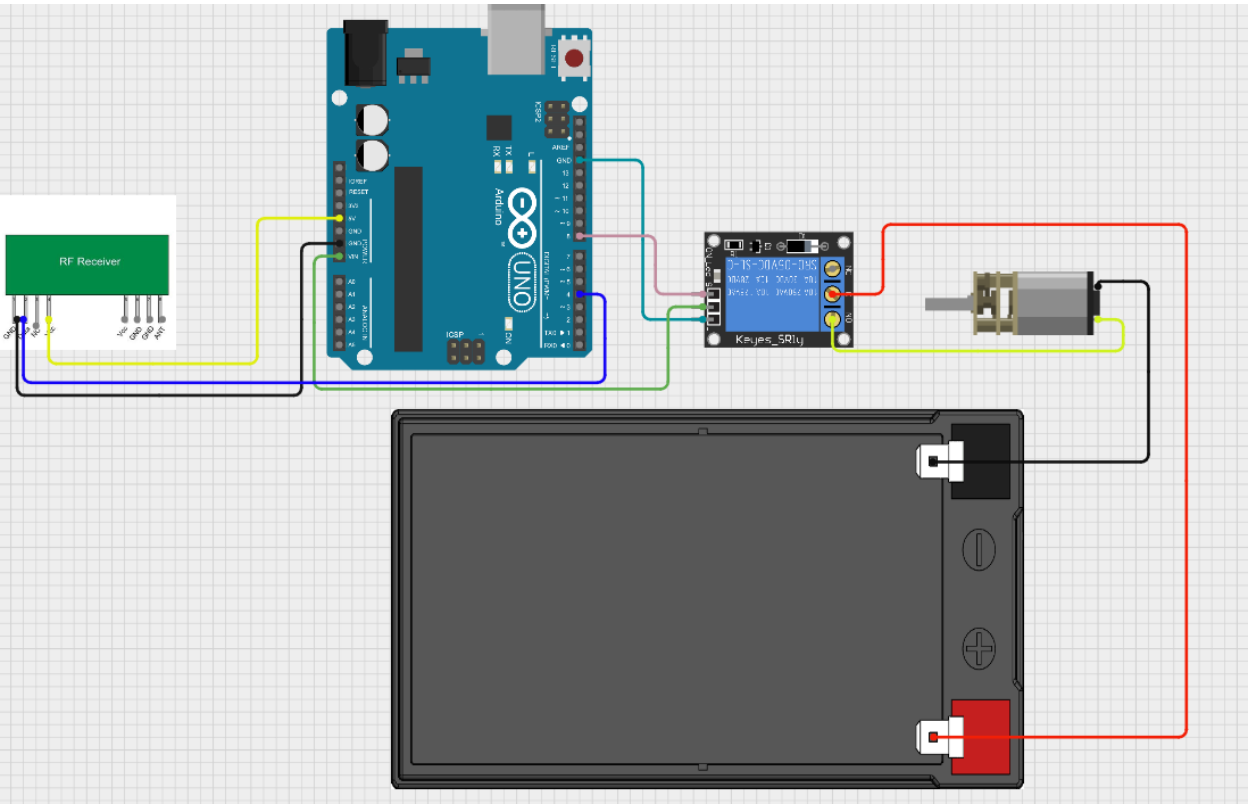


Figure 3-18 BRAKING SYSTEM CIRCUIT

5. Design of glasses

Three-dimensional (3D) printing of eyeglass frames is an important new technology in the design and development of electronic and medical devices. This technology allows for the creation of complex, customized structures with high precision and low cost compared to traditional manufacturing. Some of the importance of 3D printing eyeglass frames include:

Design customization: 3D structure printing allows for the design of glasses that are precisely customized to an individual's needs, increasing wearing comfort and performance efficiency.

Reduced cost and time: Instead of using costly and time-consuming traditional manufacturing processes, a 3D printed eyeglass frame can be printed quickly and at a relatively low cost.

Complex design: The technology enables the creation of complex structures and fine details with extreme precision, enabling additional features such as sensors or electronics to be added integrally within the glasses.

Design experience: Designers can use 3D printing to test designs and make adjustments before starting full-scale production, saving time and resources.

Delivering unique solutions: This technology enables unique solutions to design challenges, enabling the development of smart glasses and advanced mobile technology that better meets the needs of the market and users.

5.1 3D Simulation:

FRONT FRAME

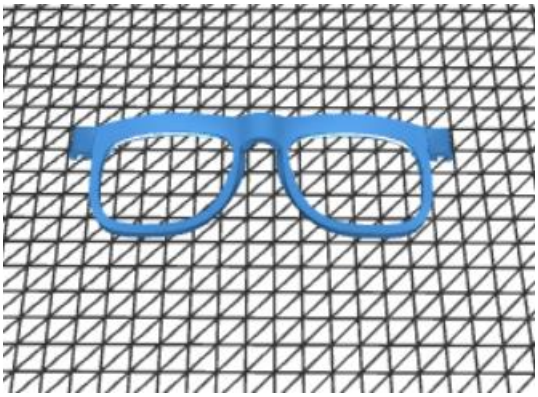


Figure 3-19 *FRONT FRAME*

RIGHT ARM LEFT ARM

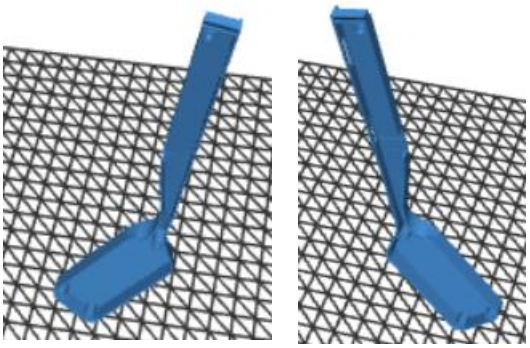


Figure 3-20 *Right and Left Arms*

MAIN FRAME

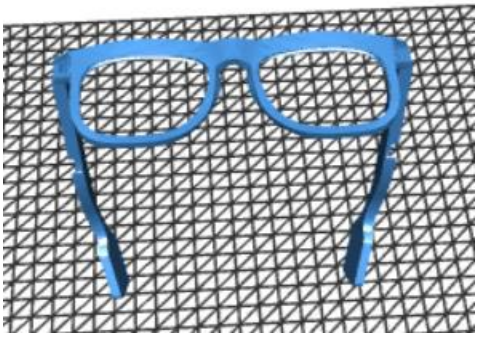


Figure 3-21 *MAIN FRAME*

RIGHT COVER LEFT COVER

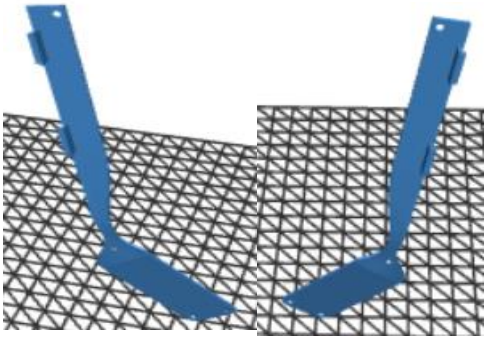


Figure 3-22 *RIGHT AND LEFT COVER*

5.2 3D PRINT

FRONT FRAME

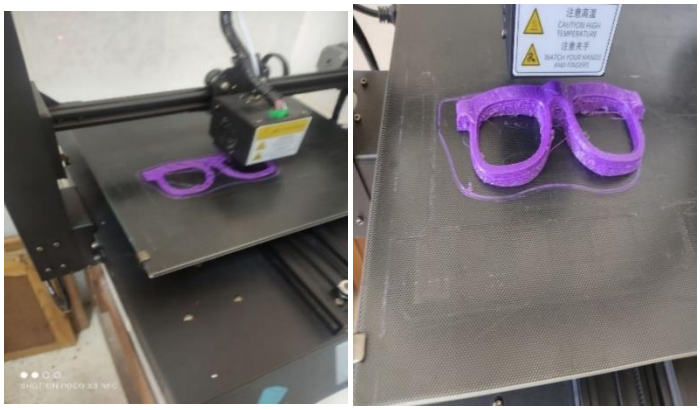


Figure 3-23 FRONT FRAME PRINTING

ARMS FRAME

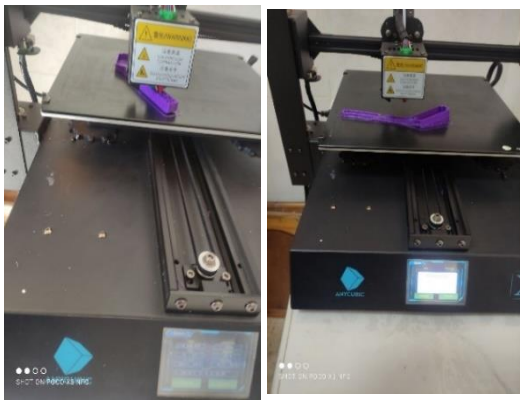


Figure 3-24 ARMS PRINTING

6. Performance Test

6.1 Detection rang

Spectacle lenses are worn at a distance of about 12 millimeters from the surface of the eye. [43]

This test was conducted to evaluate the performance of the IR sensor in detecting obstacles at specific distances. The test aims to verify the sensor's ability to operate accurately and reliably in the specified range.

Procedure:

To perform the test, we placed the infrared sensor 0.5 centimeters away from the obstacle to be detected. We then turned on the device and recorded the readings provided by the sensor. We repeated this procedure several times to check the stability of the results. Next, we repeated the test at different distances from the obstacle and recorded the readings.

Results:

At a distance from 0 to 0.5 cm:

Reading 1: [HIGH]

Reading 2: [HIGH]

Reading 3: [HIGH]

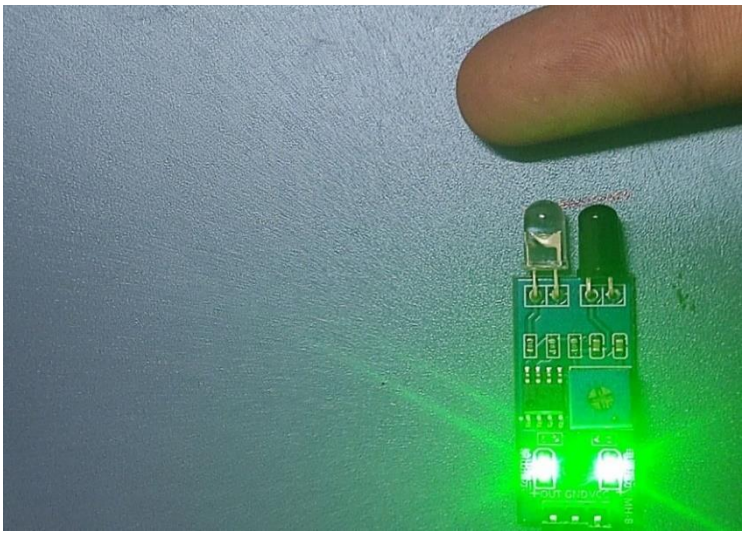


Figure 3-25 *between 0 and 0.5 cm reading*

at a distance between 0.5 cm to 1.2 cm:

Reading 1: [LOW]

Read 2: [LOW]

Reading 3: [LOW]

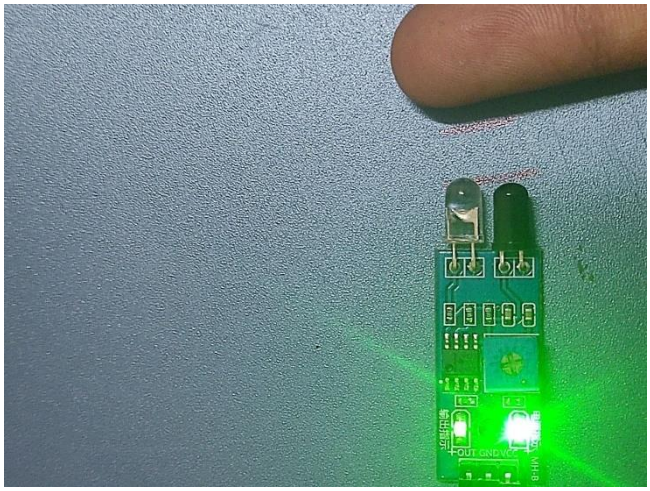


Figure 3-26 *between 0.5 cm and 1.2 cm reading*

at a distance from 1.2 cm:

Reading 1: [NONE]

Read 2: [NONE]

Reading 3: [NONE]

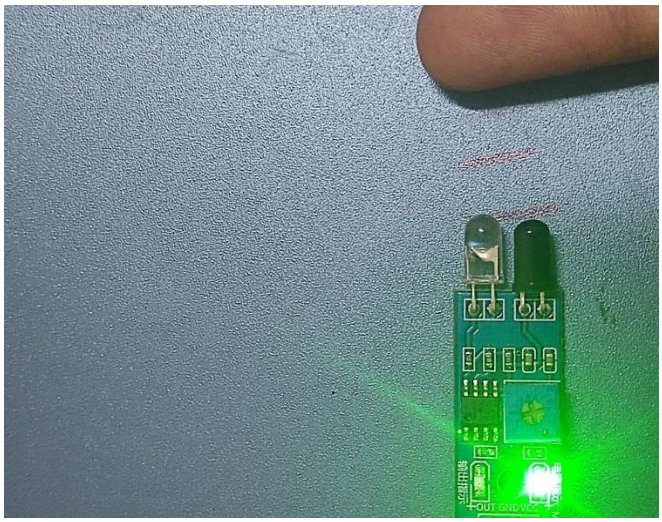


Figure 3-27 *From 1.2 cm reading*

Analysis of the results:

The IR sensor was found to respond accurately to obstacles at the specified distances.

No significant fluctuations in readings over time were observed.

The accuracy of the readings was verified by comparison with the actual distances between the sensor and the obstacles.

Conclusion:

The IR sensor was found to be able to operate accurately and reliably in the specified range of 0.5 to 1.5 cm. It can be relied upon in an obstacle detection system efficiently.

6.2 Response time (Detector)

The Flying Fish IR sensor usually belongs to the Active Infrared Sensors type.

Active infrared sensors operate in a normal temperature range of -20°C to +70°C approximately.

Alarm Response Report for Eyelash Closure Detection

Introduction:

This test was conducted to evaluate the system's response when eyelash closure is detected, in order to provide safety and alertness in case the driver is unable to pay attention while driving. The performance of the system was evaluated under various conditions including darkness and varying temperatures.

Procedure:

Normal performance test:

We opened the system and sensor to detect eyelash movement.

We recorded the time needed to detect eyelash closure.

Repeat the test several times to ensure consistent results.

Alarm recording assessed the response time from the detection of eyelash closure until the driver is alerted.

Test performance in the dark:

We ran the system in a completely dark environment.

We recorded the time required to detect eyelash closure in the dark.

We repeated the test to ensure the results were stable.

Testing performance under different temperatures:

We exposed the system to different temperatures (low and high), and recorded the time required to detect eyelash closure under each temperature.

The test was repeated to ensure consistent results.

Results:

Response time to detect eyelash closure (normal performance):

Test 1: [4ms]

Test 2: [2ms]

Test 3: [7ms]

Average: [4.33ms]

Response time to detect eyelash closure (in the dark):

Test 1: [6ms]

Test 2: [5ms]

Test 3: [4ms]

Average: [5ms]

Response time to detect eyelash closure (under varying temperatures):

Low temperature:

Test 1: [5ms]

Test 2: [3ms]

Test 3: [6ms]

Average: [4.66ms]

Elevated temperature:

Test 1: [5ms]

Test 2: [9ms]

Test 3: [4ms]

Average: [6ms]

Analysis of results:

The results showed that the system responds quickly and accurately to detect eyelash closure under all conditions.

In the dark, the response time was similar to performance under normal conditions, demonstrating the efficiency of the sensor in low-light environments.

Under varying temperatures, the system showed stable performance, with no significant differences in response time between different temperatures.

Conclusion:

The system was found to respond effectively and quickly to detect eyelash closure, ensuring that the driver is alerted in the event of inattention while driving. Tests also showed that the system is reliable in low-light environments and under varying temperatures.

6.3 Response time (Motor)

Introduction:

This test was conducted to evaluate the engine's response when the emergency braking system is activated under normal conditions. The objective of this test is to ensure that the engine responds quickly and efficiently when emergency braking is required.

Procedure:

Prepare for the test:

To conduct this test, we started by installing the engine in the system. Next, we connected the sensor that detects emergency conditions to the system, ensuring that the connection is secure and the sensor is functioning correctly. Once done, we set up the necessary equipment to record the response time of the engine when the emergency braking system is activated.

Test steps:

Activate the emergency detection sensor.

Record the time required to start the engine after the alarm is activated.

Repeat the test several times to ensure stable results.

Results:

Response time to start the engine (normal performance):

Test 1: [8ms]

Test 2: [7ms]

Test 3: [11ms]

Average: [8.66ms]

Analysis of the results:

The results showed that the engine responds quickly to the activation of the emergency braking system under normal conditions.

The response time was consistent across all tests, demonstrating the stability and efficiency of the system.

Conclusion:

The test proved that the engine responds effectively and quickly to the activation of the emergency braking system under normal conditions. This confirms that the system can be relied upon to improve driving safety in emergency situations.

6.4 Emergency Stop Time

For the safety of the driver, we study the stopping time after braking

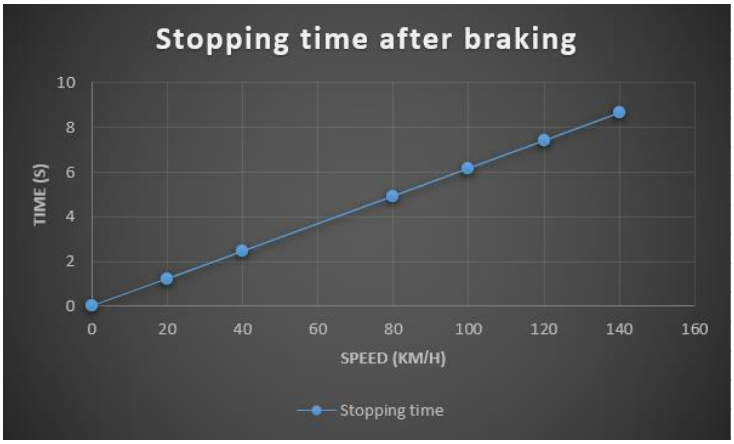


Figure 3-28 *The stopping time after braking*

7. The Integrated prototype

We are pleased to introduce the prototype of the Integrated Safety System for conventional cars, which combines modern technologies with innovative technologies to ensure driver safety. This prototype integrates glasses with IR sensors and a high-torque motor. The sensor detects eyelash closure to indicate drowsiness or dozing off, while the motor automatically applies the brakes in case of an emergency.

We leave you with an illustration of the prototype with the Figure 3-29, which represents an important step towards achieving greater road safety and reducing traffic accidents. The prototype is the result of rigorous testing and design to ensure its effectiveness and quick response in various conditions

(a) **(b)**

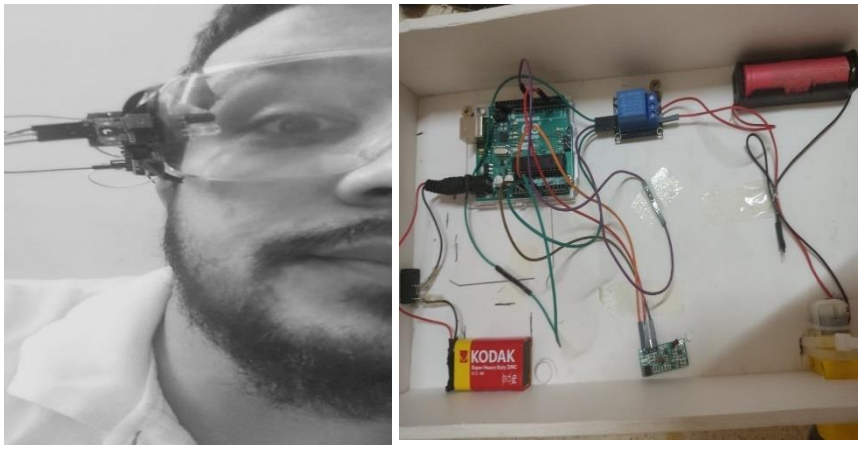


Figure 3-29 *Prototype :(a) Glasses system ,(b) Braking system*

8.Conclusion

In this chapter, we conducted a series of trials and performance tests to assess the effectiveness and responsiveness of the alert and emergency braking system under normal conditions and in different environments. The tests included testing the alarm response when eyelash closure is detected and evaluating the engine response time when the emergency braking system is activated, as well as additional tests in dark conditions and different temperatures to ensure the system's stability and efficiency in all situations.

Both systems performed consistently and reliably, even in dark conditions and different temperatures, demonstrating the quality of the design and integration of the various components. These trials reflect the significant progress we have made in developing an integrated system that enhances traffic safety and provides a practical and effective solution for conventional cars that do not have built-in emergency braking systems.

General Conclusion

General Conclusion

As in many countries around the world, the scale of road insecurity in Algeria is considerable, with increasingly alarming figures for road accidents and their consequences. These alarming statistics underline the urgent need for innovative and effective solutions to combat the persistent threat of road accidents, which entail considerable human, economic and social costs.

Despite the efforts made by the Algerian government, the road safety situation has not achieved the desired results, due to the increasing number and severity of road accidents in recent years. For this reason, we set out to find a technological solution involving the detection of drowsiness, one of the main factors in the majority of accidents, followed by an automatic braking system.

The development and implementation of smart glasses to detect driver drowsiness represent a proactive approach to addressing one of the critical factors contributing to road accidents: driver fatigue. By leveraging advanced technologies to monitor and alert drivers in real-time, these smart glasses have the potential to significantly reduce the incidence of accidents caused by drowsiness. The integration of this technology with vehicle systems further enhances its capability to prevent accidents through automated interventions.

Our research meticulously examines the extent of accidents due to driver drowsiness, details the technological components of our solution, and outlines the design and implementation process. In addition, we conducted extensive testing of the device in various environments and obtained excellent results, demonstrating the robustness and effectiveness of our solution across different driving conditions.

Practical implementation often comes with challenges. During the implementation of this project, we faced many challenges. First of all, the challenge of selecting suitable communication chips for all conditions and designing the body of the glasses to align with the components and provide a comfortable shape, which forced us to conduct research in the field of mechanics and 3D design. In addition, we also had to solve issues related to the motor's ability to pull the brakes of various vehicles. Furthermore, the issue of battery consumption for working with long distances and our lack of experience in these areas posed an additional challenge. Despite these obstacles, we

consider this project to have been beneficial to us, allowing us to enhance our theoretical knowledge gained during our undergraduate studies and paving the way for future research. To improve it, we suggest integrating the sensor with the lenses of the glasses to increase user comfort. We also propose to put a feedback platform and, in this way, users will be able to give feedback. Another suggestion is to design a system that is also compatible with autonomous cars that lack such systems.

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