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DEPARTEMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
OPTION: ELECTRICAL TECHNOLOGY

IMPLEMENTATION OF A SMART RUNWAY ILLUMINATION: RADAR-CONTROLLED LIGHTING SYSTEM

The final year project submitted in partial fulfillment of the requirements for the award of Advanced Diploma in Electrical Technology

Submitted By

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DECLARATION

I, NZITA MPEZO Grace, hereby declare that this research proposal submitted to the Department of Electrical and Electronics Engineering at ULK Polytechnics Institute is my original work. It has never been presented for any academic award in whole or in part at this school or any other university, college, or higher learning institution.

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DEDICATION

To the almighty God

To my parents and family

To my friends and colleagues

To the entire staff at large of the UPI

ACKNOWLEDGEMENT

First and foremost, I express my heartfelt gratitude to Almighty God for His grace, protection, and countless blessings throughout my academic journey. Without His guidance and provision, reaching this milestone would not have been possible.

I would like to extend my deepest thanks to my loving parents and family members for their tireless financial and moral support. Their encouragement has been my driving force. I am also grateful to my friends and colleagues for their assistance and companionship throughout my studies.

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ABSTRACT

There is always a need to improve technology for safety, efficiency, and reliability in aviation and in operating airports. This is under this project on " Implementation of a Smart Runway Illumination: Radar-Controlled Lighting System" that has noted most of the limitations mentioned against the traditional runway lighting systems. This research mainly aims to develop an intelligent runway lighting system that can use real-time radar information in combination with high-intensity LED light and smart control algorithms to adapt to oncoming aircraft information, including its position, speed, and direction, and environmental factors. It consists of advanced LED and radar technologies, with a developed smart control algorithm that allows runway illumination to be adjusted in real-time, optimizing lighting conditions for aircraft at landing or take-off.

Research has found that the smart runway illumination system not only deals with the drawbacks of the existing systems but also helps in overcoming high-energy consumption. The integration of radar information with such an LED lighting system by the use of intelligent algorithms is a significantly more reliable and efficient lighting system, ensuring the overall safety of the airport's operation. This paper is of high relevance in proposing a possible solution toward the operational constraints of the conventional runway lighting systems, with further potential to save energy and improve safety. Installation of this system in airports to enhance operational efficiency and safety is recommended. Future work that is carried out to study the integration of other environmental data and to free this system for other uses in the airport would greatly beneficial the airport operations. Availing such a remarkable contribution to the aviation technology area, since the proposed system is practical and hence the existing problem with the traditional conventional runway lighting system can be solved.

Keywords: smart runway; radar: controlled; lighting system.

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LIST OF ACCRONYMNS AND ABBREVIATIONS

a. A-CDM: Airport Collaborative Decision Making
b. A-SMGCS: Advanced Surface Movement Guidance and Control System
c. IR: Infrared
d. IoT: Internet of Things
e. LED: Light Emitting Diode
f. LiDAR: Light Detection and Ranging
g. PIR: Passive Infrared
h. RWSL: Runway Status Lights
i. ULK : Université Libre de Kigali (Kigali Independent University)
j. UPI: ULK Polytechnic Institute

CHAPTER 1 :

GENERAL INTRODUCTION

1.0 Introduction

Just as land borders constitute the entrance of a country, city, town… airport too plays key role to the development of the country where adequate infrastructures need to be put in place to achieve this goals as Technological Moving forward relies on day by day integration in our daily life, advancement in the aviation technology have led to the creation of smarter runway lighting system including a radar controlled illumination. This project stimulates a system the effectiveness in optimization of the runway operation, reduce power consumption and enhance air traffic safety by doing a Dynamic adjustment on lighting based on real-time radar data, this innovative approach aiming to improve visibility during crucial and critical phases of aircraft movements, ultimately enhancing safety standards and operational efficiency at airports.

1.1 Background of the study

Traditional airport lighting systems have a host of problems, most of which deal with how they are energy-intensive and inefficient. These systems are normally installed to operate continuously, irrespective of any real conditions that may be in view concerning aircraft, weather changes, or visibility levels, and the result has been the consumption of large amounts of energy and much higher operational costs. Second, because they cannot respond to real-time conditions, such as changes in the weather, safety hazards may arise during periods of poor visibility, resulting from fog, rain, or storms. (Reuters,2011). The following research study proposes a new way to deal with these issues by designing and developing a smart runway lighting system using radar-controlled lighting. It is designed to trigger on only when an aircraft comes in close proximity to the airport-that is, within the airfield or airspace near the runway. Such dynamic response to the presence of aircraft means lighting is provided only when needed, therefore radically reducing energy consumption in the absence of aircraft. The radar-controlled lighting system will not only save energy but also contribute to operational efficiency by providing optimal lighting at those most critical moments: during the landing, taking off, or even taxiing of planes on the runway. The adaptive nature of the system elevates standards of safety through offering enhanced real-time visibility, fitted to needs, especially in bad weather conditions. The smart lighting system also allows the airport to save energy and, consequently, reduce its carbon footprint in line with international goals of sustainability. Other added value to the airport is cost benefits in operations, since this directly reflects on reduced energy use. This double effect-enhanced safety and energy efficiency-meets global sustainability objectives and addresses the specific needs of local airports. This, in turn, will ensure enhancement of runway safety, energy saving, and reduction of operational costs for making the world's airports' lighting system more sustainable and effective. (Okapi-Congo, 2017)

1.2 Problem statement

There is recent runway lighting system failure in my hometown that caused planes to be rerouted to other airports serves as a bright reminder for the need of reliable and inefficient runway lighting system solution. This incident highlighted a specific problem: the deficiency of territorial immutable runway lighting system to sustain continued correct operation and therefore safe performance. Current systems are equipment dependent, get easily disabled and consume a lot of energy as they cannot respond to real-time needs effectively. Studies have indicated that adaptive lighting systems can enhance benefits of operational efficiency and safety in airports ((FAA), 2020),however, Most of the current implementations miss the advanced technologies such as radar for precise control and energy optimization. This solution is aiming to present the implementation of the Smart Runway Illumination system using radar-controlled lighting, to fill up these gaps. our system proposed in this study will turn on illumination only in the presence of an aircraft, resulting to high reliability, increased safety, and reduced energy consumption. By the utilization of radar technology, this study seeks to develop a more rugged and efficient illumination solution that can adjust to different diversified operational demands and changing environmental conditions.

1.3 Research objectives

1.3.1 General objective

The aim of this project is to implement a Smart Runway Illumination system using radar-controlled lighting to achieve the goals of enhanced reliability, increased safety, and optimization in energy consumption.

1.3.2 Specific objectives

1. To design a system combining radar technology that can detect the presence of an aircraft for the purpose of switching on the runway lights.

2. To evaluate energy efficiency of the radar-controlled system: Measure and compare the energy consumption of the new system against that of traditional static runway lighting systems in order to find out potential energy savings.
3. To state the impact of the radar-controlled lighting system on the safe landing and takeoff of aircraft, basically referring to the improvement in visibility and the reduction in incidents.

1.3.3 Research questions

from the objectives of the study, research questions are proposed as follows:

1. How can a system be designed to combine radar technology to detect the presence of an aircraft for the purpose of switching on runway lights?
2. How can the energy efficiency of the radar-controlled system be evaluated by measuring and comparing its energy consumption with traditional static runway lighting systems to identify potential energy savings?
3. How does the radar-controlled lighting system impact the safety of aircraft during landing and takeoff, particularly in terms of improving visibility and reducing incidents?

1.3.4 Scope

1.3.4.1 Geographical scope

This study is focus geographically to Bangoka International Airport in Kisangani. The location was chosen because of a recent incident where the lighting system of the runway failed to turn on at the time and flights had to be redirected to Goma international airport. The focus of research on this airport addresses local challenges with a view to providing a practical solution that can be observed and measured in a real-world context.

1.3.4.2. Time scope

The time scope for this project is from twenty twenty-one to twenty twenty-four; initial work in the form of research and building up an idea regarding the project has been going on, including the study of a literature review of traditional runway lighting systems, understanding radar-controlled alternatives, and more. While detailed system designs were developed by twenty twenty-two, and a functional simulation was designed, built, and tested on simulated environments, implementation of the system started in twenty twenty-three. Rigorous testing had been conducted concerning energy efficiency, safety, and operational reliability under various conditions, data for which was collected to compare with traditional systems. In the year twenty twenty-four, the project entered its final phaseperformance analyses, documentation of results, and preparations for large-scale deployment or refinement based on findings. This timeline thus provided the necessary scope for structured development, thorough testing, and comprehensive analysis of the radar-controlled lighting system.

1.3.4.3. Content scope

It will spread over developing, and implementation of a smart runway illumination system that integrates radar-controlled lighting. In the present work, several areas are covered, such as creating a radar-controlled system for the detection of aircraft, assessing the system's energy efficiency compared to traditional lighting methods, the performance evaluation in different weather conditions, and analyzing its impact on operational safety and incident reduction. These limitations will essentially be related to resources in terms of prototype development, technical problems that may be encountered with respect to radar integration, and the extent of testing to be carried out to establish the system's reliability under varying environmental conditions.

1.4 Significance of the study

1.4.1 Personal Interest

An installed Smart Runway Illumination system at Bangoka International Airport would quite literally be a matter of interest, both individually and personally, to citizens of Kisangani and its surroundings. Better lighting on the runway can secure a far clearer and safer flying experience by bringing down the chances of misfortune and hence providing assurance to both the flyers themselves and the family waiting for their safe return home. It can further reduce cases of flight delays or cancellations, hence promising hassle-free journeys to people commuting for work purposes or otherwise with improved operational efficiency.

1.4.2 Public Interest

This study is relevant to the level of greater Kisangani and the Democratic Republic of the Congo as a whole in terms of the public. Reliable airport infrastructure is critically important for the facilitation of economic increase, investment, and tourism. Improving safety and efficiency at Bangoka International Airport, therefore, benefits the public through its findings on aspects that relate to economic development, the creation of employment, and general welfare enhancement in the region. Furthermore, easier travel connectivity by air integrates the region and furthers cultural exchange and cooperation.

1.4.3 Institutional Interest

This institutional stakeholder group consists of many different projections with vested interests in the implementation of a radar-controlled lighting system at Bangoka International Airport. On the part of the government agencies, ensuring the safe operation and reliability of transportation infrastructures supports their mandate about protection of public welfare and fostering sustainable development. The airport authorities will also benefit from operational efficiency in terms of the potential for their reputation to be enhanced, more airlines and passengers will thus be attracted to their facilities, and a resultant increase in potential revenue generation will follow. On the airline operator perspective, reduced operational risk and costs associated with flight diversion and delays improve profitability and customer satisfaction. The overall institutional interest is in strategic advancements to the infrastructure of the airports in terms of meeting industry standards, enhancing competitiveness, and supporting the growth of the aviation sector in the region.

1.5 Organization of the study

The research work is divided into chapters, as outlined below:

- In the chapters that follow, chapter one briefly introduces the project, the motivation for undertaking this project, and the methodology that is used to develop the project. The limitations, significance of the project to the nation, and also the scope are discussed.
- Chapter two, takes into consideration the literature review which includes substantive findings as well as theoretical and methodological contributions to the project
- Chapter three discusses the research methodology, research design and population, sample size and sampling procedures, Choice of the research instrument, Validity and Reliability of the Instrument, Data Gathering Procedures, Data Analysis and interpretation, Ethical considerations and Limitations of the study
- Chapter four talk about the system design analysis and implementation encompasses the drawings, calculation and cost estimation, Implementation (Optional depending on the project)
- Chapter five conclusion and recommendations.

1.6 Summary

In conclusion, therefore chapter one talked about; introduction, background to the study, problem statement, objectives, research questions, scope, significance of the study and the organization of the studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, we will provide a comprehensive overview of existing literature relevant to the design and implementation of smart runway illumination systems. The review explores the concepts, ideas, and technologies that have been developed in the field of airport lighting, with an emphasis on integrating radar and advanced control systems. It will examine key theoretical frameworks, past studies, and gaps that this research seeks to address, providing a foundation for understanding the importance of smart runway lighting solutions.

2.2 Concepts, Opinions, and Ideas from Authors/Experts

Airport lighting systems have been widely criticized for their inefficiencies, high energy consumption, and frequent operational failures. These shortcomings pose significant challenges to airport safety and environmental sustainability. The literature review emphasizes research on the use of advanced LED technologies, radar integration, and smart control algorithms to enhance runway lighting systems. Research has shown that advanced LED lighting significantly reduces energy consumption while providing reliable illumination. When radar technology is integrated into lighting systems, real-time adjustments can be made based on aircraft movement, speed, and environmental conditions, leading to greater operational efficiency and safety. However, while these developments are promising, there is still room for improvement in implementing these systems in diverse airport environments.

2.3 Definition of concepts

This section explores the fundamental concepts derived from the project's title: "implementation of a smart runway illumination: radar-controlled lighting system" with a focus in Kisangani town in DR Congo.

2.3.1 Design

A design is the concept of or proposal for an object, process, or system. The word, design, refers to something that is or has been intentionally created by a thinking agent, although it is sometimes used to refer to the inherent nature of something – its design.

Context: in our project the term Design will mainly refer to the creation of the intelligent runway lighting system, using radar-controlled lighting. This involves the design of system architecture where radar will detect aircraft and switch on runway lights with emphasis on improved safety and energy efficiency. The design shall ensure that the system meets the objectives of the project: enhanced operational efficiency and reduce energy consumption. (Michael Erlhoff & Timothy Marshall, 2008)

2.3.2 implementation

Implementation is the execution or practice of a plan, a method or any design, idea, model, specification, standard or policy for doing something.

Context: In your project, implementation refers to executing the radar-controlled runway lighting system, putting the design into practice by installing and testing the radar sensors, lighting components, and control systems to ensure they function as intended. (Mustaque Ahamad, Gil Neiger, & James E. Burns, Princ, 2019)

2.3.3 runway

A runway is a defined area at an airport, most commonly made from asphalt and concrete, for take-off and landing of aircraft. Depending on the airport, this area could be nothing more than a strip of grass, dirt, or sand. However, most airport runways are made from asphalt and concrete.

Context: In your project, the runway refers to the defined area at the airport where the radar-controlled lighting system is installed to enhance visibility during aircraft take-off and landing, typically made of asphalt or concrete. (HORONJEFF, 2012)

2.3.4 radar

Radar (Radio Detection and Ranging) is a system that uses radio waves to detect, locate, and track objects such as aircraft, ships, and weather formations. It works by transmitting radio waves that bounce off objects and return to the radar system, allowing it to determine the object's distance, speed, and direction. (Simon Kingsley & Shaun Quegan, 1999)

2.3.5 lighting

Lighting refers to the application of light to illuminate an area, object, or space. This can include natural light, such as sunlight, as well as artificial sources like lamps, bulbs, and LEDs, used to enhance visibility and safety, create ambiance, or highlight specific features. (Mitsunori Miki, Masashi Nagano, Masato Yoshimi, Hiroyuki Yonemoto, & Kenta Yoshida, 2012)

2.3.6 System

A system is a set of interconnected components or elements that work together to achieve a specific goal or perform a particular function. It can include both physical and conceptual elements, such as hardware, software, processes, and people, all interacting in an organized manner. (Backlund, 2000)

2.3.7 Energy Efficiency

Energy efficiency in runway lighting is the means of using technologies along with best management practices that would reduce power usage while maintaining standard illumination in terms of both safety and operational efficiency. It could range from LEDs, smart control systems and, ideally, even renewable energy sources, to cut the overall energy footprint. (Kenneth Gillingham, Richard G. Newell, & Karen Palmer, 2009)

2.3.8 Radar Integration

Radar integration means the incorporation of radar technology on the runway lighting system for the handling and monitoring of positions and movements of aircraft. It means that this information avails itself to enable the lighting system to automatically make the right adjustments under real-time information for the sake of safety and efficiency in the provision of illumination that is needed on the runway. Context: This implies that, within our project, the term "radar integration" means taking runway lighting with radar technology to locate aircraft positions and their respective movements. With this, the lighting system will be able to automatically adjust in real time for effective and safe illumination on the runway. (Peng, 2022)

2.3.9 Automation and Control Algorithms

Automation and control algorithms are those software programs and logical procedures which drive the operation of the smart runway lighting system. Algorithms process the input data provided by the radar and other sensors for decisions on lighting variability in real-time and automatic mode without any human intervention so as to attain the system's maximum performance level. context: Software and logical procedures that are operating the Smart Runway Lighting systems are involved in the automation and control algorithms of our project. These algorithms take input from the radar and sensors and drive the changes in lighting automatically based on real-time data collected as input to achieve the highest performance without any human intervention. (LOWRIE, 2018)

2.3.10 Regulatory Compliance

Regulatory compliance secures the system to be applied with the necessary measures of safety in aviation by conforming to the standards and regulations stipulated in the regulations of aviation. It follows the aviation authorities' guidelines regarding the procedure in the design, installation, and operation of runway lights to ensure a safe system and reliable service. (Starkie, 2002)

Context: Regulatory compliance in our project will ensure the runway lighting system is to standards and regulations to ensure safety, depending on aviation safety. The system will adhere to guidelines laid down by aviation authorities with respect to the design, installation, and operation of the light system to make sure it is safe and reliable.

2.3.11 Sensors

Devices sensitive to and react to a stimulus received from the environment.

Context: Arduino-based systems, with in-built sensors, may monitor the turning on and off, updating the information in real time for process control. (Satish Kumar V & Sudesh K. Kashyap)

Context: A sensor, in aviation, is any type of device that measures or otherwise responds to a stimulus such as aircraft motion, changeable weather conditions, or proximity. Sensors, for the purposes of this project, take the form of real-time data outputs to control systems whereby automation such as runway lighting is enabled or inhibited on the basis of aircraft presence to effect safe and efficient operation.

2.3.12 Microcontroller

A compact computer placed on a single integrated circuit that is planned to manage one operation on the gadget in which it is embedded. (Ng, 2016)

Context: Arduino is a microcontroller board utilized for lighting automation.

2.4 Theoretical Perspectives

2.4.1 System Theory

This theory becomes an enriching point of view from which to properly delve into the interaction that exists between the elements in the smart runway illumination system: how the integration of radar technology with the lighting controls at the landing strip goes a long way toward working with operational efficiency and safety.

2.4.2 Control Theory

Control theory is applied to develop algorithmic controls in the automation of general light operations through the use of radar data. It concerns feedback mechanisms and how they can be utilized so the characteristics of dynamic systems can be controlled and optimized in such a manner that the runway lighting changes emerge according to the timeline, barring any time or environmental and mission changes.

2.4.3 Human Factors Theory

Human factors theory is very significant because it involves how pilots, air traffic controllers, and ground personnel interface and depend on the runway lighting systems. It covers ergonomic design principles to ensure that the lighting system inside affords clear and intuitive signals to raise situational awareness and reduce the potential for human error during critical flight phases.

2.5 Related Studies

The following studies provide insights into similar technologies and applications in airport lighting, highlighting potential design considerations and best practices that informed this research:

2.5.1 Follow-the-Greens Concept

Taxiing at any major hub airport constitutes a workload intense navigation and monitoring. Although the pilots are supported by signage on the airport surface and possibly even taxiway centerline lights, this task can be complicated even in good weather conditions. Radio communication technology is near capacity limits in many airports today resulting in waiting times for the flight crew to negotiate the next taxi clearance. Apart from well-known safety issues this often leads to delays - for the passengers as well - and ultimately impacts the environment. Solutions are given by the European research program SESAR (Single European Sky Air Traffic Management Research) which aims at modernizing and harmonizing the European Aviation network. A new surface traffic management concept dispenses with radio communication and proposes the automated use of AGL with individually switched green taxiway centerline lights indicating the path for the flight crew to be followed. For each aircraft a segment of taxiway centerline lights can be illuminated in front of it. The areas not needed are switched off, minimizing the risk of errors. The new concept is independent from cockpit equipment. The procedure is called "Follow-the-Greens". The SESAR European Airports Consortium "SEAC" validated the new concept under the leadership of Fraport with its partners DFS, ENAV, Flightdecksystems and ATRiCS under the support of Lufthansa in 2013. A real-time simulation platform for the Frankfurt airport area layout combined two Airbus A320 fixed based simulators with highly integrated controller working positions. The concept's effect on taxi times and route deviation was examined. The appropriate length of the green line, different ways of (de-)activating the lights and different visualizations of a stop instruction were tested. Results from the successful validation with twenty pilots are reported in this paper indicating a safer, easier, quicker and greener surface traffic management concept for the future. (Biella, et al., 2015)

2.5.2 Study on Installation of Runway Status Lights

Runway Status Lights (RWSL) System uses light to send information to aircraft pilots and vehicle drivers to enhance their situational awareness, so installation and layout of runway status lights are of crucial importance. Based on the common configuration of the runways/taxiways of the domestic airports, we analyze the requirements imposed by the applicable standards on classification and installation of runway status lights and, on the basis of facts, select the optimal strategy for practical installation in Runway Status Lights System Verification Project implemented at Shanghai Hongqiao Airport. Actual testing indicates that lights can effectively send information from the view of pilots. The above analysis and study indicate that a runway status lights system with rationally arranged lights is able to inform aircraft pilots and vehicle drivers of runway safety status and plays a positive role in preventing runway intrusion incidents. (Li Jiang, et al., 2022)

2.5.3 Advanced Surface Movement Guidance and Control System (A-SMGCS)

- Implemented globally (e.g., London Heathrow, Charles de Gaulle Airport): A-SMGCS uses radar, multilateration, and ADS-B technology to monitor and control ground movement. Although it primarily manages taxiways and aprons, the system's interaction with lighting controls provides valuable lessons for radar-based runway lighting systems. (International Civil Aviation Organization, 2004)

2.5.4 Proposal for an intelligent lighting system, and verification of control method effectiveness

In recent years, various types of equipment have become more intelligent. In this research, we propose an intelligent lighting system for providing the necessary illuminance to a desired location; actually construct a fundamental experiment system based on that concept; and verify the effectiveness of the newly developed control method. Verification tests were conducted using an optimization algorithm specialized for lighting control, and the results showed that the various illuminance sensors converged to the preset target illuminance. We also confirmed that the system can respond adaptively to the movement of illuminance sensors and contingencies like lighting malfunctions. Adapted to - Research and Pilot Programs: Several airports are experimenting with intelligent lighting systems that integrate radar and other sensor technologies to optimize lighting based on aircraft movements. Although still in experimental phases, these systems offer insights into the future of adaptive runway lighting solutions. (M. Miki, T. Hiroyasu, & K. Imazato, 2004)

2.5.5 Airport Collaborative Decision Making (A-CDM)

With the development of civil aviation, congestion and flight delay caused by traffic flow is becoming more and more prominent. Since 2012, airport collaborative decision making (A-CDM), as a means to improve efficiency and quality of airports operation, has been gradually generalized to the domestic airports with passenger throughput more than 10 million. This paper first analyzes the development status of A-CDM system, and then proposes the concept of Intelligent A-CDM and introduces the overall framework of Intelligent A-CDM system, finally points out the key technologies and main research and development directions of Intelligent A-CDM, providing theoretical basis and technical support for the next development of A-CDM system. In short Implemented in Europe and other regions: A-CDM integrates various airport systems, including radar, to improve overall airport efficiency. Though its focus is broader than runway lighting, A-CDM demonstrates how data-driven decision-making can enhance airport operations, including lighting management. (Yinger Zheng, Jiahe Miao, Ningning Le, Yunpeng Jiang, & Yang Li, 2019)

2.5.6 Runway Lighting and Lighting Control Systems

The purpose of this study; In order to perform a safe landing and takeoff of the aircraft, it is to examine the runway lighting system, light guidance elements and the control unit of these equipments. Based on this information in the study, of Erzincan airport runway lighting system has been examined. Runway lighting system are investigated as threshold lights, runway threshold identification lights, runway end lights, runway center line lights, runway edge lights, touchdown zone lights, taxiway edge lights, taxiway center line lights. Also, stop bars, approaching fixtures, runway fixtures, runway edge fixtures, beacon light system, PAPI and so on. Lighting components and related to them, are given extensive information about the control systems. (Mustafa Şahin, 2016)

2.5.7 Reliability of LED-based systems

Reliability is an essential scientific and technological domain intrinsically linked with system integration. Nowadays, semiconductor industries are confronted with ever-increasing design complexity, dramatically decreasing design margins, increasing chances for and consequences of failures, shortening of product development and qualification time, and increasing difficulties to meet quality, robustness, and reliability requirements. The scientific successes of many micro/nano-related technology developments cannot lead to business success without innovation and breakthroughs in the way that we address reliability through the whole value chain. The aim of reliability is to predict, optimize and design upfront the reliability of micro/nanoelectronics and systems, an area denoted as 'Design for Reliability (DfR)'. While virtual schemes based on numerical simulation are widely used for functional design, they lack a systematic approach when used for reliability assessments. Besides this, lifetime predictions are still based on old standards assuming a constant failure rate behavior. In this paper, we will present the reliability and failures found in solid-state lighting systems. It includes both degradation and catastrophic failure modes from observation towards a full description of its mechanism obtained by extensive use of acceleration tests using knowledge-based qualification methods. (Willem D. van Driel, B. Jacobs, P. Watte , & X. Zhao , 2022)

2.5.8 Detection and discrimination of radar targets.

A new method for detection and discrimination of radar targets is described. The basis for this method is that the gross structure of a radar target can be identified from scattered fields of the target at harmonic radar frequencies located just in the low resonance region. This is in sharp contrast to many target signature schemes that operate at much higher frequencies and observe many of the details of the target in lieu of its gross features. Multiple frequency radar scattering data and the complex natural resonant frequencies of radar targets are integrated into a predictor-correlator processor. The method is illustrated using as target models both classical shapes and thin-wire configurations of simple geometry. Integral equation programs are utilized to calculate multiple frequency backscatter data for the wire geometries and to deduce the complex natural resonant frequencies of the wire structures. Discrete multiple frequency radar scattering data spanning a particular spectral range are shown to be desirable for optimum capability but discrimination and detection can be achieved using just two near-conventional radars, even if the radars are located at different sites and hence view the target from different aspects. (D. Moffatt & R. Mains, 2012)

2.5.8 Design and implementation of a smart runway illumination: radar-controlled lighting system

The "Design and Implementation of Smart Runway Illumination: Radar-Controlled Lighting System" project gives better safety and efficiency to aviators by filling the deficit of traditional runway lighting. Real-time radar data, characteristic high-intensity LED lights, and smart control algorithms that adjust illumination depending on aircraft position, speed, and direction, along with other environmental factors, form the core of this smart system. The smart runway illumination system provides increased reliability and reduced energy consumption. It combines the radar data with the LED lighting to provide better solutions and more efficiency, thus ensuring increased safety at airports. This should be installed in all airports to enhance efficiency and safety operations. Further research on combining other data in the environment that can increase its applications in airports could help in enhancing operations. This technological new step in aviation gives a lot of improvement to the technology by addressing numerous challenges that are facing traditional runway lighting systems. (Grace, Design and implementation of a smart runway illumination: radar-controlled lighting system, 2024)

2.6 Summary

In conclusion, therefore this chapter talked about; Concepts, Opinions, and Ideas from Authors/Experts, Definition of concepts and related study.

CHAPTER 3

RESEARCH METHODOLOGY

3.0 Introduction

This chapter exhibits the research methodologies used in the project, entitled " Implementation of a Smart Runway Illumination Radar-Controlled Lighting System." It describes the research design, population, sample size, sampling procedures, research instruments, data gathering procedures, data analysis, and interpretation. It also discusses ethical considerations and the limitations that one might meet in the study.

3.1 Research Design

The research design for this current study is experimental in educational development, aimed at the integration of advanced LED lighting with radar technology to cause a resultant in the development of a "smart" runway illumination system. This approach was meant for testing the effectiveness of the system intended for use in real-time scenarios and validating its reliability and efficiency. This required data collection and insights gathering from both quantitative and qualitative methods of analysis.

3.2 Research Population.

The total population for the study would consist of engineers, technicians, and managers who deal with airport runway lighting systems. In fact, this category includes installers, maintainers, and persons responsible for management functions related to such systems. Find out how many, considering the scope of your study, be it an airport or a set of airports, and try to get that number from specific industry reports or from airport authorities.

3.3 Sample Size

A sample size of 152 respondents was selected out of accessibility from the relevant stakeholders and experts. This small sample will help to have a representative variety of views and expertise. However, the generalizability of the findings will not be possible. More robust data can be derived from a large sample size in future studies.

3.3.1 Sampling Procedure

The selection of the sample population was done through purposive sampling, targeting participants with direct experience in airport runway lighting systems, including the use of radar in such systems.

Participants were approached individually to ascertain that they add value to the study, through direct invitations and professional networks.

3.4 Research Instrument

3.4.1 Choice of the Research Instrument

The study will have research instruments to be structured interviews, observation checklists, and standardized questionnaires. The choice of these instruments was for collecting qualitative and quantitative data. The interview guide and observation checklist were developed after the insights, stemming from the literature review. And the questionnaire was standardized with utmost care and pre-tested to establish its reliability and validity.

3.4.2 Validity and Reliability of the Instrument

The validity of the instruments was established through expert reviews and pilot testing with a small group of respondents not included in the main study. Reliability was ensured by using standardized instruments and conducting consistency checks during data collection. Multiple instruments were used to triangulate data and enhance the overall reliability of the findings.

3.5 Data Gathering Procedures

Data was gathered through several steps:

1. Identification and Selection of Respondents: Respondents were chosen according to their knowledge and skill of airport runway lighting learners and radar technology.

2. Structured Interviews and Observations: These were conducted in several channel of communication to gather primary data on the current lighting programs for runways.

3. Questionnaires: These were administered to a variety of stakeholders to collect quantitative data through various networks.

The information was well structured and then summarized and analyzed.

3.5.1 Primary data

We collected primary data for our simulation through an insight visit, paid to the ULK Polytechnic electronic workshop (EEE), for our project entitled "Design and Implementation of a Smart Runway Illumination: Radar-Controlled Lighting System." The assistant was very cooperative and had guided us impeccably on a number of components crucial for the development of our system. They explained very well how each of these components should be sized, how it should work, and how it is to be used in order that we understand fully the importance and application of each. The visit became extremely beneficial with the necessary hand-on experiences, adding to practical knowledge and first-hand information on the various components required. Deepening in our understanding, there was sufficient expertise on the part of the assistant, who explained in detail to make a correct choice, ensuring that we picked up the most appropriate component for the project. Only deepening our understanding, this visit reiterated the importance of the right choice of components for the overall success and efficiency in our smart runway illumination system.

3.5.2 Secondary data

Secondary data is already sampled and analyzed information by different persons or agencies. In pursuit of this data in implementing our project, "Design and Implementation of a Smart Runway Illumination: Radar-Controlled Lighting System," there was an extensive research on some books to bridge the concept gap in implementing our project. We targeted literature that was peculiar to the subject matter of our project, making sure that we had gained full understanding of the available knowledge in this field. Apart from the books reviewed, we did extensive research on the internet. We browsed various websites to extend our knowledge and gain further information. This search on the internet proved valuable in giving us a wider outlook and the most recent updates on the most current concepts and standard practice regarding our project.

During the research, many times it occurred that some vital data or notes were missing in our materials, very important for our project. Again, it is then that our supervisor stepped in to help us out. This expertise and advice made a big difference while doing the exact, correct sizing and design of our system where our second-hand literature couldn't provide us with enough information.

Reviews of books, research on the Internet, and supervision combined to provide us with a robust body of secondary data. This approach ensured that we had a well-rounded and detailed foundation of knowledge to support the successful design and implementation of our smart runway illumination system.

3.6 Data Analysis and Interpretation

Thematic analysis was done on the qualitative data retrieved from the interviews and observations to deduce patterns and insights regarding how effective the smart runway illumination system was. The performance and efficiency of the questionnaire were statistically judged with the application of statistical techniques on the quantitative data: chi-square test, correlation analysis, and ANOVA. These therefore made it easier to answer the research questions and validate the hypotheses set in this study.

3.7 Ethical Considerations

Ethical concerns were the obtaining of informed consent from all respondents, preservation of confidentiality, and respecting privacy and rights of respondents. Ethical approval was sought from the concerned institution review board. And data collected and reported in conformity to ethical guidelines.

3.8 Summary

In conclusion, therefore this chapter talked about; introduction, research design, research population, sample size, sampling procedures, research instrument, data gathering procedures, data analysis and interpretation and ethical consideration.

CHAPTER 4

IMPLEMENTATION AND ANALYSIS

4.0 Introduction

This chapter presents a critical design description of the Smart Runway Illumination with a bias for radar-controlled lighting. In the chapter, the essential features of the system design will be critically discussed, including relevant calculations, technical drawings, and any detailed specification critical for the implementation of the proposed system. Cost estimation for the different components that make up the system and the overall budget of the project are also done to ensure the viability of the design. Implementation discussion, where applicable, is made to outline the way the system can be brought to operational status, and it mainly emphasizes practical challenges and solutions. This comprehensive analysis forms a basis for understanding the technicality of the project, hence giving easy transition from the concept design to functional deployment.

4.1 BLOCK DIAGRAM

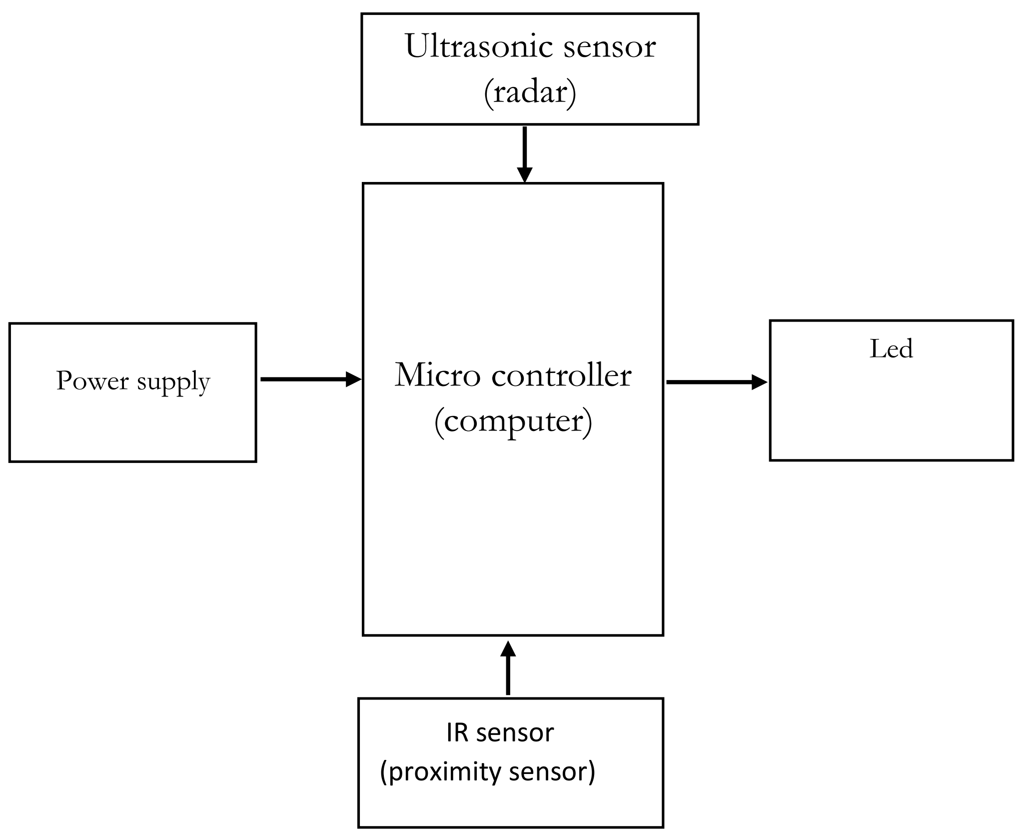

Figure 1: Block diagram

4.2 FLOW CHART

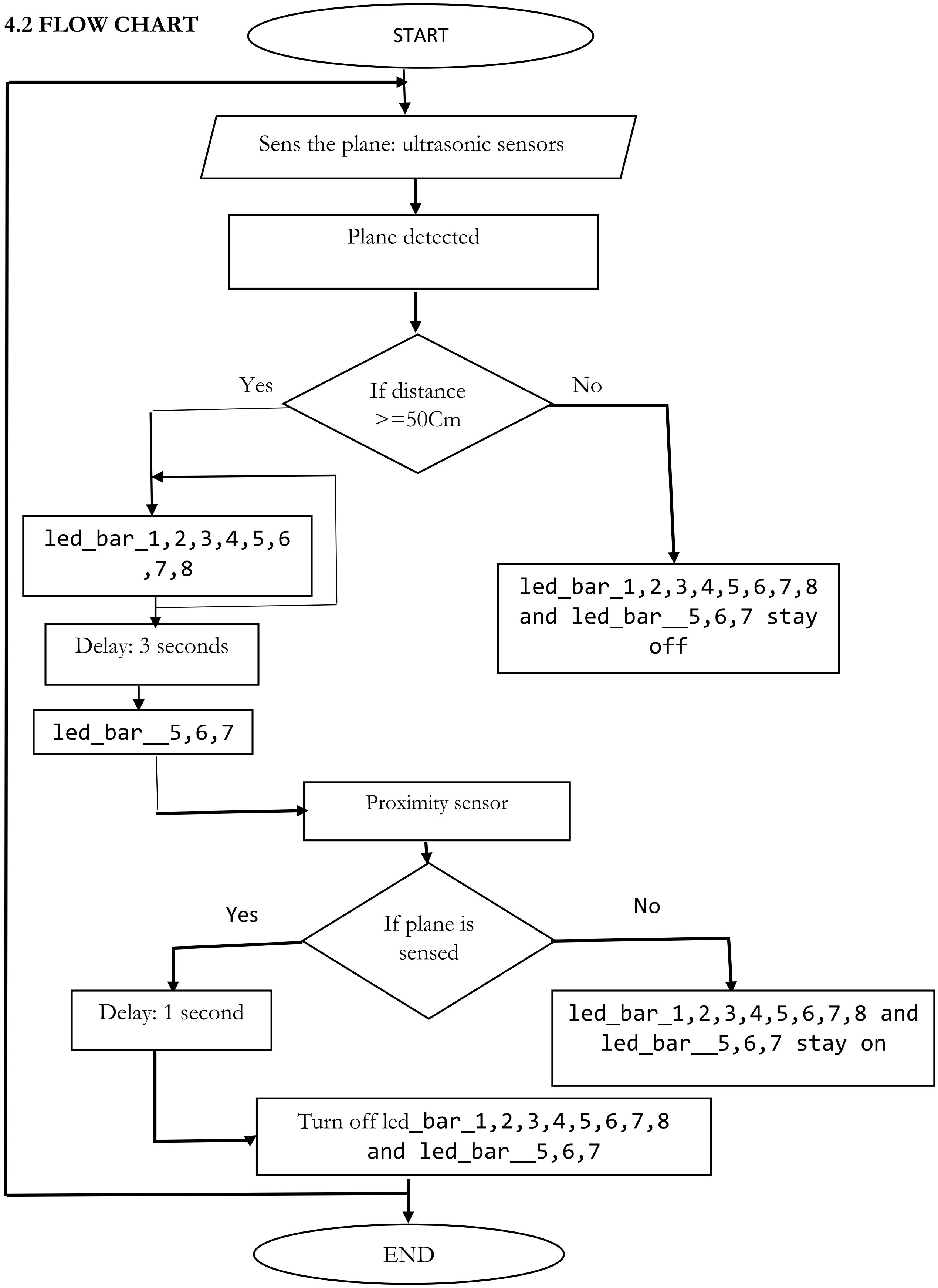

Figure 2: System floor chart

4.4 CIRCUIT DIAGRAM

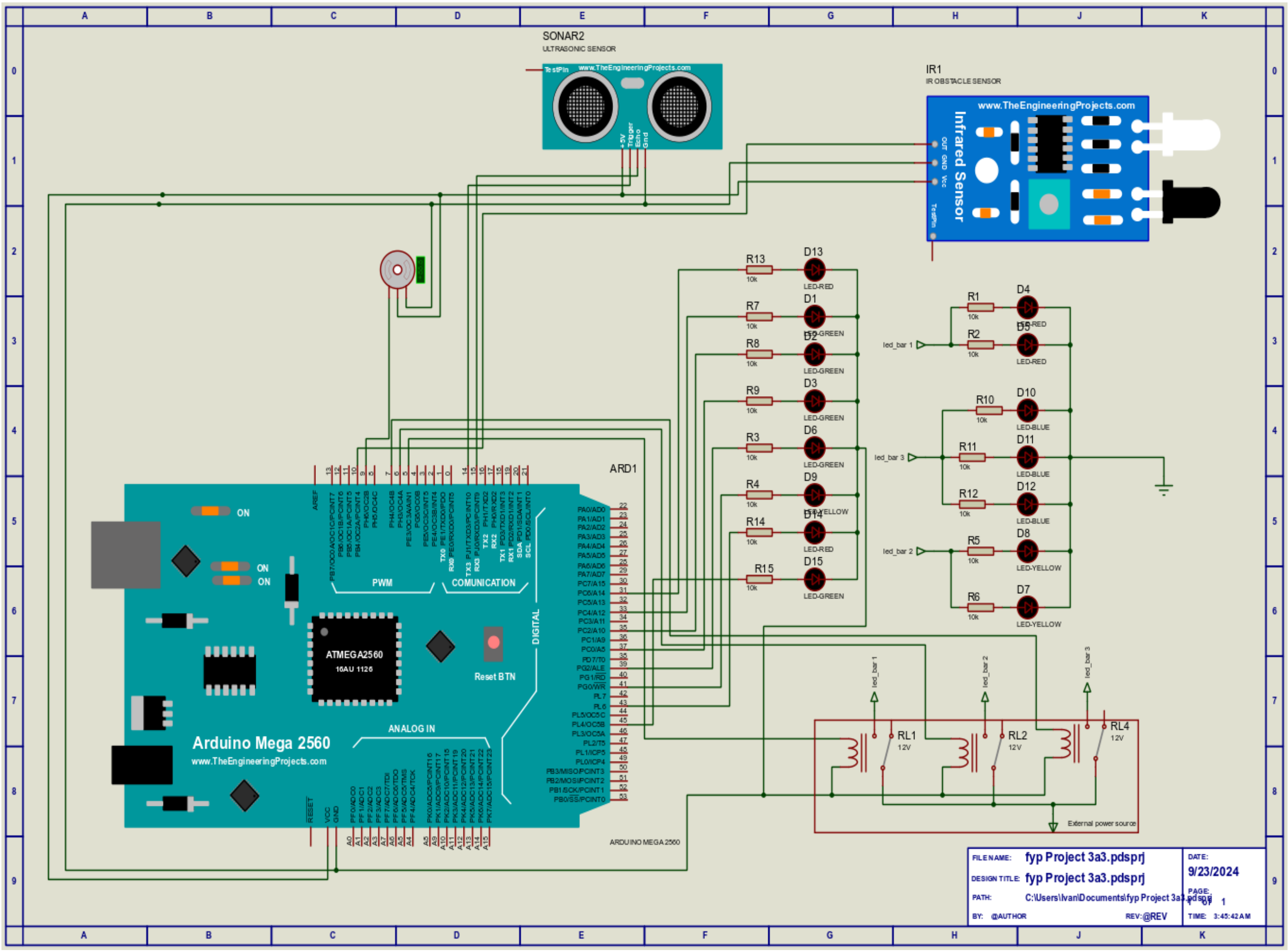

Figure 3: System circuit diagram

4.5. CALCULATION

1. Radar Range Calculation:

The radar range equation estimates the maximum distance at which an object (e.g., aircraft) can be detected:

$$R_{max} = \frac{(P_t \times G^2 \times \lambda^2 \times \sigma)^{1/4}}{((4\pi)^3 \times Pmin)}$$

Where:

- R_{max} = Maximum detection range (m)
- P_t = Transmitter power (W)
- G = Antenna gain
- λ = Wavelength of the radar signal (m)
- σ = Radar cross-section of the target (m^2)
- P_{min} = Minimum detectable signal power (W)

2. Energy Consumption Comparison:

To prove the system's energy savings, we can compare the **energy consumption** of the traditional lighting system versus the smart system:

$$E_{traditional} = P_{light} \times t_{on}$$

$$E_{smart} = P_{light} \times t_{active}$$

Where:

- $E_{traditional}$ = Energy consumption of the traditional system
- E_{smart} = Energy consumption of the smart system
- P_{light} = Power consumption of the lighting system (W)
- t_{on} = Time the traditional system remains on (hours)
- t_{active} = Time the smart system is active (based on aircraft proximity

3. Aircraft Proximity Calculation (Using Ultrasonic Sensor):

The distance d between the aircraft and the sensor is calculated based on the time of flight for ultrasonic waves:

$$d = \frac{(v \times t)}{2}$$

Where:

- d = Distance to the aircraft (m)
- v = Speed of sound in air (343 m/s)
- t = Time for the ultrasonic signal to return (s)

4.5 Materials used with descriptions

1. Arduino Mega 2560

Figure 4: Arduino mega

The **Arduino Mega 2560** is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega 2560 board is compatible with most shields designed for the Uno and the former boards Duemilanove or Diecimila. (arduino s.r.l. - partita IVA, 2020)

Arduino Mega Applications

- Weighing Machines: Used in industrial scales and smart weighing systems.

- Traffic Light Count Down Timer: Efficiently manages multiple traffic lights due to its numerous I/O pins.

- Parking Lot Counter: Tracks the number of vehicles entering and exiting a parking lot.

- Embedded Systems: Serves as a versatile microcontroller in various embedded applications.

- Home Automation: Powers smart homes, controlling lights, security systems, and appliances.

- Industrial Automation: Manages sensors, motors, and complex control systems in factories.

- Medical Instruments: Used in prototyping devices like heart rate monitors, glucose sensors, and more.

- Emergency Light for Railways: Controls emergency lighting systems for safety in railway stations.

Arduino Mega Programming

Programming on an Arduino Mega is done using the Arduino IDE, which is based on a simplified version of C++. It's user-friendly, making it accessible to beginners. Below are the steps and key concepts you'll encounter when programming the device.

Steps to Program an Arduino Mega

1. Installation of the Arduino IDE: Download and install the Arduino IDE from the official website.

2. Plug in the Arduino Mega: Use a USB cable to connect the Arduino Mega to your computer.

3. Select the Board and Port:

- Go to `Tools` and change the `Board` to `Arduino Mega or Mega 2560`.

- Go to `Tools` and select the `Port` where the Arduino Mega is connected.

4. Writing the Code: Write your code, known as a sketch, in the Arduino IDE. Each sketch consists of two main functions:

- `setup()`: Initializes settings and runs only once when the program starts.

- `loop()`: Contains the main program logic and runs repeatedly after `setup()`.

Uploading the Code

Once the code is written:

1. Verify: Click on the checkmark icon to compile the code and check for errors.

2. Upload: Click on the arrow icon to upload the compiled code to the Arduino Mega.

Key Concepts

- pinMode(pin, mode): Configures a pin as either `INPUT` or `OUTPUT`.

- digitalWrite(pin, value): Sets the pin to `HIGH` (ON) or `LOW` (OFF).

- delay(ms): Pauses the program for the specified number of milliseconds.

Additional Features

The Arduino Mega supports numerous libraries and features that allow for advanced functionalities. Libraries are collections of pre-written code that simplify complex tasks:

- Servo Library: Enables control of servo motors.

- LiquidCrystal Library: Facilitates working with LCD displays.

- Wire Library: Helps in communicating with I2C devices.

Resources

- Official Arduino Documentation: Offers detailed guides and function references.

- Arduino Community: Includes tutorials, forums, and open-source contributions from the Arduino community.

The key difference between programming the Arduino Mega and the Arduino Uno is the increased number of pins and memory available on the Mega, making it more suitable for larger, more complex projects.

2. Distance Sensing with Ultrasonic

(Carullo,2001). Sensor an ultrasonic sensor is a device that can measure the distance to an object by using sound wave it measures distance by sending out a sound wave at a specific frequency and listening for that sound wave to bounce back.by recording the elapsed time between the sound wave being generated and the sound wave bouncing back, it is possible to calculate the distance of objects. (TIF Labs Pvt. Ltd, 2023)

Plugging in the sensor

VCC --->Arduino +5v pin

GND --->Arduino GND pin

Trig--->Arduino digital pin 9

Echo--->Arduino digital pin 10

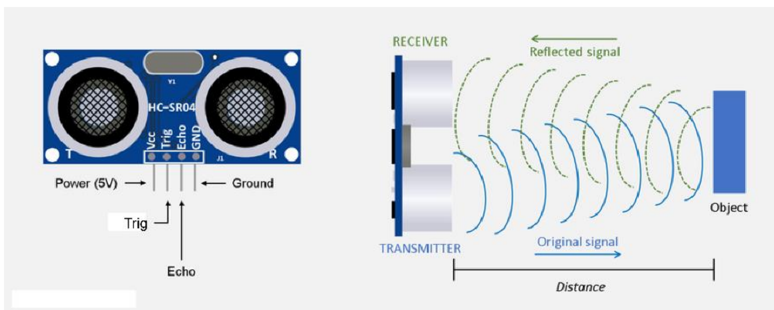

Figure 5. ultrasonic sensor

A sonar sensor works like this when your program sends a trigger signal through a digital pin (figure 1(B) first row), the sensor emits an ultrasound burst shown in the second row of figure 1(B), and sets the voltage of the echo pin to a HIGH (5V) value, which you can read from a digital pin on the Arduino board.

When the ultrasound burst returned after bouncing on an obstacle, the sensor sets the voltage of the echo pin to a low (0v). The trig pin will be used to send the sign pin will be used to listen for the assembly looked like this:

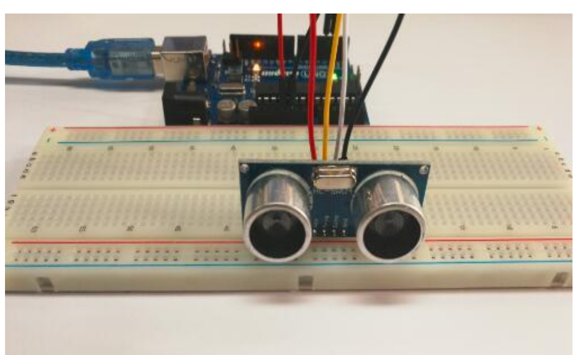

Figure 6. ultrasonic sensor with Arduino

How Ultrasonic Sensors Work

Ultrasonic sensors use sound to determine the distance between the sensor and the closest object in its path. How do ultrasonic sensors do this? Ultrasonic sensors are essentially sound sensors, but they operate at a frequency above human hearing.

The sensor sends out a sound wave at a specific frequency. It then listens for that specific sound wave to bounce off of an object and come back (Figure 1). The sensor keeps track of the time between sending the sound wave and the sound wave returning. If you know how fast something is going and how long it is traveling you can find the distance traveled with equation 1. Equation 1. $d = v \times t$

3. LED (Light Emitting Diode)

Basically, an LED is a semiconductor device that emits light when an electric current passes through it. The working of the principle comes when an electric current passes through an LED; electrons start recombining with holes and emite light during this process. An LED allows current flow in one direction—forward—and blocks it in the reverse direction. (F.K. Yam, 2004)

Figure 7. LED (Light Emitting Diode)

4. infrared (IR) sensor

An infrared (IR) sensor is an electronic device used to measure and detect infrared radiation in its surrounding environment. What then is infrared radiation? Infrared radiation - also known as infrared light - refers to electromagnetic radiation that has wavelengths longer than those of visible light. In fact, it is said to encompass wavelengths from around 1 millimeter to around 700 nanometers (the nominal red edge of the visible spectrum). It is thus invisible to the human eye but can be detected as a sensation of warmth on the skin. (Team YoungWonks, 2021)

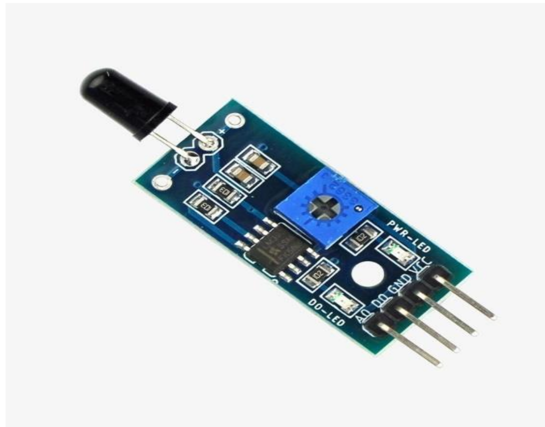

Figure 8. infrared (IR) sensor

How an Infrared Sensor Works?

Operation for the Ir Basic

- Components: IR LED can be considered as a light transmitter and IR photodiode as a receiver.
- Function: IR LED emits Infrared radiation, invisible to the human eye, and can be detected as light by the IR photodiode.
- Process: IR lighting that has been issued will reflect off of an object and return to the photodiode. As a result of this, IR light is detected, and the changes in resistance and the output voltage are determined by the sensor's output.

Applications of Infrared Sensors

1. Speed Sensors:

- Applications: Multi-Motor synchronization.

2. Temperature Sensors:

- Applications: In industrial temperature control.

3. Passive Infrared (PIR) Sensors:

- Applications: Automatic door opening systems.

4. Ultrasonic Sensors:

- Applications: For measurements of distances.

Devices Using IR Sensors

- IR Imaging Devices:

- Examples: Thermal imaging cameras, night vision cameras.

- Function: It is used to detect IR radiation from objects to form temperature distribution images.

Radiation Thermometers:

- Function: Temperature measurement using radiation emitted due to thermal radiation without contact.

- ❖ Flame Monitors:

Application: Detect flame light for the monitoring of combustion.

Moisture Analyzers:

Application: Moisture content of samples is measured with IR wavelengths.

- ❖ Gas Analyzers:

Application: Detecting and measuring gas for ensuring safety, quality, and efficiency

Applications

- Meteorology & Climatology
- Photo-bio Modulation
- Water/Gas Analysis
- Anesthesiology Testing
- Petroleum Exploration
- Rail Safety
- Motion Detection

5. Servo motor

A servo motor is a type of motor that can rotate with great precision. Normally this type of motor consists of a control circuit that provides feedback on the current position of the motor shaft, this feedback allows the servo motors to rotate with great precision. If you want to rotate an object at some specific angles or distance, then you use a servo motor. It is just made up of a simple motor which runs through a servo mechanism. If motor is powered by a DC power supply then it is called DC servo motor, and if it is AC-powered motor then it is called AC servo motor. (ApoorvE, 2015)

Figure 9. a servo motor

It consists of three parts:

1. Controlled device
2. Output sensor
3. Feedback system

It is a closed-loop system where it uses a positive feedback system to control motion and the final position of the shaft. Here the device is controlled by a feedback signal generated by comparing output signal and reference input signal.

6. **4 channel relay module**

The four-channel relay module contains four 5V relays and the associated switching and isolating components, which makes interfacing with a microcontroller or sensor easy with minimum components and connections. The contacts on each relay are specified for 250VAC and 30VDC and 10A in each case, as marked on the body of the relays.

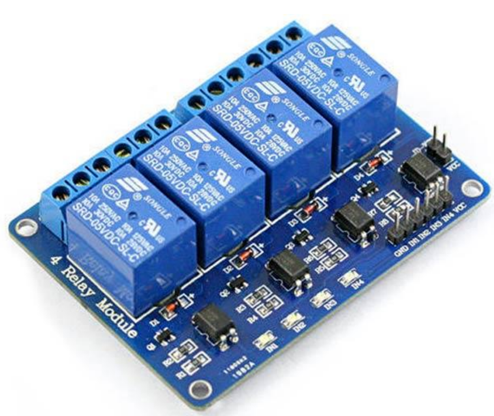

Figure 10: 4 channel relay module

4.6 Components specifications

1. **Servo motor**

Technical data gave by the manufacturers:	**Steering gear definition of three lines:**	**Package includes**
▪ Size: 21.5mmX11.8mmX22.7mm ▪ Weight: 9 grams ▪ No-load speed: 0.12 seconds / 60 degrees (4.8V) ▪ Stall torque of 1.2 – 1.4 kg / cm (4.8V) ▪ Operating temperature: -30 to +60 degrees Celsius ▪ Dead-set: 7 microseconds ▪ Operating voltage: 4.8V-6V	1. Dark gray: GND 2. Red: VCC 4.8-6V 3. Orange line: pulse input	▪ 1x SG90 servo motor with attached 9.5" control cable ▪ 3x Arms/honors for various interface applications ▪ 3x Screws for mounting arms the servo and mounting the servo

Table 1: servo motor specifications

2. Arduino

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB

EEPROM	4 KB
Clock Speed	16 MHz
LED_BUILTIN	13
Length	101.52 mm
Width	53.3 mm
Weight	37 g

Table 2: Arduino mega specifications

3. **Infrared Obstacle Avoidance Tracking Sensor Module**

Specifications Working voltage: DC 3.3V-5V Working current: 20mA Operating Temperature: -100C-+500C Detection distance: 2-40Cm IO interface: 4 wires interface (-/+/S/EN) Output signal: TTL level (low level there is an obstacle, no obstacle high) Adjustment: adjust multi-turn resistance Effective angle:350 Size: 28mm*23mm Weight Size: 9g	It is equipped with a precision potentiometer adjustable sensitivity adjustment. Power LED: Illuminates when power is applied Obstacle LED: Illuminates when the obstacle is detected The output is in the form: DO digital switching outputs (0 and 1) and AO analog voltage output. Additionally, there are fixed bolt holes for easy installation.

Table 3: Infrared Obstacle Avoidance Tracking Sensor Module

4. **HC-SR04 Ultrasonic Sensor**

Working Voltage DC 5 V Working Current 15mA Working Frequency 40Hz Max Range 4m	Ultrasonic ranging module HC - SR04 provides 2cm - 400cm non-contact measurement function, the ranging accuracy can reach to 3mm. The modules

Min Range 2cm Measuring Angle: 30 degree Trigger Input Signal 10uS TTL pulse Echo Output Signal Input TTL lever signal and the range in proportion Dimension 45*20*15mm	includes ultrasonic transmitters, receiver and control circuit

Table 4: HC-SR04 Ultrasonic Sensor

5. 4 Channel 5V Relay Module

▪ Usage: General Purpose ▪ Contact Load: High Power ▪ Theory: Voltage Relay ▪ Model Number: Relay Module ▪ is customized: Yes ▪ Protect Feature: Epoxy ▪ Power Source: DC ▪ Voltage: Other ▪ Size: 6mm*38.8mm*19.3mm ▪ dc controller relay remote ▪ Type: Voltage Regulator	▪ Condition: ***New*** ▪ Application: ***Computer*** ▪ Supply Voltage: 5V ▪ Dissipation Power: 300W ▪ Operating Temperature: -40 -85℃ ▪ Model Number: 4 Channel 5V Relay Optocoupler ▪ is customized: Yes

Table 5: 4 Channel 5V Relay Module

2.7 Implementation

This project on Smart Runway Illumination utilizes radar technology to detect the presence, speed, and position of aircraft near or on the runway. When the radar detects an approaching aircraft, it sends a signal to the system, which activates the LED lights in the specific area where illumination is needed. The lighting adjusts dynamically in real time, based on the aircraft's movement, ensuring optimal visibility during landing, takeoff, or taxiing. When no aircraft is detected, the lights automatically turn off, reducing unnecessary energy consumption. This approach not only improves operational efficiency but also enhances safety by providing targeted lighting during critical phases of flight.

Figure 11: implementation

2.8 Summary

In conclusion, therefore this chapter talked about; introduction of the chapter, the block diagram, flow chart, circuit diagram, calculations, components used for implementation and components specifications.

CHAPTER 5:

CONCLUSION AND RECOMMANDATION

5.0 Introduction

This chapter summarizes the findings of the research, conclusions from the study, and recommendations based on the results. It also makes some suggestions for further research in the area of runway lighting systems, especially with regard to radar-controlled lighting technology. The findings highlight the need to enhance the level of safety, efficiency, and reliability during airport operations by introducing an intelligent runway illumination system.

5.1 Conclusions

This research studied the development of an intelligent runway lighting system where upgraded airport safety and energy efficiency are envisaged with the embedding of advanced radar technologies into LED lightings. The research has overcome some of the major limitations to the traditional runway lighting system, which normally is not responsive in real-time with respect to aircraft movement and environmental factors.

The first question, therefore, focused on how radar technology would be applied in runway lighting control. The present study makes it clear that radar data, along with intelligent algorithms, serves to adjust lighting intensity in real-time fashion according to aircraft speed, position, and direction, reducing energy consumption compared to conventional systems, which operate at set intensities irrespective of actual requirement.

The second research question sought to establish whether the system enhances overall operational safety at the airport. The findings indicated that, through dynamic lighting adapted to the coming or departing aircraft, the system reduces the level of risk of flight accidents during these critical phases of flight, which mainly involves landing and takeoff. To this end, the adaptive lighting system saves energy while, at the same time, improving pilot visibility and hence safer flights.

Finally, the study considered the feasibility of the system in existing airports. It was indeed established in this research study that this radar-controlled lighting system is fully supportive of the current infrastructure and practical and scalable in most of airports.

5.2 Recommendations

while conducting the study on this project various area to improve came up on our case based on research findings, these recommendations is to extend the system of other areas of airport operation for further efficiency and safety improvement such as:

1. Installation of Computer Vision Systems for Taxiway and Tarmac: Supplementing the radar system, computer vision and camera systems need to be implemented in airports for keeping track and controlling lightings on taxiways and tarmacs. Such systems will monitor positions of aircraft and ground vehicles at any instant in real time and change the lighting conditions according to precise positioning for increased visibility, hence offering increased safety during ground operations.

2. LiDAR for Ground Operations: LiDAR offers very accurate 3-D mappings of airport surfaces for more accurate object detection and the tracking of movement, including taxiways and tarmacs. Integration with smart lighting systems allows LiDAR to provide lighting only when needed, hence managing energy use with greater efficiency, especially in complex and busy airport environments.

3. Automation via IoT: Installation of IoT-enabled sensors at taxiways and tarmacs will be able to provide automation of lighting through real-time data. These sensors can detect aircraft and vehicle movement, weather conditions, and many other factors, which further seamlessly automate lighting and other critical systems with no need to rely on radar.

4. Low Visibility Operations-Heat Imaging Applications: International/national airports should make accommodations for integrating thermal imaging technology into routine operations, including nighttime and foggy conditions. This aids the cameras in locating the aircraft and other ground vehicle heat signatures, thus turning the light systems on only when needed for the best possible visibility under such unfavorable circumstances.

5. AI and Machine Learning for Predictive Automation: AI and machine learning are the next levels of integration into lighting and airport ground operations. The systems survey historical data and provide predications of aircraft movement patterns, enabling AI-driven lighting to anticipate oncoming aircraft and adjust to minimize energy use while ensuring maximum safety.

6. Solar-Powered Lighting for Energy Efficiency: Airports desiring to cut carbon emissions may use solar-powered lighting installed with motion detection capabilities. These systems store solar energy

during the day and activate at necessary periods, thereby saving on huge energy costs without compromising on safety in taxiway and tarmac operations.

7. Training and Maintenance: Complete training of airport technical staff in terms of new lighting systems should be given for the smooth operation and troubleshooting. Regular maintenance schedules should be provided for system updates and ensuring the systems' reliability.

8. In the course of this project, it has been realized that some components needed for the implementation of the smart runway lighting system and its simulation are costly based on the current market trend. The study hereby recommends that UKL Polytechnic look at forming alliances with manufacturers or suppliers to source components at more reasonable rates. Further studies should be conducted in alternative materials or components that may be cheaper and could ensure affordability or the feasibility of the system for wide deployment in various airport environments.

5.3 Further Research Recommendations

As an outcome of this research study, a number of aspects came to the fore which can greatly upgrade and further develop the existing system of runway lighting:

1. Integration with Environmental Data: More studies should be conducted on how other environmental conditions, such as wind speed, precipitation, and runway surface conditions, can be integrated into the logics of the lighting control system. This will provide an even greater ability for the system to adapt dynamically to changes in conditions, hence increasing safety during adverse weather conditions.

2. Taxiway and Tarmac Systems Automation: Automation in taxiway and tarmac operations beyond radar needs to be further researched. The utilization of LiDAR, thermal imaging, and IoT technologies could make lighting and other necessary systems self-automated, thus helping to save energy and enhance the safety of operations.

3. Integration of AI and Machine Learning: More studies on the use of AI in machine learning for predictive automation of runway and taxiway lights can be done to enhance this operational efficiency. The AI system will predict aircraft movements based on past trends, hence enabling higher stages of automation in advanced control systems.

4. Cost-Benefit Analysis of Alternative Technologies: Other automation technologies, like LiDAR, IoT, and vision-based systems, have to be pursued with a detailed cost-benefit analysis for finding out the best solutions for various sizes of airports and different operational requirements.

Further research on these aspects can broaden the scope of smart airport systems and significantly enhance safety, efficiency, and sustainability at various airports worldwide.

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APPENDICES

Arduino source code

```
#include <Servo.h>

Servo myservo;
int angle = 0;

const int ledPin = 12;


int led_bar_1 = 31;
int led_bar_2 = 33;
int led_bar_3 = 35;
int led_bar_4 = 37;
int led_bar_5 = 39;
int led_bar_6 = 41;
int led_bar_7 = 43;
int led_bar_8 = 45;

int led_bar__5 = 3;
int led_bar__6 = 4;
int led_bar__7 = 5;

const int trigPin = 14;
const int echoPin2 = 15;

const int irSensorPin = 10;

long duration;
int distance;
bool plane_Detected = false;
bool ledsOn = false;

unsigned long loopStartTime;
const unsigned long ledBlinkInterval = 150;
const unsigned long led6Delay = 3000;
const unsigned long led5Delay = 1000;
 const unsigned long offDelay = 1000
const int minDistance = 50;
void setup() {
  myservo.attach(9);
```

```
  pinMode(ledPin, OUTPUT);


  pinMode(led_bar_1, OUTPUT);
  pinMode(led_bar_2, OUTPUT);
  pinMode(led_bar_3, OUTPUT);
  pinMode(led_bar_4, OUTPUT);
  pinMode(led_bar_5, OUTPUT);
  pinMode(led_bar_6, OUTPUT);
  pinMode(led_bar_7, OUTPUT);
  pinMode(led_bar_8, OUTPUT);

  pinMode(led_bar__5, OUTPUT);
  pinMode(led_bar__6, OUTPUT);
  pinMode(led_bar__7, OUTPUT);


  // Set ultrasonic sensor pins

  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);

  // Set IR sensor pin
  pinMode(irSensorPin, INPUT);
  Serial.begin(9600);
  loopStartTime = millis();

}

void loop() {


// Turn the LED on
  digitalWrite(ledPin, HIGH);

  // Wait for 500 milliseconds
  delay(100);

  // Turn the LED off
  digitalWrite(ledPin, LOW);

  // Wait for 500 milliseconds
  delay(100);
```

```
  for (angle = 0; angle <= 180; angle += 2.5) {
    myservo.write(angle);
    delay(50);
  }

  delay(0);


  for (angle = 180; angle >= 0; angle -= 2.5) {
    myservo.write(angle);
    delay(50);
  }

  delay(0);

  if (digitalRead(irSensorPin) == LOW && ledsOn)
{
    delay(1000);

    turnOffLedsSequentially();
    ledsOn = false;
    return;
  }


  detect_planeWithUltrasonic();


  if (plane_Detected && !ledsOn) {

    loopStartTime = millis();


    while (true) {
      unsigned long currentTime = millis();
      unsigned long elapsedTime = currentTime - loopStartTime;


 // Sequentially blink LED bars 1, 2, 3, and 4
      if (elapsedTime % (ledBlinkInterval * 4) < ledBlinkInterval) {
        digitalWrite(led_bar_1, HIGH);
        digitalWrite(led_bar_2, HIGH);
        digitalWrite(led_bar_3, LOW);
        digitalWrite(led_bar_4, LOW);
```

```
    digitalWrite(led_bar_5, LOW);
    digitalWrite(led_bar_6, LOW);
    digitalWrite(led_bar_7, LOW);
    digitalWrite(led_bar_8, LOW);

  } else if (elapsedTime % (ledBlinkInterval * 4) < ledBlinkInterval * 2) {
    digitalWrite(led_bar_1, LOW);
    digitalWrite(led_bar_2, LOW);
    digitalWrite(led_bar_3, HIGH);
    digitalWrite(led_bar_4, HIGH);
    digitalWrite(led_bar_5, LOW);
    digitalWrite(led_bar_6, LOW);
    digitalWrite(led_bar_7, LOW);
    digitalWrite(led_bar_8, LOW);

  } else if (elapsedTime % (ledBlinkInterval * 4) < ledBlinkInterval * 3) {
    digitalWrite(led_bar_1, LOW);
    digitalWrite(led_bar_2, LOW);
    digitalWrite(led_bar_3, LOW);
    digitalWrite(led_bar_4, LOW);
    digitalWrite(led_bar_5, HIGH);
    digitalWrite(led_bar_6, HIGH);
    digitalWrite(led_bar_7, LOW);
    digitalWrite(led_bar_8, LOW);

  } else {
    digitalWrite(led_bar_1, LOW);
    digitalWrite(led_bar_2, LOW);
    digitalWrite(led_bar_3, LOW);
    digitalWrite(led_bar_4, LOW);
    digitalWrite(led_bar_5, LOW);
    digitalWrite(led_bar_6, LOW);
    digitalWrite(led_bar_7, HIGH);
    digitalWrite(led_bar_8, HIGH);

  }

  // After 3 seconds, turn on LED bar 6
  if (elapsedTime >= led6Delay && elapsedTime < led6Delay + led5Delay) {
    digitalWrite(led_bar__7, LOW);
    delay(400);
    digitalWrite(led_bar__6, LOW);

  }
```

```
      if (elapsedTime >= led6Delay + led5Delay) {
        digitalWrite(led_bar__5, LOW);

      }

      if (digitalRead(irSensorPin) == LOW) {

        turnOffLedsSequentially();
        ledsOn = false;

      }

      delay(10);
    }

    ledsOn = true;
  }

  delay(100);
}

void detect_planeWithUltrasonic() {

  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);

  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);

  duration = pulseIn(echoPin, HIGH);
  distance = duration * 0.034 / 2;

  Serial.print(" cm | Distance 2: ");
  Serial.println(distance);


  if (distance > 0 && distance < minDistance) {
    plane_Detected = true;
  } else {
    plane_Detected = false;

  }
```

```
}

void turnOffLedsSequentially()
 {
  // Turn off LED bars one after another with a delay
  digitalWrite(led_bar__7, HIGH);
  delay(offDelay);

  digitalWrite(led_bar__6, HIGH);
  delay(offDelay);

  digitalWrite(led_bar__5, HIGH);
  delay(offDelay);

  digitalWrite(led_bar_8, LOW);
  digitalWrite(led_bar_7, LOW);
  delay(offDelay);

  digitalWrite(led_bar_6, LOW);
  digitalWrite(led_bar_5, LOW);
  delay(offDelay);

  digitalWrite(led_bar_4, LOW);
  digitalWrite(led_bar_3, LOW);
  delay(offDelay);

  digitalWrite(led_bar_2, LOW);
  digitalWrite(led_bar_1, LOW);


  digitalWrite(ledPin, HIGH);
  // Wait for 500 milliseconds
  delay(100);

  // Turn the LED off
  digitalWrite(ledPin, LOW);

  delay(100);


}
```

COST ESTIMATION

Nº	Name	Unit Price (Frw)	Nbr	total
01	Arduino Mega 2560	23,000.00	1	**73,800.00**
02	Ultrasonic sensor	4,300.00	1	
03	Infrared sensor	2,500.00	1	
04	Servo motor	3,800.00	1	
05	4 channel relay	6,000.00	1	
06	Leds	100.00	48	
07	10 V adapter	4,000.00	1	
08	5 V adapter	5,000.00	1	
09	Jumper wires	50.00	30	
10	Wire	500.00	5m	
11	Resistor	80.00	30	
12	Plywood + frame	6,000.00	1	
13	Transport + restoration	8,000.00	-	
General total		-	-	**73,800.00 FRW**

Table 6: total budget