RFID-BASED LABORATORY EQUIPMENT USAGE MONITORING SYSTEM

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Bachelor of Science in Electronics Engineering

by:

Engr. Caroline Bautista – Moncada
Alaizah Mae T. Bateg
Esper Joymae F. Dalit
Vanessa R. Dungca
Thomas David G. Eclarino
Eden Hope F. Fianza
Jethro Wilson H. Hangdaan
Gicelle Trizzia C. Paluyo
Akino Brien O. Reyes
Charles Lorbil H. Salamanca

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Saint Louis University
SCHOOL OF ENGINEERING AND ARCHITECTURE
Electronics Engineering Department

INDORSEMENT

This Research entitled "**RFID-BASED LABORATORY EQUIPMENT USAGE MONITORING SYSTEM**", prepared and submitted by Alaizah Mae T. Bateg**,** Esper Joymae F. Dalit**,** Vanessa R. Dungca, Thomas David G. Eclarino**,** Eden Hope F. Fianza**,** Jethro Wilson H. Hangdaan**,** Gicelle Trizzia C. Paluyo**,** Akino Brien O. Reyes**,** Charles Lorbil H. Salamanca**,** in partial fulfilment of the requirement for the degree BACHELOR OF SCIENCE IN ELECTRONICS ENGINEERING has been examined and hereby recommended for final oral defense.

Engr. Caroline Bautista – Moncada
Promoter/Lead Author

Members of the Panel

Engr. Jeffrey Des B. Binwag
Panel Member

Engr. Elaine R. Rivera
Panel Member

Engr. Marie Kathlyn B. De Guzman
Panel Member

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CHAPTER I

THE PROBLEM AND ITS SETTING

This chapter presents the background of the study, the statement of the problem, the scope and delimitation, the research design and methodology, the significance of the study, and the definition of terms used in the study.

BACKGROUND OF THE STUDY

The International Organization for Standardization (ISO) 9000 defines quality management as "coordinated activities to direct and control an organization with regard to quality." This is intimately related to the definition of a quality system- "organizational structure, resources, processes and procedures needed to implement quality management". Equipment management is one of the essential elements of a quality management system. The benefits of a good equipment management program are many: it helps to maintain a high level of equipment performance; lowers repair costs, as fewer repairs will be needed for a well-maintained equipment; lengthens the equipment's life; reduces interruption of services due to breakdowns and failures; increases safety for workers; and produces greater customer satisfaction. Proper management of the equipment is necessary to ensure accurate, reliable, and timely testing (Yahya & Goh, 2001).

In order to achieve the highest level of accuracy and reliability, it is essential to perform all processes and procedures in the best possible way. One of the processes considered in ensuring quality in any organization with equipment is record keeping and inventory. Equipment documents and records which contain histories on all the actions that have been taken on the equipment are an essential part of the quality system (World Health Organization, 2011).

Automated monitoring systems are now becoming a trend in organizations, creating easier methods to identify items, tracking, monitoring and add on security values. In today's growing market many businesses turn toward automated systems to perform their everyday tasks. One automated system that is becoming more popular is the automated inventory and equipment monitoring system using Radio Frequency Identification (RFID) technology.

RFID, which is a "contactless technology" has gained popularity due to its ability to scan multiple devices at a rapid pace, it is user friendly, and has add-on security values, making it a potential replacement for the barcode. During the last decades, the technology of Radio Frequency Identification (RFID) has been widely used for practical functions in various fields like food industries (Tan & Chang, 2010; Ngai, et.al, 2008), animal tracking and livestock monitoring (Vouldimos, et. Al, 2010; Catarinucci, et. al., 2014; Nor Suryani Bakeri, et. Al, 2007; Bolaños, et. al, 2017; Ahmad Rafiq Adenan, et. Al, 2006), customs clearance processes and cargo inventories (Hsu, Shih & Wang, 2009; Zhang, et. Al., 2006), hospital and tourism industry (Öztayşi, Baksan & Akpinar, 2009; Oztekin, et. al., 2010), supply chain management (Yan & Lee, 2009), delivery and logistics (Babar, et. Al., 2013; Bjorninen, et. Al., 2011; ElMahgoub, et. Al., 2010), and in educational facilties (Haron, et. al., 2010; Herdawatie, et. al., 2010).

Most educational institutions and universities around the world employ RFID to control access to buildings. Some universities track assets, such as computers and desks, while others use RFID for attendance taking. Northern Arizona University use RFID student cards for attendance checking for professors with class sizes exceeding 50 students. Qatar University is already employing passive EPC Gen 2 ultrahigh-frequency (UHF) tags and readers to track 30,000 assets across most of the 40 buildings comprising its campus in Doha and plans to extend its use of the technology to track individuals and mail deliveries. The University of East Anglia (UEA) library, in Norfolk, England, has adopted an RFID book-handling system enabling it to automate most of its circulation services. This frees up the library's staff to provide additional research help to students and other patrons.

Researchers at the Hebrew University of Jerusalem's nanotechnology laboratory often work with dangerous gasses and chemicals, and may not have many people with them as they conduct experiments. If an emergency occurs, however, the school has an automated system in place that not only enables an individual to press a panic button and alert emergency personnel, but also determines where that person is located, and displays an image of him or her at that spot. The system employs a combination of active 433 MHz RFID technology and video cameras. Hebrew University uses the solution primarily to provide safety, but also for billing purposes, by tracking who is located at which area within the lab, as well as for how long. By providing an RFID badge to each researcher, student or faculty member who enters the lab, and by installing readers and antennas around the facility, the university can track each person's movements via software designed to forward alerts in the event an emergency. The software also enables the school to view a breakdown of time and place records for every individual in the lab at any given time, for billing purposes (RFID Journal, n.d.).

Over recent years, a number of educational institutions have been adopting a quality process to improve the laboratory inventory management system. The process is to instigate appropriate and effective improvement efforts on laboratories to meet regulatory requirements and monitor functionality and utilization of laboratories. Thus, the drive to create an effective and technologically innovative system for documentation and recordkeeping, ensuring the traceability of laboratory equipment. London's Kingston University is employing Tracker Point's TrackCAB solution to automate its after-hours return process, as well as to conduct inventory counts of 2,000 pieces of laboratory media equipment, such as cameras, laptops and computers, that it loans out to students and faculty. The solution enables borrowers to return goods outside of business hours, by placing items into RFID-enabled lockers, and also reduces the amount of time required for personnel to take inventory of items stored in the equipment stockroom.

Kingston University loans out media equipment to students and faculty members as needed for coursework (RFID Journal, n.d.). Guo, et. al. (2014) at the College of Physics & Electrical and Information Engineering, Shijiazhuang University, China developed a Laboratory Equipment Management System Design Based on RFID to make up for the deficiencies of the traditional bar code technology. This system can implement real-time management of the equipment's check, storage, discharge, distribution and operating and maintenance. The experiment results show that the design of the system is feasible and reliable. The system fits the ISO 18000-6C protocol, and can efficiently improve the laboratory equipment management.

Another group of researchers, Kumbhakarna and Chaudhari (2017) developed a cost-effective, accurate and efficient laboratory inventory management system is using RFID technology as its backbone. The system prevents unmonitored borrowing and provides security to all the inventories, increases management efficiency, and provides the fastest, easiest, most efficient way to record & manage laboratory materials.

In the Philippines, RFID implementation in universities is nothing new. Many universities like Ateneo De Manila, University of the Philippines, and De La Salle University have already adopted the technology for identifying students and tracking of their entry to and exit from school premises. Although numerous researches about RFID technology applications in inventory and equipment have been done, there are only a few researches about the implementation of RFID technology in laboratory equipment monitoring and management.

In 2018, Saint Louis University, Baguio City, one of the Philippines' respected and leading educational institutions in the Philippines (Erasmus Plus Friends Website, n.d.) has deployed an extensive radio frequency identification solution that encompasses student and employee access, asset tracking and library management, all on a single platform. The solution was provided by Image Innovations Services (IIS), using **Portable Technology Solutions** (PTS)'s

ClearStream RFID middleware. The deployment started in the library, but the technology is now tracking individuals' ID badges, as well as asset tags at all campus and parking-lot entrances (RFID Journal, n.d.).

On October 30, 2019, Saint Louis University School of Engineering and Architecture in partnership with the Department of Trade and Industry (DTI) Cordillera Administrative Region Chapter opened a Digital Fabrication Laboratory Shared Services Facility (FabLab) located at the 5th Floor of the Otto Hahn Building of Saint Louis University, which aimed to cater to micro-small-medium enterprises (MSME) and engineering and related sciences students in the region and other academic institutions in Northern Luzon. The FabLab houses a number of machines – a laser engraver and cutter, 3D printers, large scale printers, CNC milling machine, embroidery machine, die cut machine, among others. These machines are used by the faculty, FabLab staff, on-the-job trainees and volunteers.

As a standard procedure in management, it is very crucial to have a record of all the inventories and usage available in laboratory. This is usually done with the help of logbooks and registers. It is a very tedious and lengthy process. Many a times, there is no provision to generate a daily, monthly or even yearly report regarding the usage of inventories and equipment. There are times, when the inventory registers get misplaced and all records gets vanished. There are also times when the equipment usage are not logged because of the time it consumes. Because of all these issues, the system becomes non reliable, insecure and inefficient (Angeles, 2005).

In an interview with Mr. Ferdinand Racuya, a laboratory technician at the Saint Louis University – DTI FabLab, he claims that, currently the practice in laboratories is the use of paper-based record keeping whereby assets and equipment usage are identified manually and the monitoring of laboratory equipment is performed manually by the lab technician during each laboratory session. For every loan or use of equipment, a log book needs to be filled up in order to keep track the transaction information. This system was found to have a lot of weaknesses such as misuse of the equipment log records, losses of equipment, no in-out transaction record and misplace of equipment. The reliance on paperwork and data entry depends on the staff's efficiency. Thus, viewed as a tedious and time-consuming method in monitoring and tracking the laboratory equipment as part of fulfilling the established quality process requirement. According to Mr. Racuya, an automated logging system for equipment usage, will provide a more accurate, efficient and reliable monitoring process of equipment usage in the laboratory.

The need to improve the existing laboratory equipment usage monitoring and management challenged the researchers to propose a project study on the design and construction of an RFID-based laboratory equipment usage monitoring system with the following capabilities: automatic logging of user information and time of usage. The data logged from the system will serve as a baseline for report generation on equipment utilization and maintenance schedules.

STATEMENT OF THE PROBLEM

The main objective of the study was to design and construct an RFID-Based Laboratory Equipment Usage Monitoring System. The researchers aimed to answer the following problems:

1. What electronic principles will be needed in the design and construction of the proposed RFID-Based Laboratory Equipment Usage Monitoring System with the following capabilities:
    a. logging of user information and time of usage,
    b. providing access to the laboratory equipment, and
    c. storing and retrieving data when needed?
2. How will the proposed RFID-Based Laboratory Equipment Usage Monitoring System operate?
3. How will the microcontroller be programmed for the following functions:
    a. logging of user information and time of usage,
    b. providing access to the laboratory equipment, and
    c. storing and retrieving data when needed?
4. What are the testing procedures needed to ensure the proper functionality of the system?
5. What are the installation and maintenance procedures needed to ensure the functionality of the system?

CONCEPTUAL FRAMEWORK / PARADIGM

The researchers followed the input-process-output paradigm as a guide towards the completion of the project study. The Conceptual Framework shows the organization of key concepts essential to the analysis, design, and construction of the RFID-Based Laboratory Equipment Usage Monitoring System.

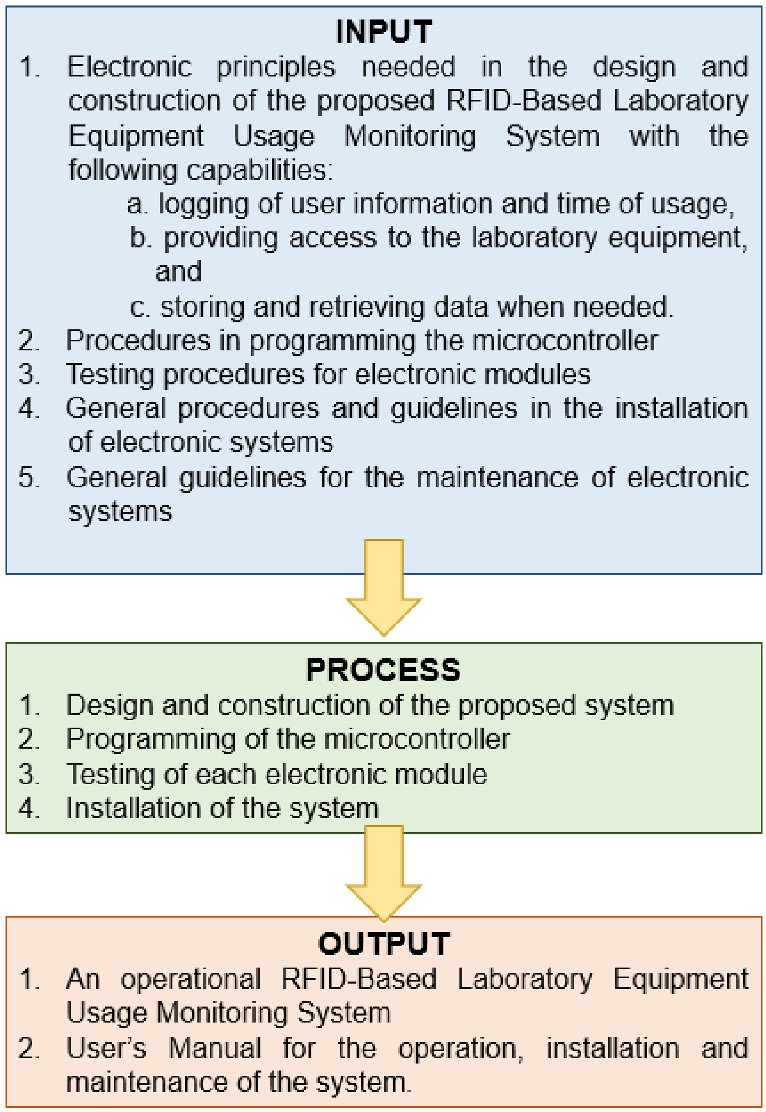


Figure 1. Research Paradigm of the RFID-Based Laboratory Equipment Usage Monitoring System

SCOPE AND DELIMITATIONS

This study focused on the design and construction of an RFID-Based Laboratory Equipment Usage Monitoring System specifically for the SLU-DTI FabLab. For this study, only the SLU-DTI FabLab will be considered because specifications of different machines should be taken into consideration and because of the limited access of students to other facilities due to the constraints of the pandemic. This project was a result of the initial stage of the reverse pitching program of the said facility. Limiting the scope of the project provided the researchers with the ease of constructing and testing the project.

The custodian's office is located on a separate room from the FabLab. Thus, this project was divided into two systems. The first system, which is the logging system will be located in the custodian's office and the second system, the equipment access system will be located on the FabLab where the machines are housed. The Logging System was composed of the RFID module interfaced to the custodian's computer. The graphical user interface (GUI) shown in the computer will allow the custodian to input the user information and generate reports on machine usage. It is in the logging system where information such as user name and FabLab project name will be entered. Reports can be generated as an MS Excel file through Google Sheets. The second system or Equipment Access System was composed of a designated card slot which contains an RFID reader. Each equipment socket has a specified RFID card. Access to the equipment will require the user to properly insert the correct RFID card in the card slot of the equipment to be used.

The researchers constructed one (1) Logging System and three (3) Equipment Access Systems. Three Equipment Access Systems was made initially for the Laser Engraving, CNC Milling machine and 3D Printer. This allowed the researchers to properly install and test the system's efficiency while considering the limited time duration of their research course.

The project study was initially proposed to be conducted over the period of January 2021 to December 2021. However, due to the pandemic restrictions and difficulty in communication, the project study lasted until January 2022. The construction of the hardware and programming of the microcontroller was done separately by assigned group members. Due to the COVID-19 restrictions, the researchers limited face-to-face meetings to do the project together. As for the actual testing of the project, the research promoter was be assigned to test the system in the FabLab.

CONSTRAINTS CONSIDERED IN THE STUDY

The design and construction of the project was guided by the following constraints: the standards in the electronics engineering practice, health and safety, availability of materials, financial constraints, manufacturability constraints, ethical considerations, and parameters concerning the users.

In terms of standards in the electronics engineering field, the Institute of Electrical and Electronics Engineers (IEEE) C95.7-2014 recommended Practice for Radio Frequency Programs is 3kHz to 300 GHz. To comply with this constraint, the system was designed such that the electronic components that have been used are within the safe 3kHz to 300 GHz radio frequencies. The RFID module that was used in the study is designed to create a 13.56MHz electromagnetic field as it communicates with the RFID tags. The RFID tags comply with ISO/IEC 14443 standard for contactless smart card communication.

In terms of health and safety constraints, the Philippine Electrical Code, more particularly sections of IEC 60364-1 from sections 131.2 to 131.7 provided requirements that were intended to ensure the safety of persons, livestock and property against dangers and damage which may arise in the reasonable use of electrical installations. This code contains provisions that will be considered minimum requirements necessary for safety. Also, the Institute of Electrical and Electronics Engineers (IEEE) C95.6-2002 Standard for Safety Levels with respect to human exposure to electromagnetic fields is 0 to 3 KHz. Compliance therewith and proper maintenance will result in an installation that will essentially be free from hazard. To comply with the aforementioned constraints, the system was designed such that the electronic components that was used were within the safe 0 to 3 KHz electromagnetic field operations. Furthermore, the researchers ensured that the electronic components used in the project did not involve risk of power surge, pointy tips/objects that may penetrate the skin of the subject.

Because of the COVID-19 pandemic restrictions, the availability of electronic components and other materials was limited. The researchers designed the system with electronic components that were purchased online. Financial constraints were also considered in the study. Considering the pandemic conditions, the researchers had limited budget for the construction of the hardware of the system.

In terms of economic constraints, the aim of this project was to minimize the complexity of the design in order to reduce the effective cost to the researchers. These costs mainly consisted of out-of-pocket expense and time spent in assembly. The fewer chips in the design, the less likelihood there is to be breakage during the assembly. The researchers coordinated with the FabLab team so that specifications will be considered in the design of the system to ensure that there would be less time expended troubleshooting a faulty circuit. The electronic components and devices used in the project were carefully chosen to give acceptable results while maintaining a low budget. The line item budget presented in Table 12 shows the actual cost in the design of the proposed project.

Environmental constraints of this project design were addressed with respect to the waste which the system produces. The intent is to minimize power consumption of this design. The researchers aimed to make the project as green as possible, by incorporating lower power parts.

Sustainability of the project design was considered with respect to future design modifications. Limiting the complexity of the design also facilitates sustainability. Minimizing the assembly required by reducing the number of parts will reduce the probability of a discontinued part. The reduction leads to less of a need for troubleshooting the system. The researchers also considered locally available parts to facilitate the changing of parts when these parts will have to be replaced in the future due to wear and tear. Also, the simpler the design, the easier it will be to find a new part if the design becomes obsolete. Furthermore, sustainability of the project also includes the perception of the users of the project of their ability to retain the project's usability even after the period of external assistance from the researchers has ended. The researchers ensured that the project was user-friendly and that adequate information will be provided to them through a user's manual should they wish to adopt the system.

Constraints in manufacturability was considered with respect to assembly. The design was to have a level of simplicity that the researchers can put together with the time available while providing an effective learning experience.

These standards and constraints were observed in the entire duration of the research and project construction.

SIGNIFICANCE OF THE STUDY

The system serves to revolutionize tracking and monitoring of laboratory equipment usage in an automated manner; as a practical solution to the continuous quality improvement effort on inventory control and management of laboratories. This study is a response to the FabLab's need for more efficient, accurate and timely reports on equipment usage and monitoring. The study and its output will benefit the FabLab initially which may also be adopted to other laboratories in the University.

In terms of the Student Outcomes, the researchers, through this project study, would be able to manifest the following:

SO4: work effectively as a member and leader in multi-disciplinary and multi-cultural teams;

SO5: formulate and solve engineering problems;

SO6: act in accordance with professional, social and ethical responsibility;

SO7: apply an in-depth understanding of the impact of engineering solutions in a global, economic, environmental, and societal context;

SO8: communicate effectively in written and oral forms using both English and Filipino as well as in graphical forms; and

SO16: demonstrate the knowledge and understanding of engineering and management principles as a member and leader in a team, to manage projects and in multidisciplinary environments

The process of design, construction, and testing of this project serves as a learning tool for the researchers. They would be able to develop and apply the electronic principles they learned as they pursue to complete the BSECE curriculum requirements. This study is also significant to them as it will serve as their contribution in providing an electronics engineering solution to address the needs of the laboratory management staff.

This study may find further applications in other academic laboratories, libraries, medical supplies and equipment storage areas and more. This study may be used by future researchers who would want to innovate this study and develop new research studies related to this topic. They can use this study as their reference.

OPERATIONAL DEFINITION OF TERMS

This section defines salient terms as to how they were used in the study:

Equipment Usage. Equipment usage, sometimes referred to as equipment utilization, is a measurement of the use and performance of any machinery, which assists to improve productivity and reduce the cost of equipment rental and project delays (Houshyar, 2004).

Fabrication Laboratory (FabLab). A FabLab is a small-scale workshop offering digital fabrication, typically equipped with an array of flexible computer-controlled equipment that cover several different length scales and various materials, with the aim to make "almost anything" (Troxler, 2016). As used in this study, the FabLab will specifically mean the SLU DTI FabLab Shared Services Facility.

Laboratory. A laboratory is a facility that provides controlled conditions in which scientific or technological research, experiments, and measurement may be performed (Bertholf, 2017). As used in this study, the laboratory will be referred to as FabLab.

Monitoring System. A monitoring system is software that helps system administrators monitor their infrastructure (Olagunju, Adeniyi & Oladele, 2018).

Radio Frequency Identification (RFID). It is a way to identify a person/object using radio frequency transmission. An RFID system includes tags, readers, and an application system (Xiao, et. al., 2007).

RFID-Based Laboratory Equipment Usage Monitoring System. It is a device that automatically logs the equipment usage information, provides access to laboratory equipment and stores this information for recording and monitoring purposes.

CHAPTER II

REVIEW OF RELATED LITERATURE

This chapter presents a discussion on fundamental electronics engineering concepts as well as related literature that aided the researchers in the design and construction of the RFID-Based Laboratory Equipment Usage Monitoring System. The order of presentation of the topics is based on the inputs in the research paradigm.

Concepts needed for the operation of the RFID-Based Laboratory Equipment Usage Monitoring System

The succeeding section gives a discussion on the concepts and principles needed for the design and construction of the RFID-Based Laboratory Equipment Usage Monitoring System.

Capturing Information

With the advancement of technology, capturing pertinent information can already be done through various automated data capture solutions. These solutions reduce the amount of manual data entry required, reducing costs, and speeding content into the designated organizational processes. The available automated data capture solutions vary in terms of accuracy, complexity, and cost. With the development of information technology, some universities have replaced the barcodes with RFID tags for equipment management. The RFID support system performs a fast scan to simultaneously identify and read multiple (Zhu & Hou, 2020). For this study a low cost and considerably reliable RFID technology will be used.

Radio Frequency Identification

RFID is an acronym for “radio-frequency identification” and refers to a technology whereby digital data encoded in RFID tags or smart labels are captured by a reader via radio waves.

RFID belongs to a group of technologies referred to as Automatic Identification and Data Capture (AIDC). AIDC methods automatically identify objects, collect data about them, and enter those data directly into computer systems with little or no human intervention. RFID methods utilize radio waves to accomplish this. At a simple level, RFID systems consist of three components: an RFID tag or smart label, an RFID reader, and an antenna. RFID tags contain an integrated circuit and an antenna, which are used to transmit data to the RFID reader (also called an interrogator). The reader then converts the radio waves to a more usable form of data. Information collected from the tags is then transferred through a communications interface to a host computer system, where the data can be stored in a database and analyzed at a later time (Xiao, et. al., 2007).

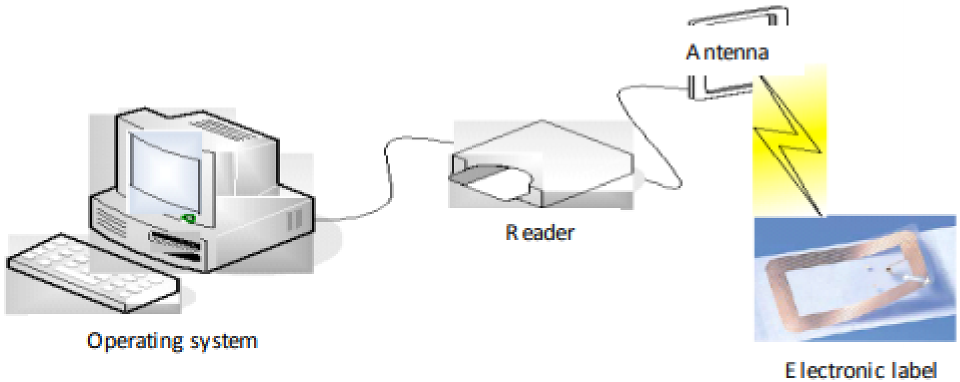


Figure 2. A Simple RFID System

The following are the advantages and disadvantages of RFID systems:

- RFID tag does not require to be in the line of sight to be scanned.
- Can store more information.
- RFID tags are used for tracking as well as for monitoring the health history of patients in the hospitals.
- RFID can be “read-only” as well as “write/read” unlike barcodes
- Used for attendance purposes. The time-in and time-out are recorded in the database of the server. Disadvantages
- Active RFID is costly due to the use of batteries.
- RFID devices need to be programmed which requires enough time.
- The external electromagnetic interference can limit the RFID remote reading.

RFID Tag

An RFID tag consists of an integrated circuit and an antenna. The tag is also composed of a protective material that holds the pieces together and shields them from various environmental conditions. The protective material depends on the application. For example, employee ID badges containing RFID tags are typically made from durable plastic, and the tag is embedded between the layers of plastic. RFID tags come in a variety of shapes and sizes and are either passive or active. Passive tags are the most widely used, as they are smaller and less expensive to implement. Passive tags must be "powered up" by the RFID reader before they can transmit data. Unlike passive tags, active RFID tags have an onboard power supply (e.g., a battery), thereby enabling them to transmit data at all times. RFID tags are classified into Active RFID tags and Passive RFID tags. Passive RFID tag Passive RFID tags consist of three elements: an integrated circuit or chip, an antenna, and a substrate. The RFID chip stores data and performs specific tasks. Depending on its design, the chip may be read-only (RO), write-once, readmany (WORM), or read-write (RW). Typically, RFID chips carry 96 bits of memory but can range from 2-1000 bits, attached to the chip is the second component, the antenna, whose purpose is to absorb radio-frequency (RF) waves from the reader's signal and to send and receive data. Passive RFID tag performance is strongly dependent on the antenna's size: the larger the antenna, the more energy it can collect and then send back out. Larger antennas, therefore, have higher read ranges (although not as high as those of active tags). Antenna shape is also important to the performance of the tag. Low- and high-frequency (LF and HF, respectively) antennas are usually coils because these frequencies are predominantly magnetic in nature. Ultrahigh-frequency (UHF) antennas, on the other hand, look similar to oldfashioned TV antennas (“rabbit ears”) because ultrahigh frequencies are solely electric in nature, and the third component of a passive RFID tag is called a substrate, which is commonly a Mylar or plastic film. Both the antenna and the chip are attached to the substrate, which may be thought of as the “glue” that holds all of the tag’s pieces together.

MIFARE 13.56 Mhz tag

This is a basic RFID tag that functions within the MIFARE Classic® 1K guidelines. That can be used for all sorts of identification and sensing applications. The tag also has 1K of data storage which can be read and written from a compatible device. The MIFARE Classic® card is fundamentally just a memory storage device, where the memory is divided into segments and blocks with simple security mechanisms for access control. They are ASIC based and have limited computational power. Due to its reliability and low cost, these tags are widely used for electronic wallet, access control, corporate ID cards, transportation or stadium ticketing (Capurso, n.d).

RFID Tags

Tags/transponders vary in size and shape, and often look like small portions of paper on which metal patterns are printed. A tag is composed of an antenna and maybe a silicon chip, usually only containing small portions of information, while some tags can contain up to 1024 bits of information (Boss, 2003). A tag’s size ranges from the size of a grain of rice to two-inch squares [8]. RFID tags are easy to hide, for example, in the seams of clothes, between layers of cardboards, in plastic or rubber, and in consumer package design (Cavoukian, 2004; Boone & Whalen, 2003). New RFID tags can be produced as small as tiny coded beads invisible to human eyes, and can be embedded in inks, currency, automobile paint, exploisive, etc. (Cavoukian, 2004). Some tags are bendable and even capable of being torn without suffering data loss or transmission capabilities. Tags cannot sense the presence of other tags and therefore, an anti-collision algorithm is needed to reduce collision among tags. Tags can be classified into chipless tags and chip tags, and can also be classified into passive tags and active tags.

RFID Readers

Readers are devices that read/interrogate tags, and each reader is equipped with antennas, a transceiver, and a processor. In other words, a reader is an electronic component that is capable of communicating with tags and supplying energy to them. The antennas are used for sending/receiving radio signals, and the transceiver and the processor are used to encode/decode data. Readers normally look like circuit boards or handheld scanning devices, and are sometimes mounted in locations where they strategically sense tags. Handheld readers are mobile devices used for, for example, inventory or warehouse. During interrogating tags, a reader receives a tag’s radio transmission, performs error checking, and communicates with an application system. Readers also provide power to passive tags by transmitting an energy field to wake up passive tags, powering chips, and enabling them to transmit/store data. Examples of readers include retailer self check-outs, library book sensors, security exit sensors, sorters, and portable sensors. A reader has a finite range called interrogation zone, and the size of the zone depends on applications. Passive tags, relying on outside power have weak signals so that they have smaller interrogation zones, whereas active tags have larger interrogation zones. A reader must be able to read multiple tags within its range. Most readers have difficulty of interrogating tags in the presence of other readers, especially when mobile handheld readers are moving close to other readers.

RFID in Monitoring

RFID is a wireless automatic identification that is gaining attention and is considered by some to emerge as one of the pervasive computing technologies in history (Robert, 2006). As the technology grows very rapidly, RFID has received considerable worldwide attention and widely used in monitoring and tracking ranging from human identification to product identification. Previous research has successfully indicated that RFID has been increasingly expanded in various fields such as retail supply chain, asset tracking, postal and courier services, education, construction industry, medical, and etc.

The work presented by Tan and Chang (2010) who had developed an RFID-based e-restaurant system to change the traditional restaurant services which is considered as passive. The utilization of RFID is to improve the service quality which is customer-centered that enable waiters to immediately identify customers via their own RFID-based membership card. It can also provide customized services such as enhanced dining table service; pay the bills, instant transmission of customer orders to kitchens and flexibility of managing payments of bills and discounts. However, in Ngai et. al. (2008), designed and developed RFID-based sushi management system to help a conveyor belt sushi restaurant to achieve better inventory control, responsive replenishment, and food safety control, as well as to improve its quality of service.

In the perspective of animal tracking or livestock monitoring management system, Vouldimos et. al. (2010) developed FARMA project which combined with RFID technology and mobile wireless networking to track animal and the data in repository which contains animal data records. The purposes of the system are to identify animal in case it gets lost and identify some basic information about particular animals. A similar work done by Nor Suryani Bakeri et. al. (2007) and Ahmad Rafiq Adenan et. al. (2006) developed a livestock monitoring system using RFID. An RFID tag is used and attached to each livestock to monitor its movement in and out as well as the basic information about any particular animals.

The use of RFID also could assist in customs clearance process by reducing the delay time. According to Hsu, Shih and Wang (2009), the use of RFID can improve the efficiency of cargo process, and reduce the inventory and labor cost. The work presented based on the mathematical model of the customs clearance process-delay and the network of customs delay is reconstructed based on the use of RFID. RFID also has been successfully applied in global postal and courier services in monitoring the parcel delivery. One of the well known courier service company is DHL which has been using RFID in their services since 1988 and carried out 20 trials on active and passive technology and successfully proved it improved the service and reduce the costs (EPC Global, 2005). The application of RFID in global market in postal and courier services contribute 650 billion per year and Europe was the leader in utilizing RFID in postal and courier services (Zhang, et. al., 2006).

High quality service lead to customer satisfaction, increase market share, and enhance profitability of service organizations. Oztaysi, Baysan, and Akpinar (2009) have done a study to investigate the possibility of using RFID as a tool for improving service quality in hospitality industry and primarily concern in tourism industry. In monitoring of asset tracking, an effective and efficient managing the tracking of medical assets in healthcare facilities can be performed by the means of RFID. Oztekin et. al. (2010) has done a study using enhanced maximal covering location problem along with critical index analysis metric to optimize the design of a medical-asset tracking system constrained by a limited number of RFID readers. Results indicate that the proposed technique has improved by 72% compared to the currently utilized expert placement strategy.

Yan and Lee (2009) developed RFID application in Cold Chain monitoring system to track the cold-chain product flowing in supply chain, ensure the products’ quality and comply with relevant provisions during transportation. The system executes in real-time environment and can track the location and monitor the temperature of cold-chain products to ensure the quality. However, according to Loebbecke (2005) has done a research regarding the application of RFID in retail supply chain at a brink-and-mortar supermarket to investigate the advantages and challenges with the early RFID applications in terms of technological issue such as standardization, challenges on the data, network and application layers. Haron, et. al. (2010), designed and developed of a context aware notification system for university students using RFID. The system aims to deliver urgent notifications to the intended students immediately at their respective locations. A quite similar work done by Herdawatie et. al. (2010) which integrates RFID and biometric sensor to track students in a boarding school of their location at the selected restricted area.

Researcher's Notes:

Based on the successful of RFID applications in various fields as discussed above, it shows that its application is endless. This section onwards explains the RFID application in tracking of laboratory equipment movement to ensure its availability. It also aims at helping the lab administrator in monitoring the equipment from lost or misplaced. Because of these numerous applications, the researchers decided to the use of RFID instead of barcodes for the design of the project.

Minimum Hardware Requirements for the Construction of the RFID-Based Laboratory Equipment Usage Monitoring System

This part of the chapter presents the related literature for the minimum hardware requirements for the construction of the RFID-Based Laboratory Equipment Usage Monitoring System and a brief description of how each hardware works.

A. RFID Module

The researchers will use the RC522 RFID Module, a 13.56MHz RFID module based on the MFRC522 controller from NXP semiconductors. The module can support I2C, SPI, and UART and normally is shipped with an RFID card and key fob. It is commonly used in attendance systems and other people/object identification applications

Figure 3. RC522 RFID Module

Table 1 shows the specifications that the researchers used in designing the information logger as a part of the system to meet the minimum hardware requirement in programming the complete system.

Table 1. RFID-RC522 Specification

Input voltage	*DC 3.3V*
Working current	*13mA to 26mA*
Standby current	*10mA to 13mA*
Sleeping current	*< 80uA*
Peak current	*< 30mA*
Working frequency	*13.56MHz*
Card reading distance	*0mm to 30mm*
Dimension	*40mm x 60mm*

Source: RFID CARD READER MODULE RC522. (n.d.). Retrieved from Mybotic: https://www.mybotic.com

An RFID system normally works as follows:

A reader sends out a signal via a radio frequency;

All tags are tuned to the reader's radio frequency and receive the signal with their antennas;

Selected tags transmit their stored data;

The reader receives the tag's signal with its antenna and decodes it;

The reader transfers the data to the application system;

B. Arduino Uno Microcontroller

Arduino is an open-source platform used for building electronics projects. Arduino consists of both a physical programmable circuit board (often referred to as a microcontroller) and a piece of software, or IDE (Integrated Development Environment) that runs on the computer, used to write and upload computer code to the physical board. The Arduino platform has become quite popular with people just starting out with electronics, and for good reason. Arduino does not need a separate piece of hardware (called a programmer) to load new code onto the board -- and use a USB cable. Additionally, the Arduino IDE uses a simplified version of C++, making it easier to learn to program. Finally, Arduino provides a standard form factor that breaks out the functions of the micro-controller into a more accessible package. (BEN, n.d.) The researchers will use the Arduino Uno Microcontroller as part of the system to meet the minimum hardware requirement in programming the complete system.

Figure 4. Arduino Uno Microcontroller

The Arduino Uno board is a microcontroller based on the ATmega328. There are 14 digital input/output pins, 6 can be used as PWM output, 16MHz ceramic resonator, ICSP header, USB connection, 6 analog inputs, power jack and reset button. This includes all the support required for a microcontroller. The Arduino Board can be simply connected to a computer using a USB cable or AC-DC adapter or battery. The Arduino Uno Board is different from all other boards and does not use the FTDI USB-serial driver chip. Features Atmega16U2 (Atmega8U2 ~ version R2) programmed with USB-serial converter. The Arduino Uno board is a microcontroller based on the ATmega328. There are 14 digital input/output pins, 6 can be used as PWM output, 16MHz ceramic resonator, ICSP header, USB connection, 6 analog inputs, power jack and reset button. This includes all the support required for a microcontroller.

Table 2 shows The Specifications of the Arduino Uno Board. It shows the size and functionality that satisfies the desired characteristics of the project.

Table 2. Arduino Uno Specifications

Microcontroller	*ATmega328P- 8 bit AVR family microcontroller*
Operating Voltage	*5V*
Recommended Input Voltage	*7-12V*
Input Voltage Limits	*6-20V*
Analog Input Pins	*6 (A0 – A5)*
Digital I/O Pins	*14 (Out of which 6 provide PWM output)*
DC Current on I/O Pins	*40 mA*
DC Current on 3.3V Pin	*50 mA*
Flash Memory	*32 KB (0.5 KB is used for Bootloader)*
SRAM	*2 KB*
EEPROM	*1 KB*
Frequency (Clock Speed)	*16 MHz*

Source: Arduino Uno. (2018, February 28). Retrieved from Components 101: https://components101.com/

C. Arduino Nano Microcontroller

The Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3.0) or ATmega168 (Arduino Nano 2.x). It has more or less the same functionality of the Arduino Duemilanove, but in a different package. It lacks only a DC power jack, and works with a Mini-B USB cable instead of a standard one.

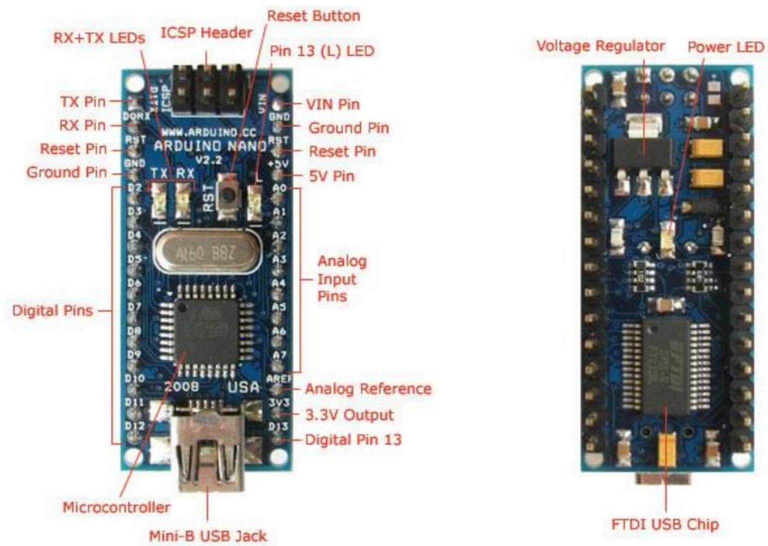


Figure 5. Arduino Nano Microcontroller

Table 3. Arduino Nano Specifications

Microcontroller	ATmega328
Architecture	AVR
Operating Voltage	5 V
Flash Memory	32 KB of which 2 KB used by bootloader
SRAM	2 KB
Clock Speed	16 MHz
Analog IN Pins	8
EEPROM	1 KB
DC Current per I/O Pins	40 mA (I/O Pins)
Input Voltage	7-12 V
Digital I/O Pins	22 (6 of which are PWM)
PWM Output	6
Power Consumption	19 mA
PCB Size	18 x 45 mm
Weight	7 g

Source: Arduino Nano https://www.arduino.cc/en/pmwiki.php?n=Main/ArduinoBoardNano

D. Light Emitting Diodes (LEDs)

A light-emitting diode (LED) is a semiconductor device that emits visible light when an electric current passes through it. The light is not particularly bright, but in most LEDs it is monochromatic, occurring at a single wavelength. The output from an LED can range from red (at a wavelength of approximately 700 nanometers) to blue-violet (about 400 nanometers). Some LEDs emit infrared (IR) energy (830 nanometers or longer); such a device is known as an *infrared-emitting diode* (IRED).

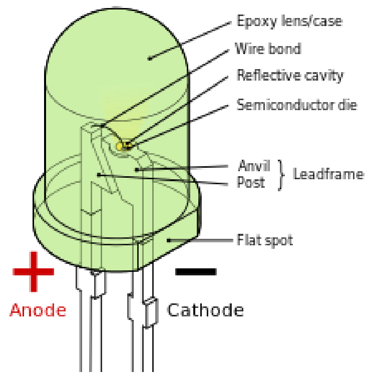


Figure 6. A Light Emitting Diode

When a Light Emitting Diode (LED) is forward biased, free electrons in the conduction band recombines with the holes in the valence band and releases energy in the form of light.

The process of emitting light in response to the strong electric field or flow of electric current is called electroluminescence. A normal p-n junction diode allows electric current only in one direction. It allows electric current when forward biased and does not allow electric current when reverse biased. Thus, normal p-n junction diode operates only in forward bias condition.

Like the normal p-n junction diodes, LEDs also operate only in forward bias condition. To create an LED, the n-type material should be connected to the negative terminal of the battery and p-type material should be connected to the positive terminal of the battery. In other words, the n-type material should be negatively charged and the p-type material should be positively charged.

The construction of LED is similar to the normal p-n junction diode except that gallium, phosphorus and arsenic materials are used for construction instead of silicon or germanium materials.

In normal p-n junction diodes, silicon is most widely used because it is less sensitive to the temperature. Also, it allows electric current efficiently without any damage. In some cases, germanium is used for constructing diodes. However, silicon or germanium diodes do not emit energy in the form of light. Instead, they emit energy in the form of heat. Thus, silicon or germanium is not used for constructing LEDs.

Light emitting diode (LED) symbol

The symbol of LED is similar to the normal p-n junction diode except that it contains arrows pointing away from the diode indicating that light is being emitted by the diode.

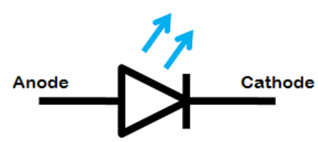


Figure 7. The Schematic Symbol for an LED

LEDs are available in different colors. The most common colors of LEDs are orange, yellow, green and red. The schematic symbol of LED does not represent the color of light. The schematic symbol is same for all colors of LEDs. Hence, it is not possible to identify the color of LED by seeing its symbol.

Output characteristics of LED

The amount of output light emitted by the LED is directly proportional to the amount of forward current flowing through the LED. More the forward current, the greater is the emitted output light. The graph of forward current vs output light is shown in the figure.

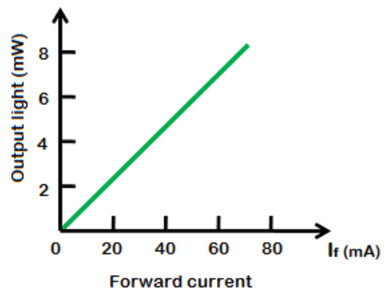


Figure 8. Forward Current vs. Output Light of an LED

Advantages of LED

1. The brightness of light emitted by LED is depends on the current flowing through the LED. Hence, the brightness of LED can be easily controlled by varying the current. This makes possible to operate LED displays under different ambient lighting conditions.
2. Light emitting diodes consume low energy.
3. LEDs are very cheap and readily available.
4. LEDs are light in weight.
5. Smaller size.
6. LEDs have longer lifetime.
7. LEDs operate very fast. They can be turned on and off in very less time.
8. LEDs do not contain toxic material like mercury which is used in fluorescent lamps.
9. LEDs can emit different colors of light.

Disadvantages of LED

1. LEDs need more power to operate than normal p-n junction diodes.
2. Luminous efficiency of LEDs is low.

E. 5 leg SPDT 5VDC power relay

A power relay is an electronic component that uses an electromagnet to open or close a circuit when the coil is correctly excited. They provide a high level of isolation between the control signal (coil) and the output (contacts) A power relay may have both normally open (NO) and normally closed (NC) contacts or just normally open (NO) contacts. Power relays are reliable and efficient when it comes to switching high currents.

Figure 9. A 5 Leg SPDT 5VDC Power Relay

Table 4. 5 Leg SPDT 5VDC Power Relay Specifications

Contacts configuration	SPDT
Rated coil voltage	5V DC
AC contacts rating @R (at resistive load)	10A / 120V AC
DC contacts rating @R (at resistive load)	10A / 24V DC
Contact current max.	10A
Switched voltage	max. 100V DC, max. 240V AC

Source: https://www.tme.com/ph/en/details/leg-5/miniature-electromagnetic-relays/recoy-rayex-electronics/

F. 5V TWO OUTPUT CHARGER MODULE

A Power Supply Unit (PSU) is a vital part in any electronic product design. Most household electronic products like Mobile Chargers, Bluetooth Speakers, Power Banks, Smart Watches etc require a Power Supply circuit that could convert the AC main supply to 5V DC to operate them.

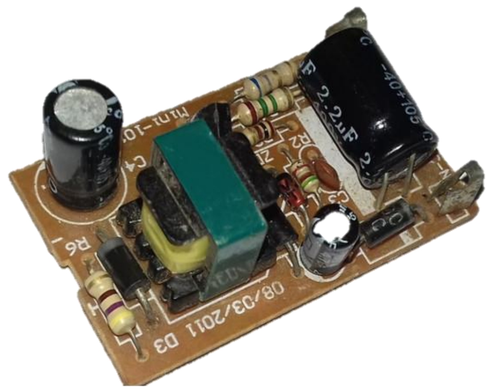


Figure 10. A 5V Two Output Charger Module

Table 5. 5V Two Output Charger Module Specifications

Output rating	5V / 3.1 A
Input AC Voltage Rating	100 – 240V
Frequency	50/60 Hz

Source: https://circuitdigest.com/electronic-circuits/5v-2a-smps-power-supply-circuit-diagram

G. 5V MODULE RELAY

A relay is a programmable electrical switch, which can be controlled by an Arduino or any other microcontroller. It is used to control on/off devices according to how it was programmed. The 5V module can work with high voltages and/or high current. It is used as a bridge between the microcontroller and high voltage devices. The relay used as a switching device can work with two modes: normally closed and normally open.

Figure 11. A 5V Module Relay

Table 6. 5V Module Relay Specifications

Output Voltage	5VDC
Maximum Input Voltage rating	250VAC / 10 A

Source: https://arduinogetstarted.com/tutorials/arduino-relay

PROGRAMMING OF THE ARDUINO UNO AND NANO MICROCONTROLLER

A. Arduino IDE

Microcontrollers are typically programmed in higher-level languages such as C++ or Java. One of the essential tools needed to program a microcontroller is an integrated development environment (IDE). The open-source Arduino Software (IDE) makes it easy to write code and upload it to the board. It runs Windows, Mac OS X, and Linux. The environment is written in Java and based of Processing and other open-source software.

This software is usually developed by the creators of the microcontroller and contains useful tools to help a person program the microcontroller. Common tools found in IDE's include code editors, compilers, and debuggers. Depending on the application of the microcontrollers, additional features may be added as well. Once a suitable IDE is obtained, the user can begin writing code. For explanatory purposes, this guide shows an example of the Arduino IDE in use. Below is an example of a simple Arduino program that makes an LED blink on and off at a frequency of 1Hz. The code is split into 4 different sections as follows:

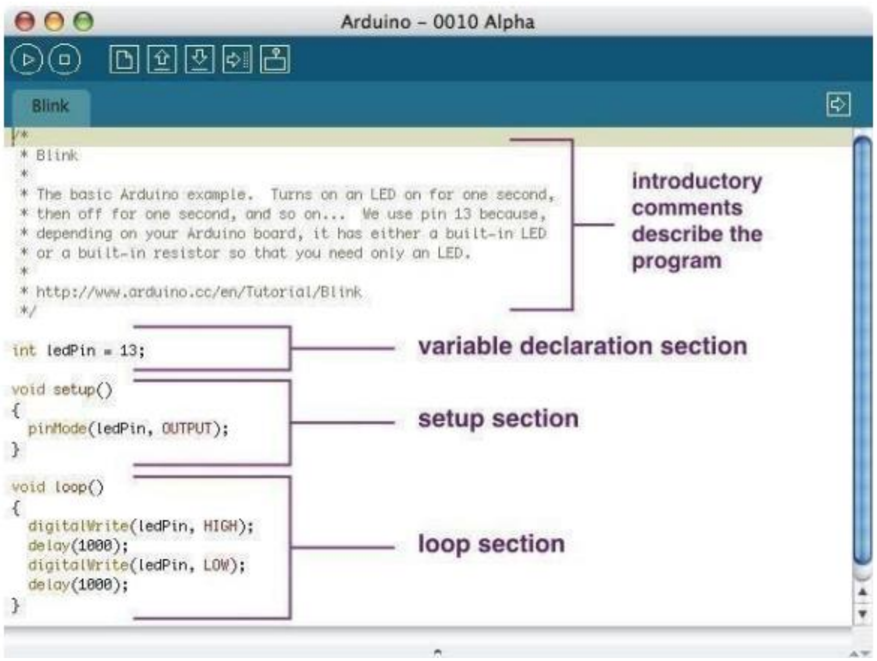


Figure 12. Arduino IDE

It is a generally accepted practice to start any code with a comment section containing a general description of what the code/program does. While this section has no effect on the program's functionality, it is always a good idea to document it for future reference. User instructions, company, and copyright information are also commonly placed here as well.

The second section is the Variable decoration. These variables are global and can be called in any sections that follow. It is also common to create variables to describe each pin's function and set them equal to the pin number on the board to make coding more intuitive.

Thirdly, is the “Void Setup()” section. Digital pins on microcontrollers are commonly used as inputs or outputs, but very rarely can they be both. In this section, the user defines which pins are inputs or outputs, as well as any other parameters that must be initialized. While the method of doing so varies for different microcontrollers, almost all of them require a similar step to configure the microcontroller's internal circuitry to fit the needs of the design. Lastly, the "Void Loop()" section. This section is where the function of the microcontroller is written. Any actions that require reading or writing values from pins, or computing the values of different variables is done here.

Compiling and Uploading to the Arduino Microcontroller

This step is almost always handled by the IDE. Once the code is written, it must be uploaded to the microcontrollers. Most have USB interfaces, but some smaller microcontrollers require special hardware to be programmed. Typically, microcontrollers are programmed in higher-level languages, the microcontroller itself runs on assembly. To translate code to a format usable by a microcontroller, a compiler must be used. A compiler is a software tool that takes higher-level code and optimizes it for assembly. Assembly provides specific instructions to the microcontroller on what register operations to perform to match the operation of the original code. Once the assembly code is created, it can be uploaded to the microcontroller for testing (Foxworth,n.d.).

B. Visual Studio IDE

Microsoft Visual Studio 2015 is a suite of tools for creating software, from the planning phase through UI design, coding, testing, debugging, analyzing code quality and performance, deploying to customers, and gathering telemetry on usage. These tools are designed to work together as seamlessly as possible, and are all exposed through the Visual Studio Integrated Development Environment (IDE). Microsoft Visual Studio is an integrated development environment (IDE) from Microsoft. It can be used to develop console and graphical user interface applications along with Windows Forms applications, web sites, web applications, and web services in both native code together with managed code for all platforms supported by Microsoft Windows, Windows Phone, Windows CE, .NET Framework, .NET Compact Framework and Microsoft Silverlight.

The Visual Studio product family shares a single integrated development environment (IDE) that is composed of several elements: The Menu bar, Standard toolbar, various tool windows docked or auto-hidden on the left, bottom, and right sides, as well as the editor space. The tool windows, menus, and toolbars available depend on the type of project or file the user is working in. Figure 13 shows the Visual Studio IDE.

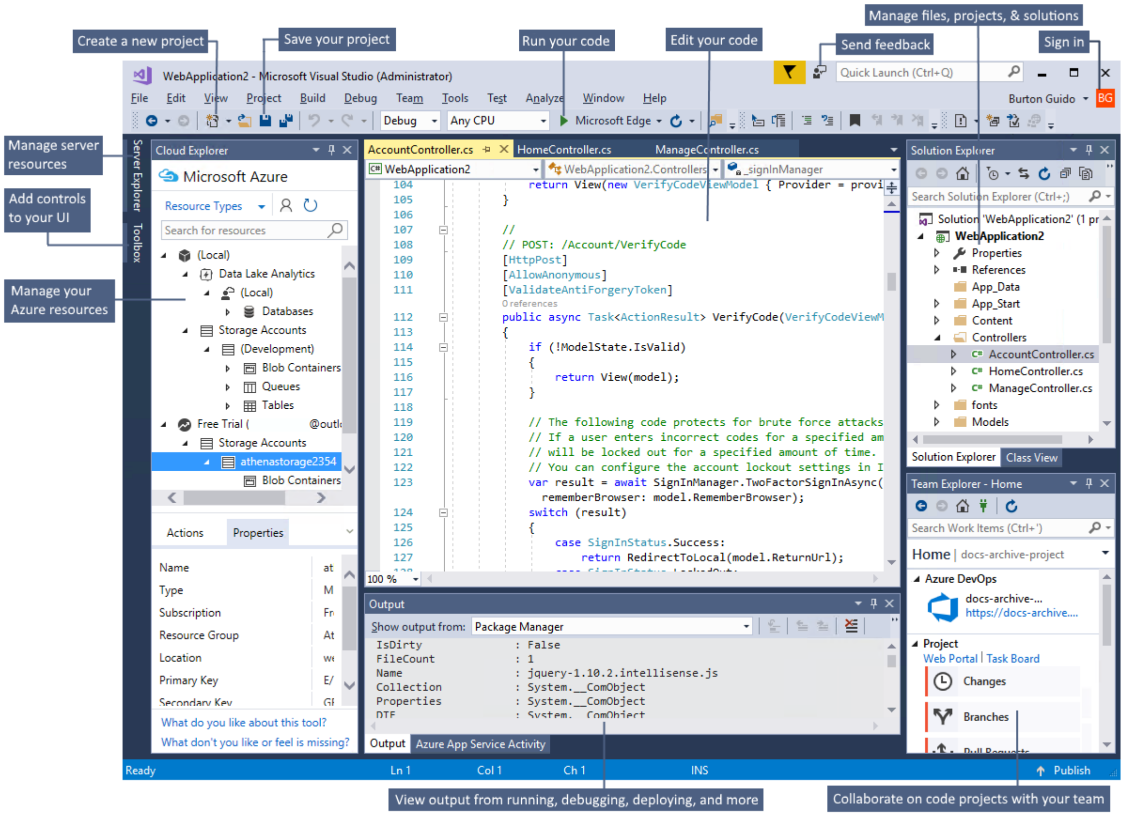


Figure 13. Visual Studio IDE

The Visual Studio uses the C# programming language. C# is a modern Object-oriented programming language. Object-oriented programming (OOP) is a programming paradigm using "objects" – data structures consisting of data fields and methods together with their interactions – to design applications and computer programs. Programming techniques may include features such as data abstraction, encapsulation, messaging, modularity, polymorphism, and inheritance.

TESTING PROCEDURES FOR AN ELECTRONIC EQUIPMENT

The counterpoint to a specification is a test procedure. With a specification and an incoming test procedure, a client can have assurance that he gets what he orders. Testing procedures are essential in determining that the system functions properly and safely. These ensure that the system operation runs smoothly and thus, be able to achieve the desired output. Testing procedures are to be done to identify the correctness of measured quantities, completeness and quality of the output.

To determine if the system is fully functional and safe, testing procedures are essential. Several tests were needed to ensure the accuracy of the project, thus improving the project’s capability of giving the desired output.

Incoming Test procedure

The incoming test procedure will normally start with the specification of the product and test that the specified features are actually delivered. This testing may be a repeat of part of the overall functional test procedure carried out by Design engineer. Handover should be used as an opportunity for the designer to demonstrate the prototype to the client, ticking off as many of the Incoming test procedure items as possible, and covering the remainder verbally.

The incoming test procedure has different objectives from the debug test procedure - its aim is to prove that the design meets the specification. Overall tests are usually good for this objective. The debug test procedure is attempting to isolate any faults in the design. This requires testing by section and thorough characterization of the design rather than just meet spec/miss spec results. The key is to minimize the impact - have a workaround, or a fix in progress, or at least have documented how and why the target was missed.

RFID Detection Test

After the design phase is complete, the system has to be tested, implemented, and retested. The hardware test includes an analysis of read rates. Any “miss conditions” should be studied and avoided. For example, in a “class attendance” type of implementation, students were each given an RFID tag, which was picked up by a reader when they walked into the classroom. The reader did not miss many tags except when the students had placed the tags next to their calculators or laptops. They were therefore instructed not to do so to ensure reliable attendance.

Software Testing includes things like debugging the code, giving feedback to the design team. Failure accelerated tests should be run on the system to test its reliability. The speed of computation should be optimized. Another important test parameter is that the new software should not interfere with any existing enterprise software. Once this independent testing of hardware and software is complete, the complete system should be implemented and tested. System testing should include aspects like “problems in integration”, “network traffic analysis and congestion control”, “identification and removal of data ambiguity”. Another important test domain is “data security and integrity”. Based on these tests, feedback should be given to the design team.

Arduino Board Test

This testing procedure is necessary to ensure that the microcontroller is properly working. To do so, first, connect the Arduino Board to the PC/Laptop using its cable, this powers up the Arduino. Install its corresponding driver. In some cases, the driver automatically installs after connecting the Arduino Board to the PC/Laptop. After the driver installation, open the Arduino IDE and select the correct Arduino board as well as the port, note that picking the correct port is essential and causes an error if the other port is selected, also the correct port does not appear unless the driver is installed successfully, therefore the researchers recommend to visit the Arduino site to further help users in troubleshooting errors as well as the driver installation.

Debug Test Procedure

The debug test procedure will be developed by the designer or engineer as the design proceeds. If he does not do this, he is either overconfident, unaware, or very pushed for time.

The aim of the debug test procedure is to divide the testing of the design into small, autonomous units. In this respect the debug test is providing a tool for the detection of faults in the design in a way that most conveniently allows them to be fixed - by finding them in isolation.

The debug test procedure will pay particular attention to suspected trouble spots in a design. For instance, if an analog input is known to be operating at a particularly low input signal level, a debug test procedure might include noise measurement, thermal drift testing, and evaluation of potential cross talk sources.

The debug test procedure will normally also include an overall functional test, based on the specification. This is basically equivalent to the incoming test procedure applied by the client.

Program Testing

Program testing is a process of executing a program with the intent of finding an error. The quality of the application can and normally does vary widely from system to system but some of the common quality attributes include reliability, stability, portability, maintainability and usability. Testing helps in verifying and validating is the program is working as it is intended to be working (Introduction to Software Testing, 2016).

PROCEDURES IN THE MAINTENANCE OF AN ELECTRONIC EQUIPMENT

The importance of an effective maintenance program cannot be overlooked because it plays such an important role in the effectiveness of any electronic system. The main purpose of regular maintenance is to ensure that all components in a system are operating at 100% efficiency at all times. Through short daily inspections, cleaning, lubricating, and making minor adjustments, minor problems can be detected and corrected before they become a major problem that can shut down or damage the entire system (Krar, S., n.d.).

Electronics equipment make use of a variety of components. A thorough knowledge of components and their limitations is thus an essential part of troubleshooting in electronic circuitry. A good understanding of special precautions in terms of handling, soldering and measurement of components would reduce the likelihood of premature failure and help in isolating failures due to design weakness or misuse. Checks and tests are fundamental maintenance procedures which include both of the following:

a. Visual Checks (such as for solder bridges, dry joints, signs of damage and missing components)
b. Movement Checks (such as loose wires and connections, incorrectly seated devices and modules

CHAPTER III

RESEARCH DESIGN AND METHODOLOGY

This chapter presents a discussion of the research design and methodology. It also includes the strategic plan on project expenses and delegation of tasks in executing the project.

Research Design and Methodology

A formal definition of engineering design is found in the curriculum guidelines of the Accreditation Board for Engineering and Technology (ABET). The ABET definition states that engineering design is the process of devising a system, component, or process to meet desired needs (ABET website, n.d.). It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to optimally convert resources to meet a stated objective. Among the fundamental elements of the design process is the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation. The engineering design process as shown in Figure 14 is a series of steps that researchers in engineering follow to come up with a solution to a problem.

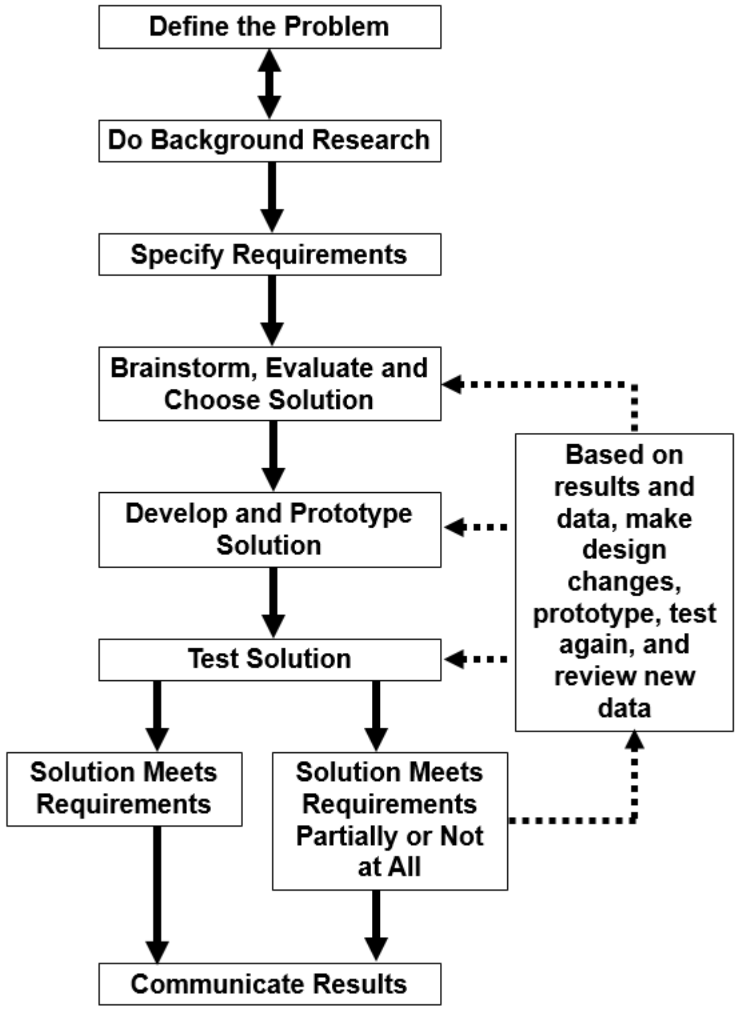


Figure 14. The Engineering Design Process

Steps of the Engineering Design Process

1. *Define the problem*

The engineering design process starts when the researchers ask questions as to what the problem is, who has the problem and why is it important for them to solve this problem. It is during this stage that the need is established. This was done through interviews with the SLU DTI FabLab staff and custodian. The problem identified by the researchers during their initial interview was the difficulty of creating an accurate equipment usage log for the SLU FabLab.

2. *Do Background Research*

This process involves gathering information relevant to the problem through literature search and interviews as well as existing solutions to similar problems. The researchers found several literature sources that confirm the applicability of RFID technologies in asset management and monitoring, as well as in laboratory equipment inventories.

3. *Specify Requirements*

Design requirements state the important characteristics or features that the solution must meet. One way to identify the design requirements of the solution is to analyze the concrete example of a similar, existing system, noting each of its key features. The requirements and system operation for this project was based on the existing literature and interviews with the laboratory custodian. The results obtained in this process was the answer to the first problem in the research (operation of the proposed system) and second problem (minimum hardware requirements for the system to operate).

4. *Brainstorm Solutions*

This process involved exploring several good possibilities for solving the design problem. Good designers always try to generate as many solutions as possible to ensure that optimal alternatives are not overlooked. Moreover, it is in this process where the researchers developed preliminary layouts and designs. This also involved evaluating the design against technical, economic and other constraints.

5. *Choose the best solution*

This step involved evaluating whether the solution meets the design requirements. Some of the solutions and designs were rejected at this stage as they were not able to meet the desired requirements. The researchers chose the design layout which they believe satisfied the requirements for RFID-Based Laboratory Equipment Usage Monitoring System.

6. *Develop the Solution*

Development involved the refinement and improvement of a solution, and it continues throughout the design process. Drawings, layouts and preliminary parts were utilized in this process. Block diagrams and flowcharts were also made during this stage of planning to come up with the algorithm of the system.

7. *Build a prototype or create the project*

A prototype is an operating version of a solution. Often it is made with different materials than the final version, and generally not as polished. Prototypes are a key step in the development of a final solution, allowing the researcher or designer to test how the solution will work. In this stage, the researchers initially built their project using breadboards and temporary connections after the design has been thoroughly examined. Applied research methodology was implemented by the researchers during this stage. This stage involved analyzing the planned block diagrams, flowcharts and algorithms. This stage involved the finalization of the block diagram of the system, the modification of available schematic diagrams, design of circuit diagrams needed for the system, PCB layouts, appropriate materials used and housing of the project. Some programming codes were based on available similar codes and were varied accordingly to satisfy the system's operation.

8. *Test and Redesign*

The design process involved multiple iterations and redesigns of the final solution. Iterative testing and analysis were done throughout this stage. Testing of the individual modules were conducted to ensure functionality before these modules were interfaced together to make the whole system. If the test results did not satisfy the requirements, then modifications in the design or program were done by the researchers.

Testing and verification are important parts of the design process. This stage involved testing each system component and module. Troubleshooting each encountered problem in the process was done. Modifications of the program codes were also done during this stage. Once each system component was tested to be functional, they were then interfaced for the testing of functionality of the whole system.

Verification is an evaluative activity to check that a device design meets its requirements. Contrary to popular belief, verification does not just involve testing but includes any activity that provides proof that requirements are being fulfilled. Verification is a three-pronged approach of tests, analyses and inspections. Simulations and measurements were done during this process.

Evaluation was conducted to evaluate the acceptability of the system based on ISO 9126 software quality and the OECD Project Evaluation Checklist. The overall functionality of the project was tested and evaluated by the FabLab staff. Each respondent used and evaluated the system to determine the level of acceptability of the system. Respondents could answer 1 (Not acceptable) to 5 (Highly acceptable) to each question on the quality of the system.

The five-point scale, range, and its verbal interpretation is shown in Table 7. A sample of the metrics is shown on Table 8.

Table 7. Five Point Scale, Range and its Verbal Interpretation

RATING	RANGE	VERBAL INTERPRETATION
5	4.51 – 5.00	Highly Acceptable
4	3.51 – 4.00	Acceptable
3	2.51 – 3.00	Moderately Acceptable
2	1.51 – 2.00	Slightly Acceptable
1	1.00 – 1.50	Not Acceptable

Likert-type scales are frequently used in medical education and medical education research. Common uses include end-of-rotation trainee feedback, faculty evaluations of trainees, and assessment of performance after an educational intervention. For this study, the researchers presented the results of the evaluation through the weighted mean and through graphs of the responses provided. The researchers also sought the comments and feedback of the evaluators of the project.

Table 8. Software Quality Metrics

Software/Prototype Quality	CRITERIA
FUNCTIONALITY The capability of the software to provide functions which meet the stated and implied needs of users under specified conditions of usage (what the software does to meet needs)	a. The ability of the system to print reports b. The ability of the system to interact directly with the RFID module c. The ability of the system to grant authorized access and control d. The ability of the system to ensure accurate interaction between the modules of the system.
RELIABILITY The capability of the software product to maintain its level of performance under stated conditions for a stated period of time.	a. The ability of the system to provide consistent correct output b. The ability of the system to maintain the same level of performance when printing reports without errors, problems, crash, or service interrupts.
EFFICIENCY The capability of the software product to provide desired performance, relative to the amount of resources used, under stated conditions.	a. The ability of the system to provide accurate response and precise records upon user's requests b. The cost of the system is justifiable
USABILITY The capability of the software product to be understood, learned, used and provide visual appeal, under specified conditions of usage (the effort needed for use)	a. The system can be used as a tool in providing information to the user, specifically equipment usage information b. The system ensures authorized access to the machines in the FabLab. c. The results obtained from the use of the system will be useful to the FabLab staff and custodian.
MAINTAINABILITY The capability of the software product to be modified which may include corrections, improvements or adaptations of the software to changes in the environment and in the requirements and functional specifications (the effort needed for modification)	a. The system can be easily modified, tested and maintained. b. Through the user's manual, the users will be able to retain the project's usability even after the period of external assistance has ended.
PORTABILITY The capability of the software product to be transferred from one environment to another. The environment may include organizational, hardware or software.	a. The system can be easily moved to another environment and easily installed.

Sources: Padayachee, Kotzé & van Der Merwe (2010). ISO 9126 & OECD Project Evaluation Checklist

The testing of the project addressed problem number 4 (testing the functionality of the system).

9. Communicate Results

To complete the project study, proper documentation was made by the researchers through the final manuscript and paper presentation. The significant results of the experiments and testing procedures were presented in the final report. Recommendations for future researchers were also documented.

PROJECT MANAGEMENT AND THE MULTIDISCIPLINARY ENVIRONMENTS CONSIDERED IN THE STUDY

As it is the role of the faculty research promoter to be the lead author, it is also the responsibility of the promoter to oversee the overall project management, as well as contribute to group decision making activities. This section details some aspects of the project management that took place in the entire duration of the study. The project management started with dividing the overall task of building the system into smaller sub-systems. These sub-systems were then assigned to the appropriate team members. This is covered under section A on Team Management. Then the time duration of the project was planned so that team members know about the deadlines involved. This is outlined in section B on Time Management and Table 10 for the Chronogram of Activities. Another management aspect to be considered in the study is Resource Management, which is detailed in section C. The proposed line item budget was finalized after the entire research project was finished. Described in section D is the management of multidisciplinary environments as used in the study. The last aspect is the organization and chairing of the weekly meetings, which is outlined in section E. Meetings were conducted on a weekly basis and were done in the presence of the faculty research promoter. Finally, the success of the project is evaluated in section F.

A. Team Management

The first task, once the purpose and specifications of the project had been discussed, was to split the project into components or sub-systems. These components were treated as separate projects for the purposes of allocating project marks. Each team member conducted the research project with a particular job description. Table 9 summarizes the tasks assigned to each member of the team. The job descriptions were assigned but not limited to the personnel listed in the table.

Table 9. Assignment of Tasks of Group Members

NAME	JOB ASSIGNMENT	JOB DESCRIPTION
Engr. Caroline Bautista-Moncada	Faculty Research Promoter/ Lead Researcher	The Faculty Research Promoter (FRP) takes on the active role as lead researcher who directs the research process from problem conceptualization up to results dissemination. In turn, the students shall serve as her research assistants and mentees.
Eclarino, Thomas David G.	SCHEMATIC DESIGNER,HEAD PROGRAMMER, ASSEMBLER,AND GUI CODER	Responsible for all the programming in C++ for the Arduino controlled circuits and C# for the GUI of the project. Responsible for making each schematic and block diagram Simulated the schematics to make sure that they are safe and have the lowest possibility of malfunctioning due to improper wiring. Responsible for putting together the parts of the project.
Hangdaan, Jethro Wilson H.	ASSEMBLER and QUALITY CHECKER	Responsible for putting together the parts of the project and checking the quality of the individual components and our project as a whole
Reyes, Akino Brien O.	LITERATURE RESEARCHER AND ASSISTANT ASSEMBLER	Responsible for searching the internet for reliable sources that may be used for our proposed project. Responsible for assisting the assemblers on putting together the parts of the project.
Salamanca, Charles Lorbil H.	RESEARCHER AND DESIGN CONSULATANT	Estimated the possibility of our physical designs. And helped examine the sample designs if it is practical. Gave suggestions and corrections on each design.

Bateg, Alaizah Mae T.	SECRETARY , ASSEMBLER AND 3D DESIGN REPRESENTER	Gave suggestions on possible upgrades of the projects design. Made the digital representation of the projects' casing and ideal structure. Took note of important details mentioned within meetings and chats. Responsible for putting together the parts of the project.
Dalit, Esper Joymae F.	LITERATURE RESEARCHER	Responsible for searching the internet for reliable sources that may be used for the proposed project.
Dungca, Vanessa R.	RESEARCHER AND DESIGN CONSULATANT	Estimated the possibility of our physical designs. And helped examine the sample designs if it is practical. Gave suggestions and corrections on each design.
Fianza, Eden Hope F.	LEADER, ASSEMBLER AND DESIGN CONCEPTUALIZER	Served as the group organizer and encouraged everyone to work and accomplish tasks before the set deadline. Researched the dimensions and specifications of each component to come up with an estimate sketch design and layout of the project proposal. Disseminated information from the promoter to the groupmates, from the groupmates to the promoter or from one groupmate to the other. Responsible for putting together the parts of the project.
Paluyo, Gicelle Trizzia C.	LITERARY RESEARCHER	Responsible for searching the internet for reliable sources that may be used for our proposed project.

B. Time Management

This section details a brief overview of the time management plan that took place for the entire project study duration. A diary style approach has been avoided as much as possible and hence only key events were noted. Table 10 shows the chronogram of activities of the researchers.

Table 10. Chronogram of Activities

ACTIVITIES	MONTH												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN
A. Finalization of research groups lecture on research, approval of project topic	X	X											
B. Preparation of research proposal													
1. Literature review, preliminary interviews, needs assessment			X										
2. Writing of the introduction (with problem objective/s research questions, significance, etc.)				X	X								
3. Writing of the methods section (with identified research design, preliminary overview of operation of the proposed project, preliminary block diagram)						X							
4. Identification of minimum hardware/software requirements, preliminary design of circuits/modules needed)						X							
5. Finalization of proposal and defense proposal							X						
6. Incorporation of suggestions/recommendations							X						
C. Project Design and Construction								X					
1. Finalization of block diagram, circuit design of modules								X	X				
2. Procurement of electronic components, construction of modules								X	X	X			
D. Testing/Troubleshooting of modules													
1. Testing individual modules according to specifications									X	X			
2. Interfacing of modules, testing/troubleshooting to complete project, recording of results									X	X	X		
E. Preparation of final report/output													
1. Writing the manuscript					X	X		X	X		X	X	
2. Editing							X		X	X	X	X	
3. Presentation and oral defense							X						X
4. Revisions							X						X

Table 11. Schedule of Submission of Deliverables

Activities	Deliverables/Output to be submitted	Deadline
A. Finalization of research groups lecture on research, approval of project topic.	List of group members Pre-proposals	January 22, 2021
B. Preparation of research proposal		
1. Literature review, preliminary interviews, needs assessment	Literature Review Interview Results	February 15, 2021
2. Writing of the introduction (with problem objective/s research questions, significance)	Draft of introduction	April 15
3. Writing of methods section (with identified research design, preliminary overview of operation of the proposed project, preliminary block diagram)	Revised Introduction Draft of Methods	May 15
4. Identification of minimum hardware/software requirements, preliminary design of circuits/modules needed)	Report of Minimum hardware / software requirements Preliminary designs, block diagrams	June
5. Finalization of proposal and defense proposal	Complete write-up of proposal Defense	July 25
6. Incorporation of suggestions /recommendations from the panel members	Revised proposal manuscript	July 30
C. Project Design and Construction		
1. Finalization of block diagram, circuit design of modules	Progress Reports Actual module	August 15
2. Procurement of electronic components, construction of modules		August 15
D. Testing/Troubleshooting of Modules		
1. Testing individual modules according to specifications		
2. Interfacing of modules, testing/troubleshooting to complete project, recording of results.	Actual project Testing results	Last week of September
E. Preparation of final report/output.		
1. Writing the manuscript	Submission of drafts Final Manuscript Powerpoint presentation Rubrics	First Week of October Until 2nd week of November
2. Editing		
3. Presentation and oral defense		Last week of November
4. Revisions	Journal Manuscript Technical Report Working Project User's Manual	First week of December

C. Resource Management

Project resources include everything necessary to complete the project. A very important consideration is the financial budget. The budget was planned based on the financial capabilities of the researchers and the availability of materials.

Since this research project is the final capstone project of the Electronics Engineering Program, the budget requirement is higher than that of other projects in the different ECE subjects. Having economical constraints in mind, the researchers exercised due diligence and care in the choice of materials used in the project. Careful planning and canvassing was done to ensure that the project did not go beyond the financial means of the group. Table 12 shows the final project cost and line item budget. Because the submissions were done online, the researchers did not have any expenses for printing the manuscript. Only minimal internet expenses will be incurred by the group.

As for the financial sources, a weekly due of Php 100.00 from each member was collected by the treasurer. The amount collected was used for the development of the project study. All expenditures were submitted to the treasurer upon approval of the assigned group leader for proper appropriation of funds. At the end of the project study, the treasurer prepared a financial statement that was reviewed by the group.

Table 12. Final Line Item Budget

ITEM	QTY	PRICE, ₱	TOTAL PRICE, ₱	SHOP	JUSTIFICATION
Arduino Uno	1pc	395.00	395.00	Layad Circuits	Easy to utilize/program; Availability, more input pins
Arduino Nano	3pcs	285.00	855.00	Layad Circuits	Easy to utilize/program; Availability, small compact size
RFID Reader and Card (13.56 Mhz)	4pcs	110. 00	440. 00	Layad Circuits	Compatibility to the chosen Microcontroller
T-Type Splicer	3 pcs	151 / 5pcs	151.00	Shopee.com	For cleaner wiring and less spliced out wires.
Key Switch	3 pcs	53.00	159.00	Shopee.com	To allow a manual over ride of our System
Metal Straps	1 set (10pcs)	88.00	88.00	Shopee.com	Metal straps for the RFID holder and basis for LED indicator light.
Pin Headers (female)	1 set (10pcs)	69.00	69.00	Shopee.com	Female pin headers for the mounting of our LEDs and Arduino. Allows the replacement of parts to be easy.
Pre-sensitized PCB with developer	2pcs	365.00	730.00	Protown Electronics	Using Pre-sensitized PCBs allows us to etch more precise copper lines.
SPDT 5V Relay Module (Heavy Duty)	3pcs	75.00	225.00	Chanco Electronics	These relay will act as a switching components between our Arduino Nano and led indicators.
5V Arduino Relay Module	3pcs	45.00	135.00	Layad Circuits	These relays are used to connect or disconnect the electricity flow between the socket and the machine. We will be using a module, which is to be controlled by the Arduino, for a more convenient and responsive circuit.
Chase Outlet (type a)	3pcs	25.00	75.00	Laguisma Electronics	Type A is one of the standard outlets.
Socket and Plug set (iec 320 – c8)	3pcs	100.00	300.00	Protown Electronics	For the power brick
Wires (with headers)	120pcs (3 sets, m-m, f-f, m-f)	200.00	200.00	Shopee.com	To keep the modular design of the project.
Copper Wires thin	30 m	7 / meter	210.00	Protown Electronics	For lower current and voltage.
Copper wires #9	2 m	25 / meter	50.00	Protown Electronics	For higher current and voltages
5V Dual Output Charging Module	3pcs	169.00	507.00	Protown Electronics	To distribute the power supply of the power brick to the whole system
220Ω Resistor	11pcs	1.00	11.00	Protown Electronics	To keep the LED from being damaged.
LED	11pcs	3.00	33.00	Layad Circuits	To indicate the status of the system.
Nuts and Bolts	268 pcs	157.00 mixed nuts and bolts	157.00	Handyman, Ace, uptown, Watch Repair	To keep everything sealed tightly
Casing	7pcs	3500.00	3500.00	Jeff 3d and Baguio 3D Print	To protect the whole system.
MISC. (ferric chloride, laser print for pcb layout,lacquer thinner, sand paper, glue etc.)			250.00	Electronics, hardware and printing shops.	
Total			**8540.00**		

D. Management of Multidisciplinary Environments considered in the study

The nature of this study focused on the various technical aspects that require inputs from multiple fields of specialization and disciplines. Since the study endeavored to construct a system capable of providing assistance in the monitoring of equipment usage in the FabLab, consultation and possible collaboration with the following areas of discipline was employed:

Electronics Engineering Discipline

The project integrates both electronics and communications principles to come up with the design needed in accordance to its objectives. The system was designed to apply concepts on electronic design fundamentals and programming. Conversely, concepts in electronics and communications would be seen on the system for the sensing and transmission of data, respectively. The design of the project involved interconnection of the electronic devices and modules to operate as stated in the objectives of the study. The researchers were guided by electronics engineering practitioners as well as related literatures and documentaries in order to accomplish this aspect of the study.

Information Technology and Programming Discipline

The software aspect of the laboratory equipment to be developed requires knowledge in the programming of the Arduino microcontroller. Specific courses in the Electronic Engineering curriculum discuss programming but only the basics. Along with this, the design and construction of the GUI using the Visual Studio is unfamiliar to some of the researchers, thus, they were guided by experienced programmers who can advise them on efficient programming techniques and algorithms that could make the software solution to the project simpler and more user friendly. Forums with experienced programmers as well as several online resources were beneficial for this aspect of the project.

Academic Discipline

The creation of a user manual will help maximize the efficiency and sustainability of the system. This manual will help non-technical users to be guided in the proper use and functions of the research project. This aspect required knowledge of both principles in the field of Engineering and Education.

E. Chairing the Weekly Meetings

Another task that required constant attention is the chairing of the weekly meetings. Each week a meeting was organized in which the project progress could be evaluated. To accomplish this, a firm meeting structure was set up and adhered to. The research team created a group chat at Facebook messenger where they were encouraged to raise any topics they wanted for clarification and suggestions before the agenda was sent out. The agenda was out at least two days in advance of the meeting. The meetings had a common structure and only allowed a small amount of time. Minutes were noted by each team member in a round robin style. Any actions identified during the meeting were assigned to a specific team member and included in the minutes. At the beginning of each meeting, the status of the actions from the last meeting were checked. Each action was either carried over to the next week or marked as complete. This ensured that actions were not forgotten. After the research team conducted the meeting, they were tasked to report to the faculty promoter as a group. Finalization of decisions were done during these meetings. The meeting with the promoter was scheduled every Friday and Saturday evening of the First and Second Semester Academic Year 2020-2021.

F. Measuring the Success of the Project

As this is a group project there were two ways to measure whether or not it was successful. For the assessment each team member's tasks was taken on an individual basis and tested against what they were supposed to do. However, this does not really measure the success of the project as a whole. The plan was to build the sub systems separately first then combine the modules once the individual modules have been confirmed and tested to be functional as based on the system requirements and specifications. Therefore, this project would have to be classified as a failure due to not meeting that success criterion. However, there was another measure of success that was considered. This was whether the project state was left in such a way that it can be continued next year by a different research group, meaning that it can be duplicated using other conditions. A project that works but has very little documentation is useless to everyone. A project that is well documented and close to completion can be continued. A complete manuscript is one of the output of the research project study course. This was evaluated during the research presentation at the end of the first semester of Academic Year 2021-2022.

CHAPTER IV
PROJECT DESIGN, CONSTRUCTION AND TESTING

This chapter presents the documentation of the design, procedures in the construction, as well as the testing done and results obtained to ensure the functionality of the project. It includes block and schematic diagrams as well as actual images of the different modules of the project.

OVERVIEW OF THE OPERATION OF THE RFID-BASED LABORATORY EQUIPMENT USAGE MONITORING SYSTEM

The RFID-Based Laboratory Equipment Usage Monitoring System is a system that allows the laboratory custodian to monitor equipment usage logs in the FabLab. The project was divided into two systems since the custodian's office is separate from the FabLab, namely: the Logging System and the Equipment Access System. The first system, which is the logging system will be located in the custodian's office and the second system, the equipment access system will be located on the FabLab where the machines are housed.

The Logging System is composed of the RFID module interfaced to the custodian's computer. Specific RFID cards were assigned to each of the machines in the FabLab. These RFID cards are placed on a designated card slot inside the custodian's office.

The custodian in charge will have to first register him or herself on the GUI. After an account is made, the custodian now has access to the GUI and a master ID. Once a student or staff requests access to the machines in the FabLab, the custodian makes a record on the GUI and taps the card of the machine which would be used. The log will include the time and date of scan and the machine used. The graphical user interface (GUI) shown in the custodian's computer will allow the custodian to input the user information (student/user name), FabLab project to be done, and generate reports on machine usage. Reports can be generated as pdf only and filtered to the desired list of information to be present.

The GUI was designed to have features such as: The Log-in page of the custodian, the Dashboard, the History and New Session buttons, the Machine maintenance and Machine registry pages and finally the printing function of the GUI.

The second system, known as the Equipment Access System is composed of a designated card slot which contains an RFID reader. This functions similarly to hotel access keycards. Each equipment socket has a specified RFID card and slot. Access to the equipment will require the user to properly insert the correct RFID card in the card slot of the equipment to be used. When the user inserts the correct RFID card in the slot, the relay will be turned on, thus allowing electricity to flow through and the machine can now be turned on. Once the user finishes using the machine, the user has to return the RFID card to the custodian, then the custodian has to tap the RFID card in the reader to signify that the machine has been shut down already.

The custodian can generate reports on a daily, weekly, monthly or yearly basis. These reports can also be useful for periodic maintenance scheduling and planning.

BLOCK DIAGRAM OF THE PROJECT

The project has two major systems: the Logging System and the Equipment Access System. The Logging System is composed of the RFID module, the microcontroller and the custodian's computer.

A. The Logging System

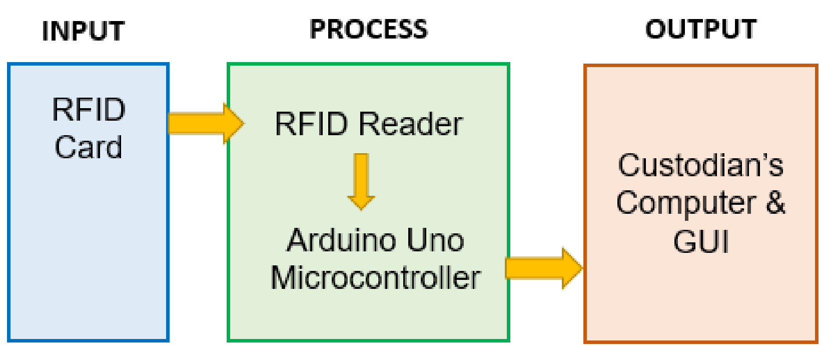


Figure 15. Block Diagram of the Logging System

DESCRIPTION OF EACH BLOCK OF THE LOGGING SYSTEM

A.1. INPUT BLOCK: RFID CARD

The input block contains the RFID Card which provides the raw data/information to the microcontroller.

A.2. PROCESS BLOCK:

A.2.1 RFID Reader

The MFRC522 RFID Reader is a highly integrated reader/writer IC for contactless communication at 13.56 MHz. The MFRC522 reader supports ISO/IEC 14443 A/MIFARE and NTAG. The MFRC522 reads the data in the RFID tag/card then sends it to the microcontroller for processing.

A.2.2 Arduino Uno

The Arduino Uno Microcontroller processes the data from the RFID Reader then sends it to the custodian's computer for further processing for the GUI.

A.3. OUTPUT BLOCK: GUI in the Custodian's Computer

The GUI will display the summarized data log in terms of data and time the RFID tag has been scanned, and the machine designation of the RFID tag/card.

B. The Equipment Access System

The Equipment Access System is composed of the RFID module, the microcontroller and the relay. Figure 15 shows the preliminary block diagram of the proposed equipment access system.

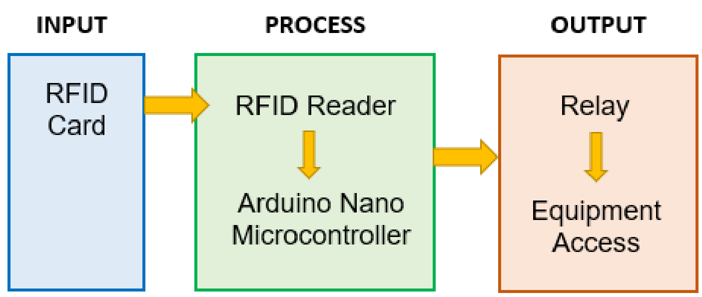


Figure 16. Preliminary Block Diagram of the Proposed Equipment Access System

DESCRIPTION OF EACH BLOCK OF THE EQUIPMENT ACCESS SYSTEM

B.1. INPUT BLOCK: RFID CARD

The input block contains the RFID Card which provides the raw data/information to the microcontroller. The RFID Card acts as the keycard that will allow access to the equipment or machine in the FabLab. Each RFID card is assigned to a single machine in the FabLab.

B.2. PROCESS BLOCK:

A.2.1 RFID Reader

The MFRC522 RFID Reader is a highly integrated reader/writer IC for contactless communication at 13.56 MHz. The MFRC522 reader supports ISO/IEC 14443 A/MIFARE and NTAG. The MFRC522 reads the data in the RFID tag/card then sends it to the microcontroller for processing.

A.2.2 Arduino Nano

The Arduino Nano Microcontroller processes the data from the RFID Reader. If the correct RFID card is detected by the reader, the Arduino Nano will trigger the relay to turn on and thus allow electricity to pass through for the equipment or machine to operate.

B.3. OUTPUT BLOCK: Relay

The relay acts as the switch for the electricity to flow so that the equipment will be able to function. A relay is a programmable electrical switch, which can be controlled by Arduino or any microcontroller. It is used to programmatically control on/off the devices, which use the high voltage and/or high current.

B.3.1 5-Leg SPDT 5VDC Power Relay

A power relay is an electronic component that uses an electromagnet to open or close a circuit when the coil is correctly excited. They provide a high level of isolation between the control signal (coil) and the output (contacts) A power relay may have both normally open (NO) and normally closed (NC) contacts or just normally open (NO) contacts. Power relays are reliable and efficient when it comes to switching high currents.

The researchers used a 5 leg 5VDC power relay to distribute the voltage of the power brick to the system and the indicator lights making the LED lights safe from sudden power surges at the same time acting as a switch for the system.

Figure 17. A 5-Leg SPDT 5VDC Power Relay

Table 13. Hardware Specifications of the 5-Leg SPDT Power Relay

Contacts configuration	SPDT
Rated coil voltage	5V DC
AC contacts rating @R (at resistive load)	10A / 120V AC
DC contacts rating @R (at resistive load)	10A / 24V DC
Contact current max.	10A
Switched voltage	max. 100V DC, max. 240VAC

Source: https://www.findernet.com/en/uk/news/what-is-a-power-relay-and-its-use-within-applications/

B.3.2 5V Two-Output Charger Module

A Power Supply Unit (PSU) is a vital part in any electronic product design. Most household electronic products like Mobile Chargers, Bluetooth Speakers, Power Banks, Smart Watches etc require a Power Supply circuit that could convert the AC mains supply to 5V DC to operate them.

The researchers used a 5V two output charging module to split the power provided by the brick between the indicator lights and the RFID system. The 5v charging module works as a power supply to power up the system and the LED indicators.

Figure 18. A Two-Output Charger Module

Table 14. Hardware Specifications of the Two-Output Charger Module

Output rating	5V / 3.1 A
Input AC Voltage Rating	100 – 240V
Frequency	50/60 Hz

Source: https://circuitdigest.com/electronic-circuits/5v-2a-smps-power-supply-circuit-diagram

B.3.3 5V Module Relay

A relay is a programmable electrical switch, which can be controlled by an Arduino or any other microcontroller. It is used to control on/off devices according to how it was programmed. The 5V module can work with high voltages and/or high current. It is used as a bridge between the microcontroller and high voltage devices. The relay used as a switching device can work with two modes: normally closed and normally open.

The researchers used a 5V module relay inside the power brick as a safety measure in case of sudden power surge or voltage increase or decrease. It also acts as a switch if in any worse case scenario, the system needs a manual override. The relay is connected to the key switch, which when unlocked by the custodian, would allow the system to operate as a normal extension cord.

Figure 19. A 5V Module Relay

Table 15. Hardware Specifications of the Two-Output Charger Module

Output Voltage	5VDC
Maximum Input Voltage rating	250VAC / 10 A

Source: https://arduinogetstarted.com/tutorials/arduino-relay

SCHEMATIC DIAGRAMS FOR THE RFID-BASED LABORATORY EQUIPMENT USAGE MONITORING SYSTEM

The succeeding figures show the schematic diagrams for the two systems of the RFID-Based Laboratory Equipment Usage Monitoring System: the Logging System and the Equipment Access System.

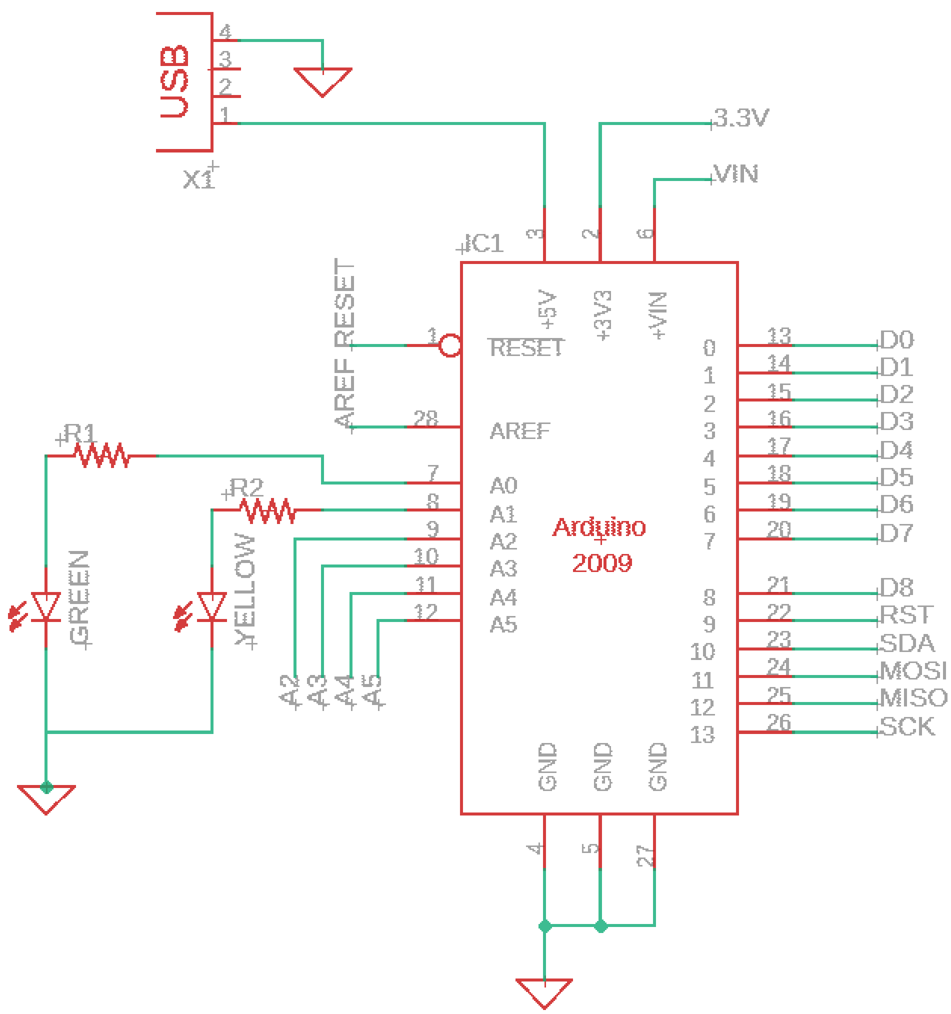


Figure 20. Schematic Diagram for the Logging System (Custodian Side)

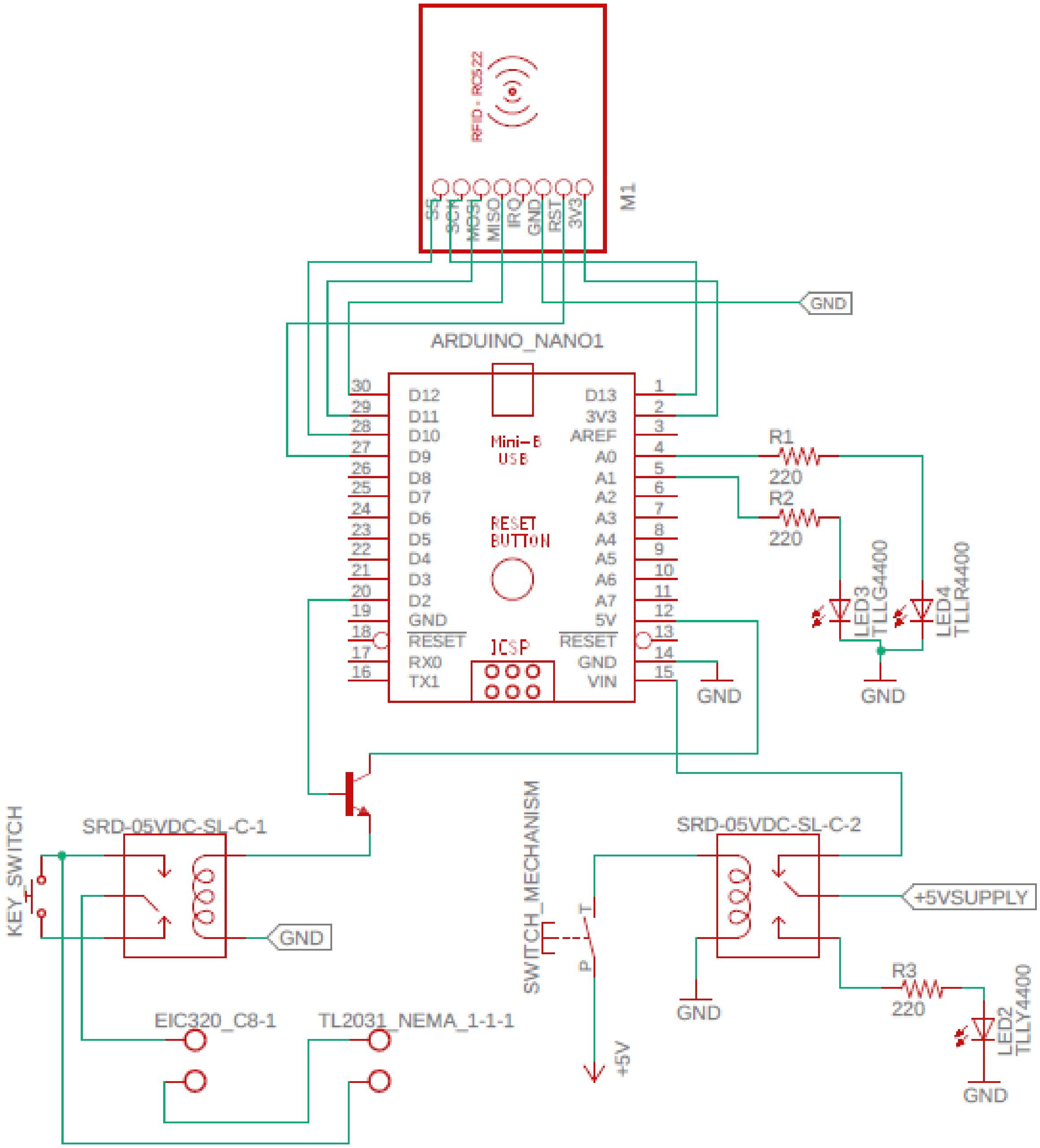


Figure 21. Schematic Diagram for the Equipment Access System (FabLab Side)

The Arduino Nano serves as the microcontroller of the system. It sends digital signals to the digital relay (SRD-05VDC-C-1 together with the transistor) through digital output 2. Furthermore, it receives digital signals from the RFID scanner (RFID MRC-522) through digital inputs D9, D10, D11, D12, and D13. Power source from the Arduino Nano (3.3V) activates the RFID ready for scanning.

In normal operation, the AC input power comes from port EIC320_C8-1 and goes to port TL2031_NEMA_1-1. The charger module supplies two 5 volts (+5V and +5VSUPPLY). The +5VSUPPLY from the charging module is applied to the left side (3 terminals) of the relay SRD-05VDC-SL-C-2. The other supply is applied to the SWITCH MECHANISM then goes to the other side of the relay. When the system detects no RFID scanner (SWITCH MECHANISM normally closed), the relay is in normally closed state which causes the yellow LED to turn on. This normally closed state of the switch mechanism implies that there is no RFID card inserted. When an RFID card is inserted, it acts as an insulator between the plates of the switch mechanism. The switch mechanism is now in a normally open position causes the SRD-05VDC-SL-C-2 relay to be in normally open state. The power is now directed to the Arduino Nano at this moment. At the same time, when the Arduino Nano is turned on, it scans the inserted RFID card.

At initial position of the system SRD-05VDC-C-1 relay is in normally open state which. This initial state of the relay provides no power to TL2031_NEMA_1-1-1 which supplies the equipment in use. If the inserted RFID card is valid (means that it is registered in the data base of the Arduino) then it sends signal through D2 to the SRD-05VDC-C-1 relay which is in normally open state. This signal causes the SRD-05VDC-C-1 relay to be in normally closed state. The same relay now sends power to TL2031_NEMA_1-1-1 which turns on the equipment in use. The equipment remains in on state as long as the RFID card is inserted.

PROCESS FLOWCHART FOR THE RFID-BASED LABORATORY EQUIPMENT USAGE MONITORING SYSTEM

The succeeding figures show the process flowchart for the two systems of the RFID-Based Laboratory Equipment Usage Monitoring System: the Logging System and the Equipment Access System.

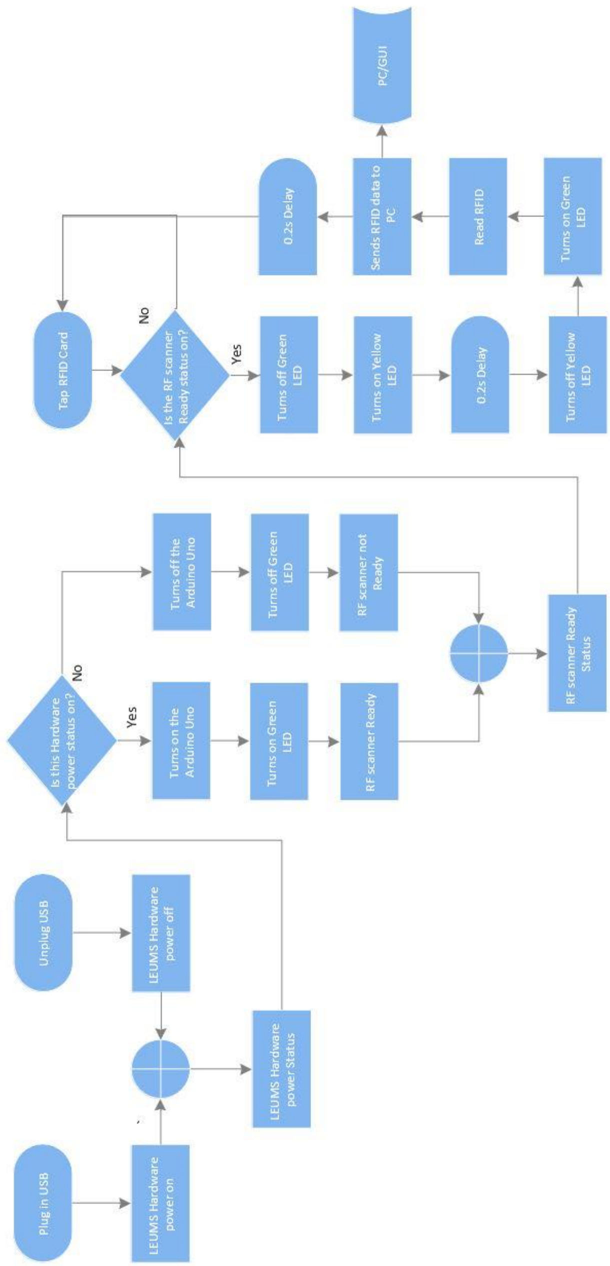


Figure 22. Process Flowchart for the Logging System (Custodian Side)

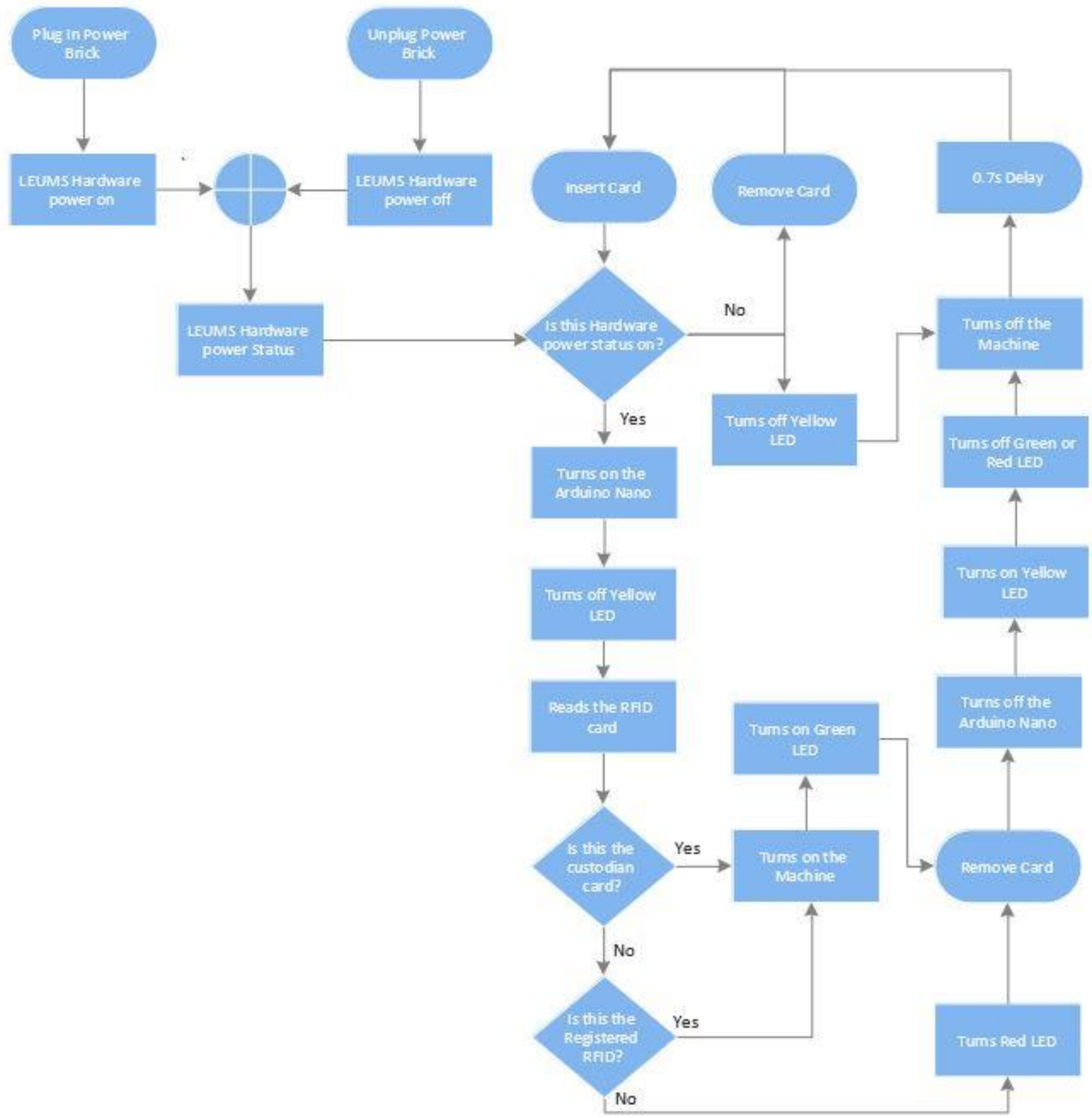


Figure 23. Process Flowchart for the Equipment Access System (FabLab Side)

PROGRAMMING OF THE MICROCONTROLLERS FOR THE RFID-BASED LABORATORY EQUIPMENT USAGE MONITORING SYSTEM

The researchers in this project made use of two Integrated Development Environments (IDEs) for the programming of the microcontrollers and the construction of the Graphical User Interface (GUI).

A. The Arduino IDE

Microcontrollers are typically programmed in higher-level languages such as C++ or Java. One of the essential tools needed to program a microcontroller is an integrated development environment (IDE). The open-source Arduino Software (IDE) makes it easy to write code and upload it to the board. It runs Windows, Mac OS X, and Linux. The environment is written in Java and based of Processing and other open-source software.

This software is usually developed by the creators of the microcontroller and contains useful tools to help a person program the microcontroller. Common tools found in IDE’s include code editors, compilers, and debuggers. Depending on the application of the microcontrollers, additional features may be added as well. Once a suitable IDE is obtained, the user can begin writing code.

A compiler is a software tool that takes higher-level code and optimizes it for assembly. Assembly provides specific instructions to the microcontroller on what register operations to perform to match the operation of the original code. Once the assembly code is created, it can be uploaded to the microcontroller for testing.

B. Visual Studio IDE

Microsoft Visual Studio 2015 is a suite of tools for creating software, from the planning phase through UI design, coding, testing, debugging, analyzing code quality and performance, deploying to customers, and gathering telemetry on usage. These tools are designed to work together as seamlessly as possible, and are all exposed through the Visual Studio Integrated Development Environment (IDE). Microsoft Visual Studio is an integrated development environment (IDE) from Microsoft. It can be used to develop console and graphical user interface applications along with Windows Forms applications, web sites, web applications, and web services in both native code together with managed code for all platforms supported by Microsoft Windows, Windows Phone, Windows CE, .NET Framework, .NET Compact Framework and Microsoft Silverlight.

The Visual Studio product family shares a single integrated development environment (IDE) that is composed of several elements: The Menu bar, Standard toolbar, various tool windows docked or auto-hidden on the left, bottom, and right sides, as well as the editor space. The tool windows, menus, and toolbars available depend on the type of project or file the user is working in. Figure 10 shows the Visual Studio IDE.

PROGRAM FLOWCHART FOR THE RFID-BASED LABORATORY EQUIPMENT USAGE MONITORING SYSTEM

A Flowchart is a type of diagram (graphical or symbolic) that represents an algorithm or process. Each step in the process is represented by a different symbol and contains a short description of the process step. The flow chart symbols are linked together with arrows showing the process flow direction. A flowchart typically shows the flow of data in a process, detailing the operations/steps in a pictorial format which is easier to understand than reading it in a textual format. The flowcharts act as a guide or blueprint during the systems analysis and program development phase. Furthermore, the flowchart helps in debugging process.

Prior to writing the computer program codes, the researchers constructed the project's flowchart to represent the logic of how the project works. Once the flowchart was drawn, it facilitated the writing of a program in high level language. Hence, it is correct to say that a flowchart is a must for the better documentation of a complex program.

The succeeding figures show the program flowchart for the two systems of the RFID-Based Laboratory Equipment Usage Monitoring System: the Logging System and the Equipment Access System. To be able to present the flowchart on paper, the researchers divided the flowchart into segments.

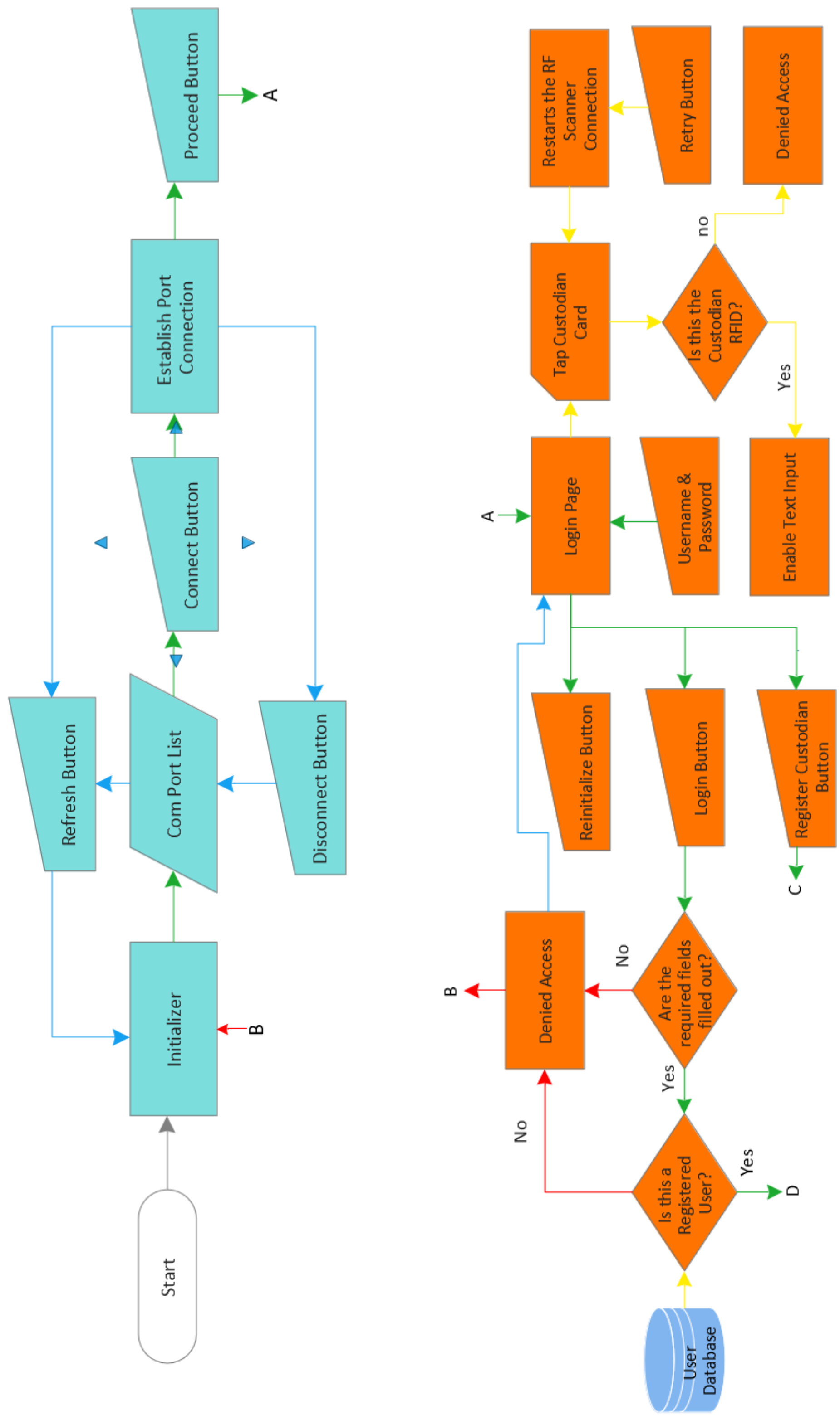


Figure 24. Program Flowchart for the GUI (Part 1)

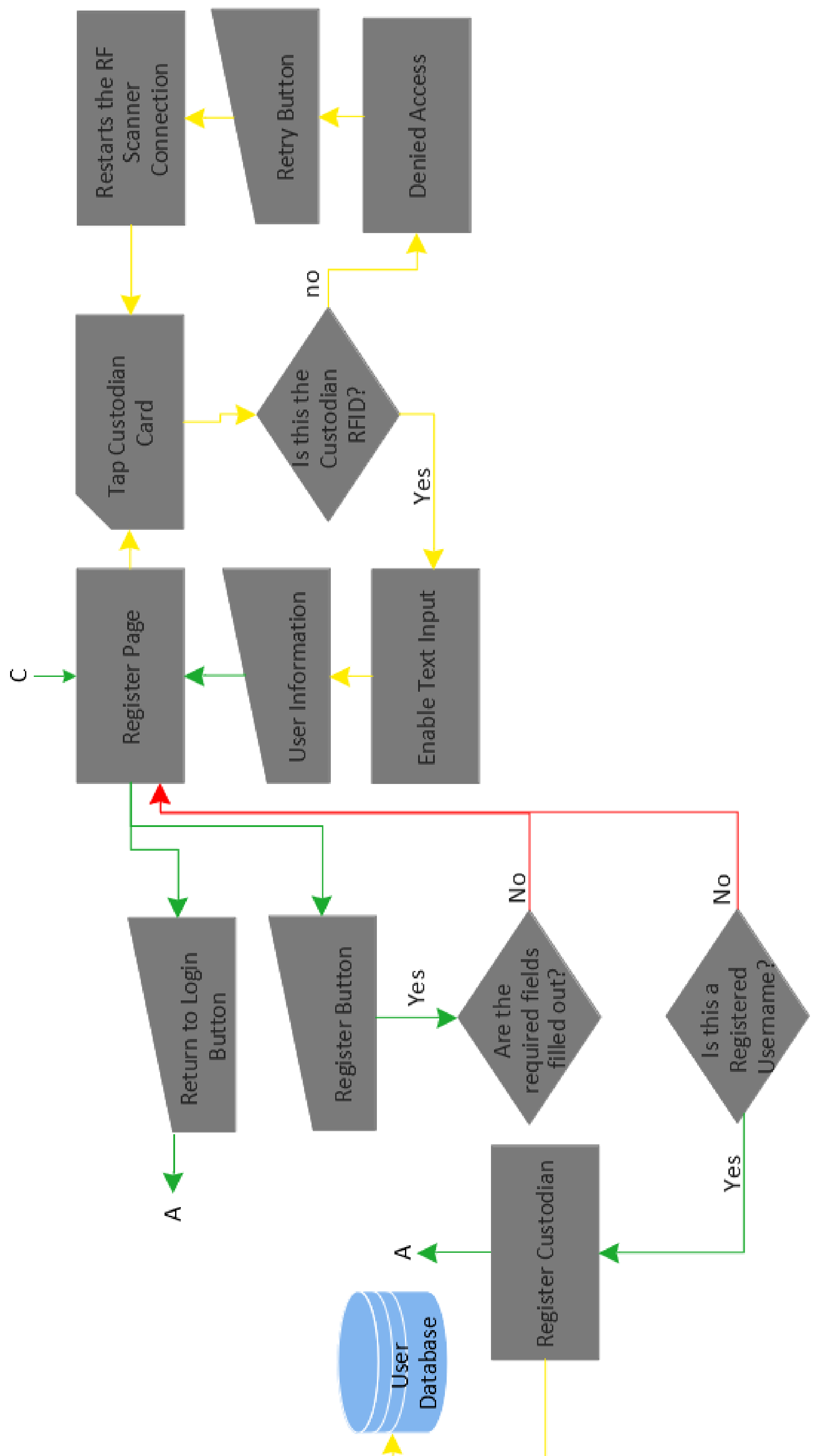


Figure 25. Program Flowchart for the GUI (Part 2)

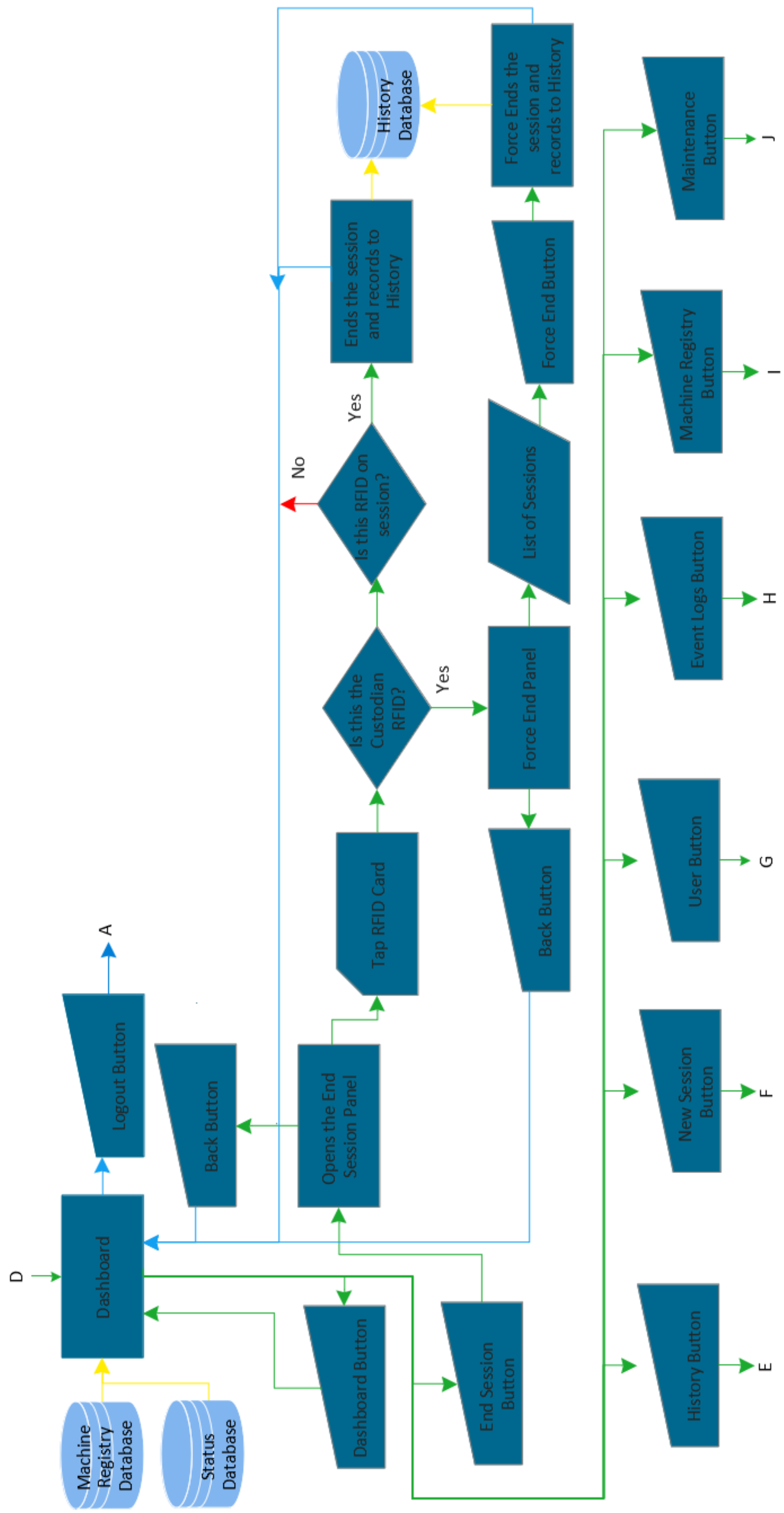


Figure 26. Program Flowchart for the GUI (Part 3)

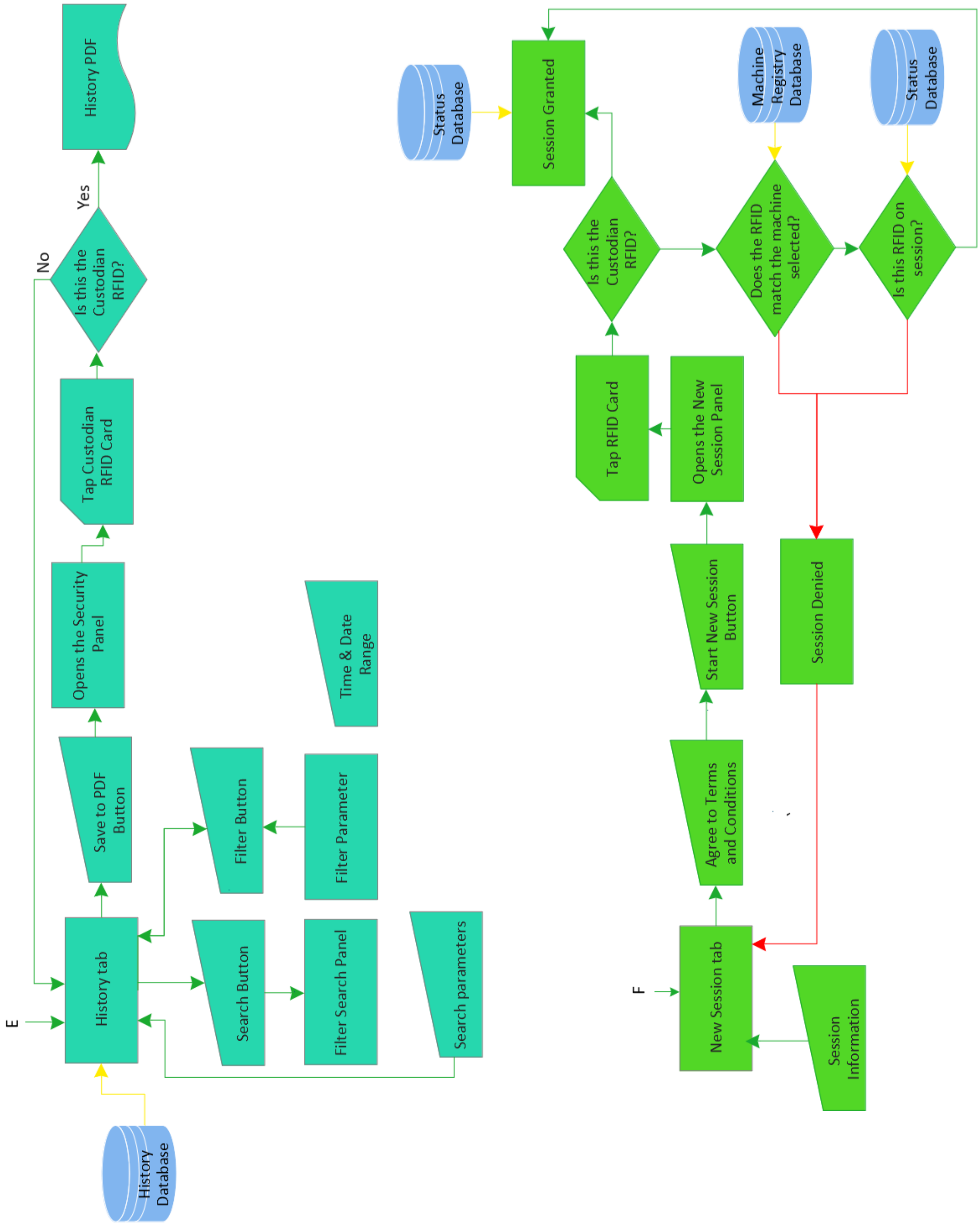


Figure 27. Program Flowchart for the GUI (Part 4)

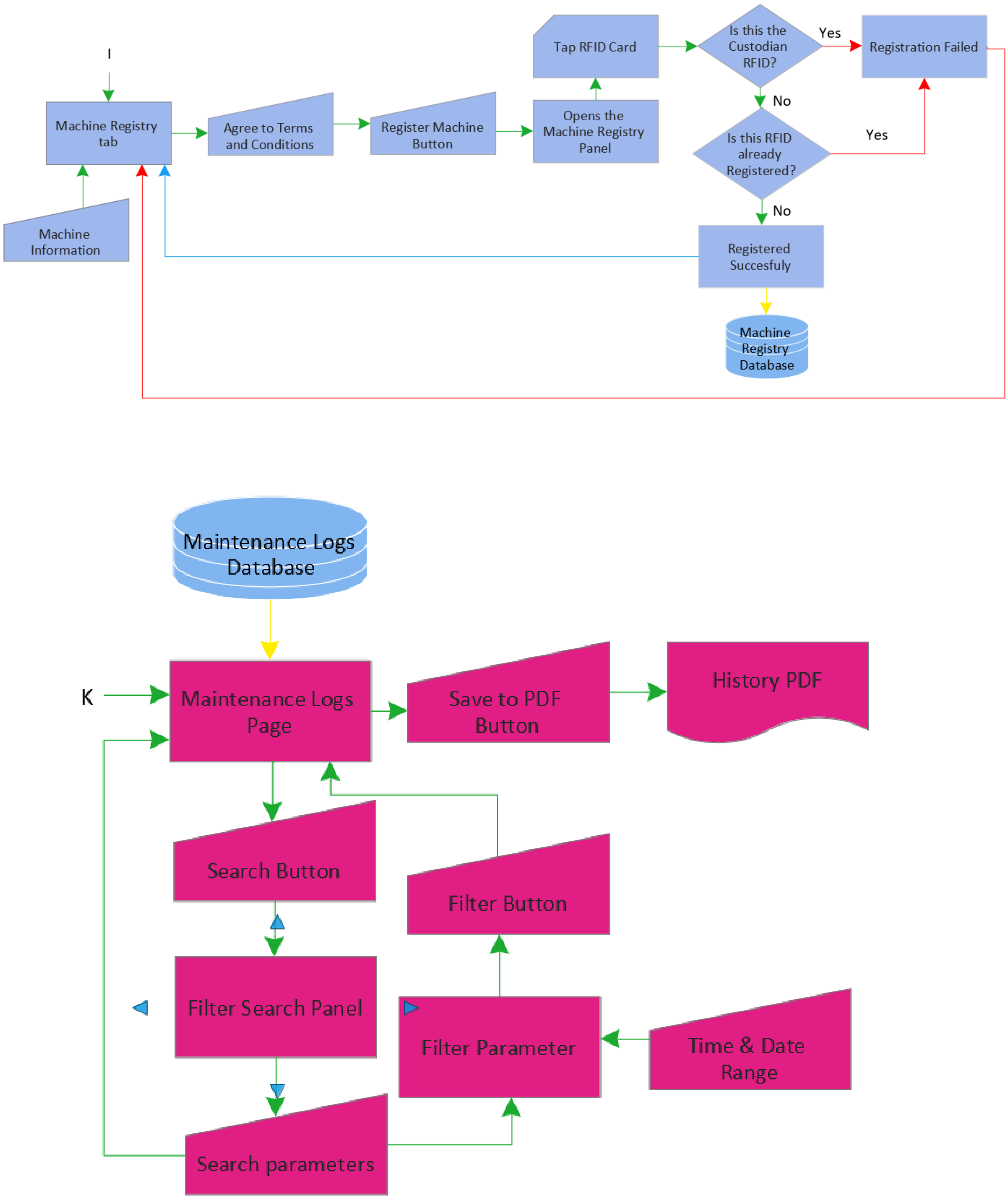
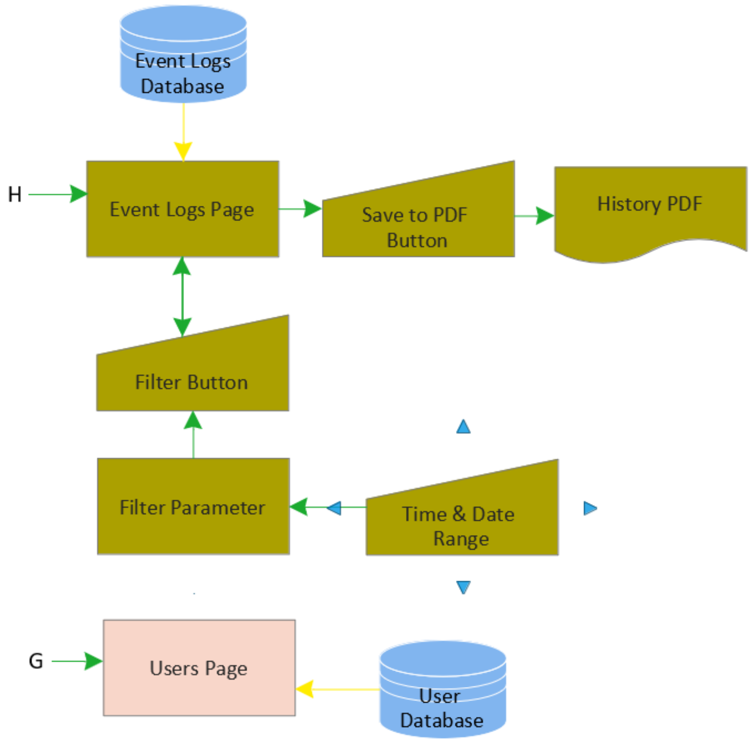


Figure 28. Program Flowchart for the GUI (Part 5)



	Initializer Section	Where the GUI will establish a stable connection with the hardware.
	Login Section	Where matters of being able to Log in to the Dashboard is handled.
	User Registry Section	Where matters of Registering a Custodian as a User is being handled.
	Dashboard Section	Where all the LEUMS features may be accessed.
	Machine Registry Section	Where all registrations for machines are being processed and handled.
	Database Components	Where the data from the GUI is being read and inserted.
	Event Logs Section	Where all activities are being recorded and handled
	Users Section	Where the user can view the data on all the registered custodians on the Application.
	History Section	Where the user can interact and view all the data of past sessions.
	New Session Section	Where all transactions for borrowing the machines are being processed and handled.
	Maintenance Report & Schedule Section	Where all the maintenance schedule and machine conditions are being kept and organized.
	Maintenance Logs Section	Where the user can interact and view all the data of past maintenances.
	Machine Registry Section	Where the user can interact and view all the data on all currently registered machines.
	Decommissioned Machine Registry Section	Where the user can interact and view all the data on all former registered machines.
	→	Progress Forward Process.
	→	Background Process.
	→	Progress Backward Process.
	→	Forced Return Process.

Figure 29. Program Flowchart for the GUI (Part 6)

PROJECT DESIGN FOR THE RFID-BASED LABORATORY EQUIPMENT USAGE MONITORING SYSTEM

The following figures show the casing designs and the actual pictures of the completed project including the parts.

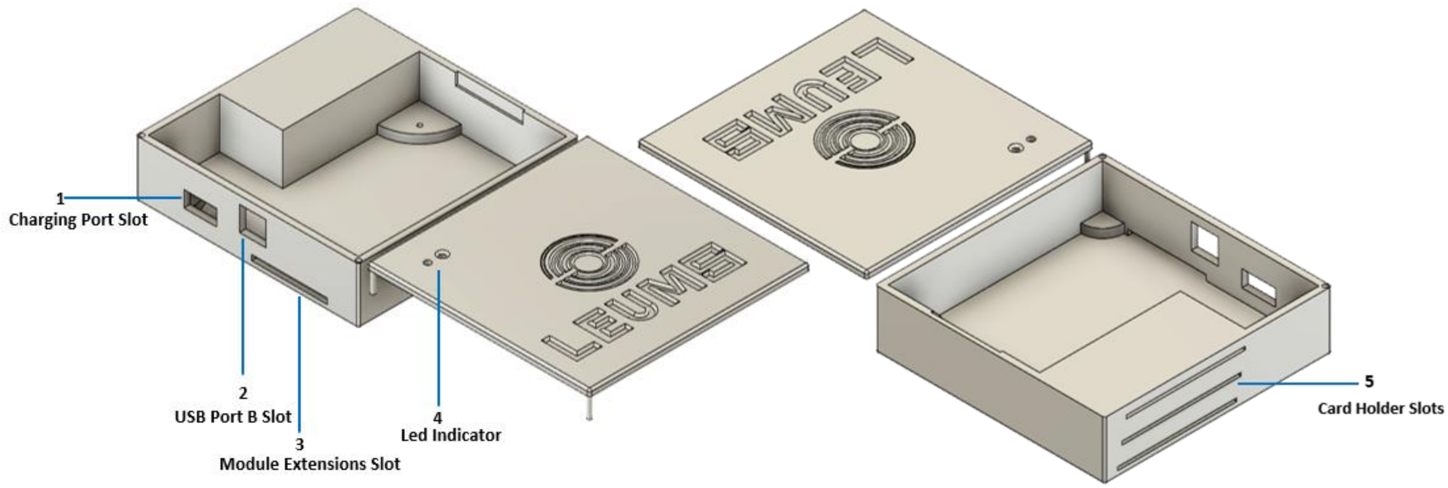


Figure 30. Casing for the Logging System Module (Custodian's Side)

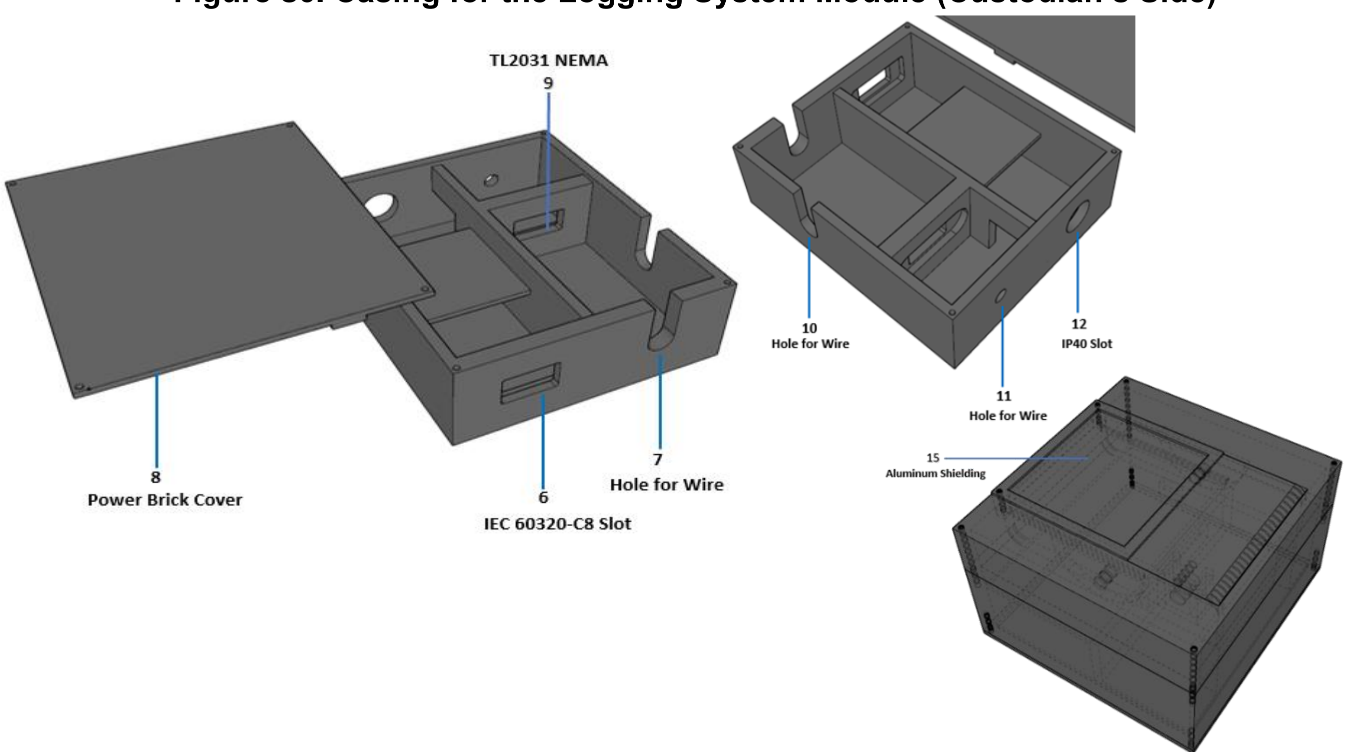
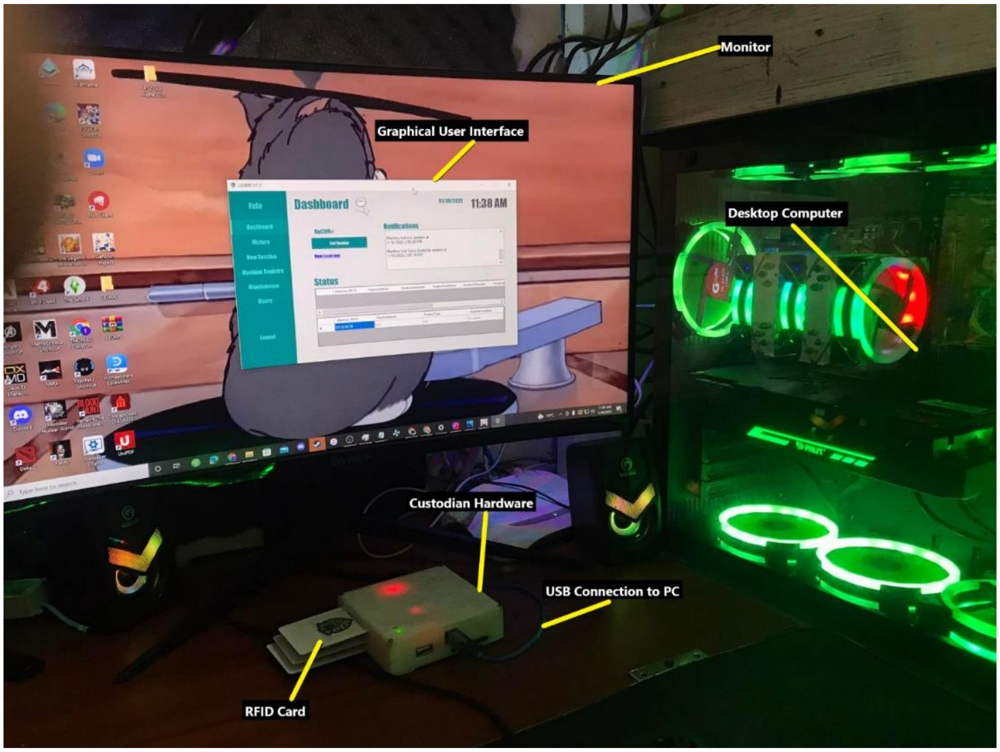


Figure 31. Casing for the Equipment Access System (Fablab Side)



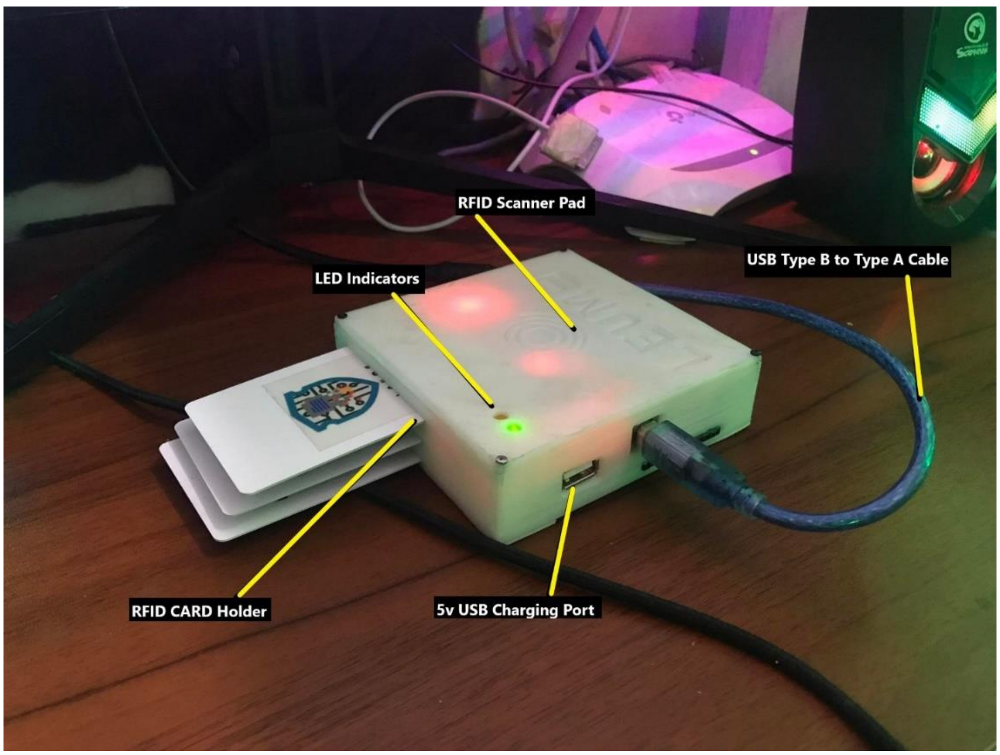


Figure 32. Actual Picture of the Logging System (Custodian's Side)

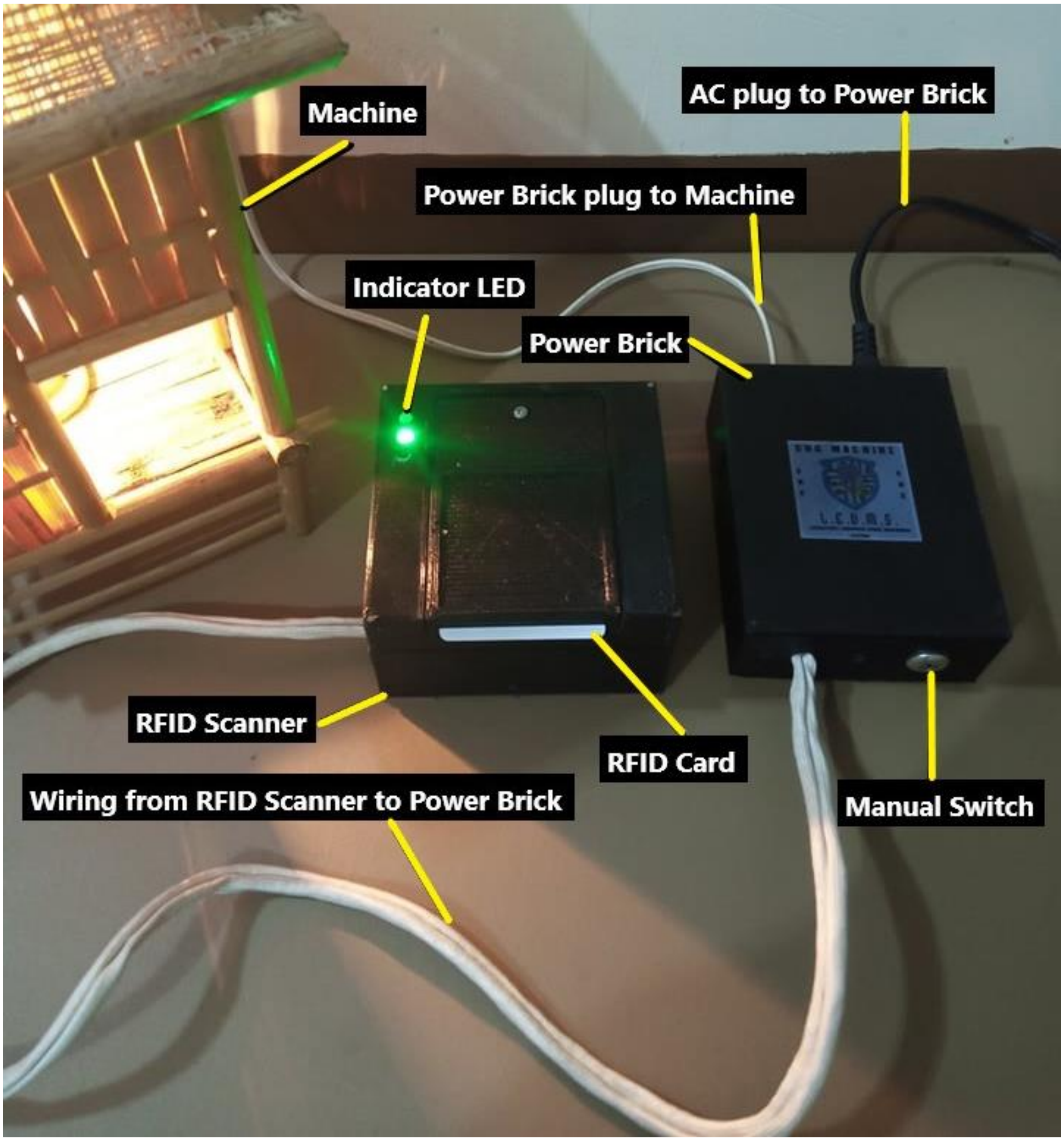


Figure 33. Actual Picture of the Equipment Access System (FabLab Side)

THE GRAPHICAL USER INTERFACE OF THE RFID-BASED LABORATORY EQUIPMENT USAGE MONITORING SYSTEM

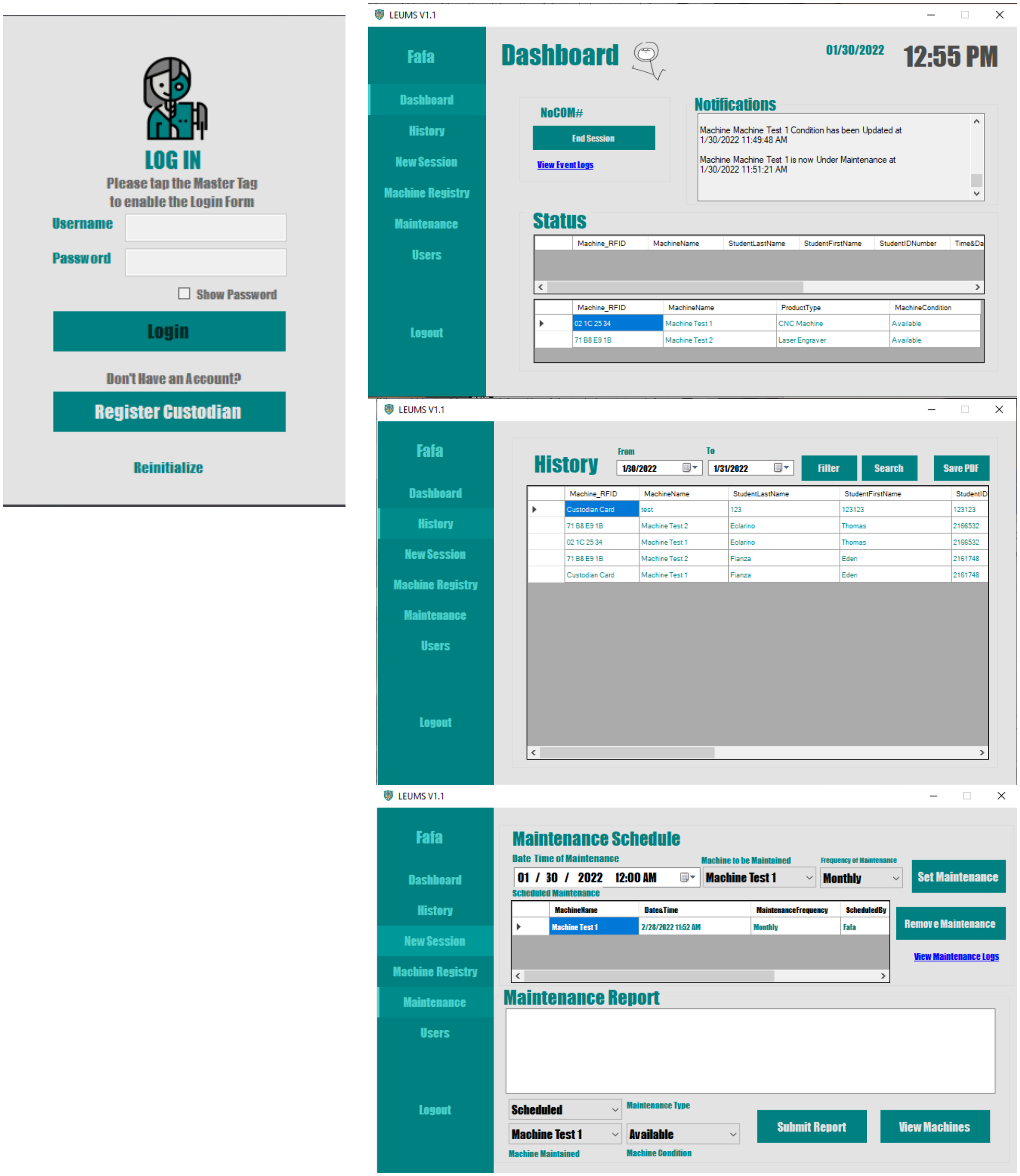


Figure 34. Screenshots of the GUI of the RFID-Based Laboratory Equipment Usage Monitoring System

Machine_RFID	MachineName	ProductType	Brand	Model/Model_Number	SerialNumber	DateAcquired	InitialConditionofMachine	MachineCondition	RegisteredBy	DateofRegistration
02 1C 25 34	Machine Test 1	CNC Machine	Toshiba	821355239	c54825fg6462	12/27/2021 12:00:00 AM	Brand New	Available	Fafa	1/30/2022 11:42:22 AM
71 B8 E9 1B	Machine Test 2	Laser Engraver	Creality	04674325	usf24432sd66	1/3/2022 12:00:00 AM	Replaced Powersupply	Available	Fafa	1/30/2022 11:43:38 AM

(a) Registry Logs

Machine_RFID	MachineName	StudentLastName	StudentFirstName	StudentIDNumber	Time&DateIn	Time&DateOut	AuthenticatedBy	ProjectNumber	ProjectDescription
Custodian Card	test	123	123123	123123	1/16/2022 2:05:09 PM	1/16/2022 2:05:18 PM	Fafa	123123	123123
71 B8 E9 1B	Machine Test 2	Eclarino	Thomas	2166532	1/30/2022 11:45:53 AM	1/30/2022 11:46:22 AM	Fafa	ECE 526	Testing the GUI
02 1C 25 34	Machine Test 1	Eclarino	Thomas	2166532	1/30/2022 11:44:50 AM	1/30/2022 11:46:27 AM	Fafa	ECE 526	Test
71 B8 E9 1B	Machine Test 2	Fianza	Eden	2161748	1/30/2022 11:48:05 AM	1/30/2022 11:48:10 AM	Fafa	ECE 526	Testing of GUI
Custodian Card	Machine Test 1	Fianza	Eden	2161748	1/30/2022 11:47:25 AM	1/30/2022 11:48:18 AM	Fafa	ECE 526	Testing of GUI

(b) History Logs

Event	Date&Time
User Fafa Logged in at 12/1/2021 2:42:43 AM	
Machine test is registered at 12/1/2021 2:43:13 AM	
User Fafa Logged in at 1/2/2022 3:36:50 AM	
User Fafa Logged in at	1/12/2022 5:26:32 AM
Machine test is in session at	1/16/2022 2:05:09 PM
Machine test Force Ended its session at	1/16/2022 2:05:18 PM
Machine test Condition has been Updated at	1/30/2022 11:40:25 AM
Machine Machine Test 1 is registered at	1/30/2022 11:42:22 AM
Machine Machine Test 2 is registered at	1/30/2022 11:43:38 AM
Machine Machine Test 1 is in session at	1/30/2022 11:44:50 AM
Machine Machine Test 2 is in session at	1/30/2022 11:45:53 AM
Machine Machine Test 2 Ended its session at	1/30/2022 11:46:22 AM
Machine Machine Test 1 Ended its session at	1/30/2022 11:46:27 AM
Machine Machine Test 1 Force Ended its session at	1/30/2022 11:48:18 AM
Machine Machine Test 1 Condition has been Updated at	1/30/2022 11:49:48 AM
Machine Machine Test 1 is now Under Maintenance at	1/30/2022 11:51:21 AM

(c) Event Logs

Machine_Name	Maintained_By	Machine_Condition	Maintenance_Type	Maintenance_Report	Time&DateSubmited
test	Fafa	Decommissioned	Breakdown	Done with initial testing	1/30/2022 11:40:24 AM
Machine Test 1	Fafa	Under Maintenance	Breakdown	Testing of Maintenance Report Function	1/30/2022 11:51:42 AM
Machine Test 1	Fafa	Available	Scheduled	Testing of Maintenance Report Function	1/30/2022 11:52:27 AM

(d) Maintenance Logs

Figure 35. Screenshots of Log sheets

TESTING AND TROUBLESHOOTING RESULTS OF THE RFID-BASED LABORATORY EQUIPMENT USAGE MONITORING SYSTEM

A. TESTING OF THE INDIVIDUAL MODULES

A.1. Testing the Arduino Microcontrollers

The objective of this testing procedure is to check if the Arduino Microcontroller is working and the board can operate on a 5Vdc power source. An orange LED near the center of the board (labeled "Pin 13 LED" in the image below) should flash on and off when the board is powered up (boards come from the factory preloaded with software to flash the LED as a simple check that the board is working).

Testing Procedures:

1. Plug the board into a USB port on the computer
2. Check that the green LED power indicator on the board illuminates. Standard Arduino boards (Uno, Duemilanove, and Mega) have a green LED power indicator located near the reset switch.
3. An orange LED near the center of the board (labeled "Pin 13 LED" in the image below) should flash on and off when the board is powered up (boards come from the factory preloaded with software to flash the LED as a simple check that the board is working). The Figure on the next page illustrates this set-up.
4. If the power LED does not illuminate when the board is connected to your computer, the board is probably not receiving power.

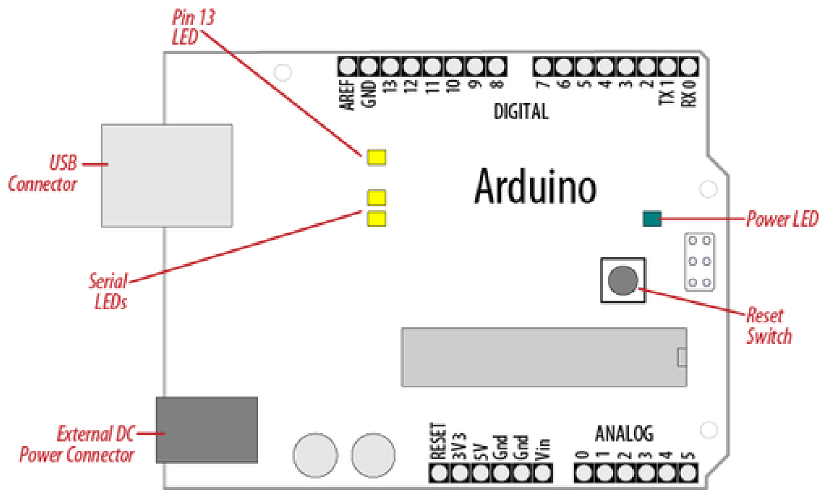


Figure 36. Set-up for LED Indicators on the Arduino Board

Results:

Since the pin 13 LED is flashing, the sketch is running correctly, which means the chip on the board is working and receiving communication from the computer correctly. The Figure below shows a documentation of the good result of this test.

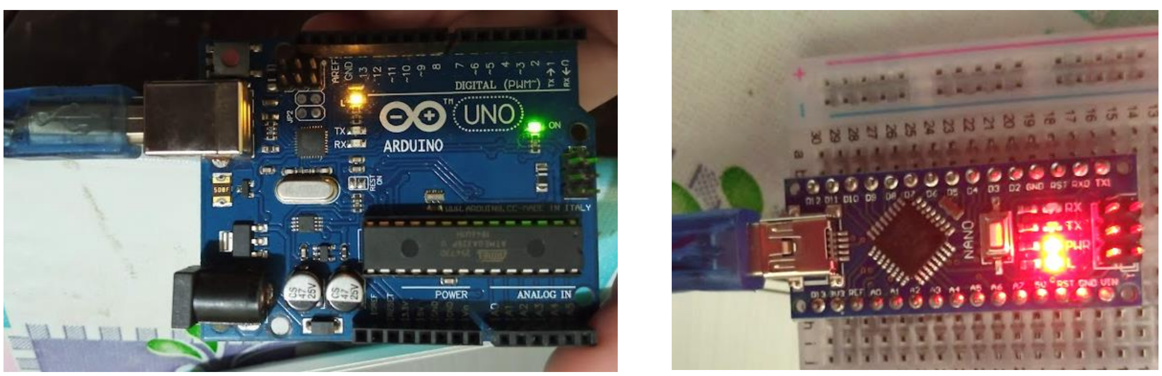


Figure 37. Result of the Testing of the Arduino Uno Board

A.2. Testing of the 5Vdc Coil Relay (SPDT)

The objective of this test is to test the de-energized condition of the relay.

Procedure:

1. Consult the relay schematic or data sheet. Relays have fairly standard pin configurations, but it is best to search for the data sheets to find out more about the number of pins from the manufacturer, if available. The figure below shows the configuration of the 5Vdc Coil Relay.

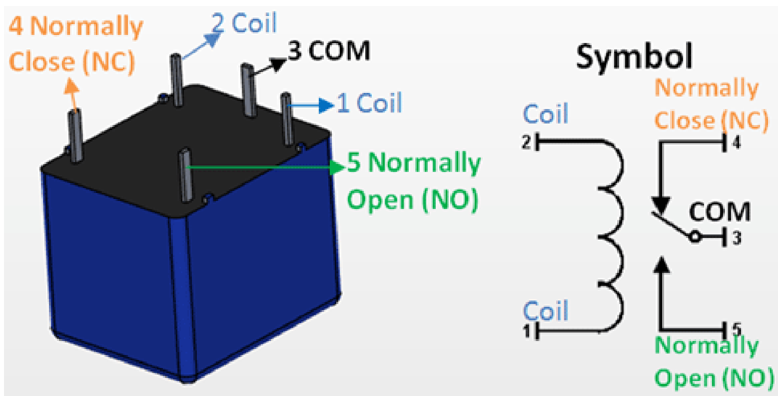


Figure 38. Configuration of the 5Vdc Coil Relay

2. Assess the contact configuration of the relay. Use a digital multimeter (DMM) to test the resistance between each pole of the relay and the corresponding NC and NO contacts for that pole. A de-energized relay must display an infinite resistance if the NO (Normally open) and Common pin is measured. While the resistance between the NC (Normally closed) and Common must be 0 ohms. When being energized a clicking sound is heard.

3. Energize the relay. Use an independent voltage source appropriate for the rating of the relay coil. If the relay coil is diode protected, make sure that

the independent voltage source is connected with the proper polarity. Listen for a click when the relay is energized.

4. Check the energized condition of the relay contacts. Use a digital multimeter (DMM) to test the resistance between each pole of the relay and the corresponding NC and NO contacts for that pole. All NC contacts should read infinite resistance to the corresponding pole. All NO contacts should read 0 ohms to the corresponding pole.

Result:

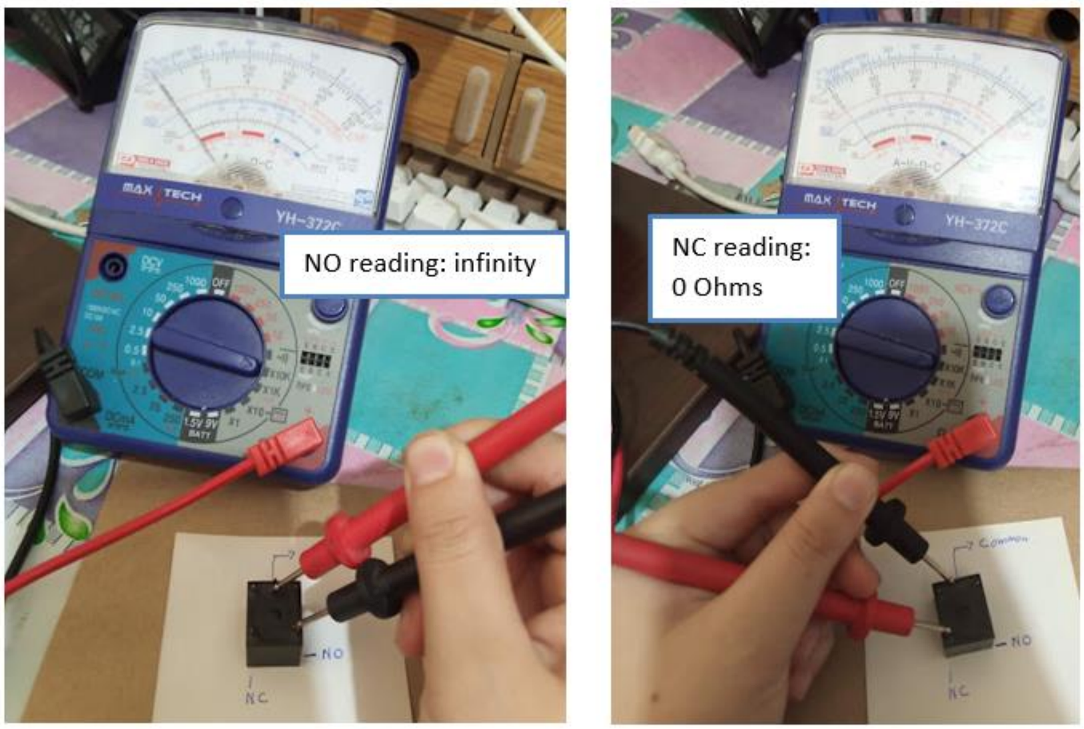


Figure 39. Testing Result of the 5Vdc Coil Relay (SPDT)

When the resistance between the NO and common pin was measured, the relay displayed an infinite resistance meaning the relay is de-energized.

Also it is at this state that the resistance between NO and common pin was zero. Furthermore, when the pin was energized, a clicking sound was heard.

A.3. Testing of the RFID Card and RFID Reader

The objective of this test is to be able to check if the RFID Reader can detect the RFID tag and can be communicated to the Arduino IDE.

Procedures:

1. Connect VCC pin on the module to 3.3V on the Arduino and GND pin to ground.
2. The pin RST can be connected to any digital pin on the Arduino. In this case, it is connected to digital pin#5.
3. The IRQ pin is left unconnected as the Arduino library used in this procedure does not support it.
4. As RC522 module require a lot of data transfer, they will give the best performance when connected up to the hardware SPI pins on a microcontroller. Note that each Arduino Board has different SPI pins which should be connected accordingly. For Arduino boards such as the UNO/Nano V3.0 those pins are digital 13 (SCK), 12 (MISO), 11 (MOSI) and 10 (SS).
5. The connections can be seen in the figure on the next page.

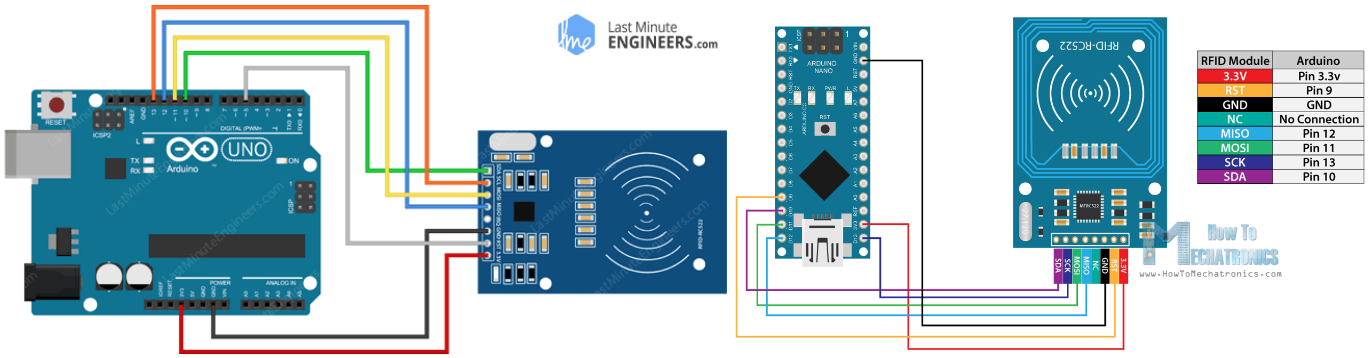


Figure 40. Wiring RC522 RFID Reader Writer Module with Arduino UNO and Nano

6. Communicating with RC522 RFID module may be done through the Arduino IDE library called **MFRC522 library** which simplifies reading from and writing to RFID tags. To install it, open the Arduino IDE, go to Sketch > Include Library > Add .ZIP Library, and then select the rfid-master.zip file downloaded.

7. Once the library is installed, open Examples submenu and select MFRC522 > DumpInfo example sketch as shown in the figure below.

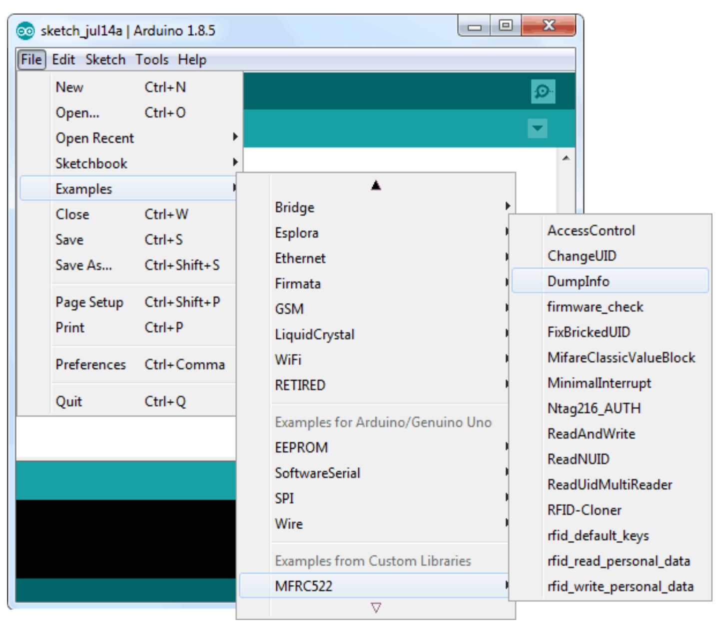


Figure 41. Screenshot of the DumpInfo Sketch in Arduino IDE

8. This sketch will not write any data to the tag. It just assures that the tag is read and displays some information about it. This can be very useful before trying out any new tag.

9. Go to the beginning of the sketch and make sure that the **RST_PIN** is correctly initialized, in this case use digital pin #5 as shown in the figure below.

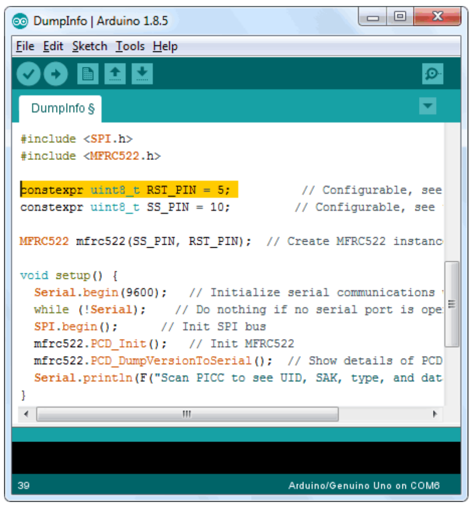


Figure 42. Screenshot of the RST_PIN Initialization

10. Upload the sketch and open the Serial Monitor. As soon as the tag is brought closer to the module, a series of information as shown in the figure below is shown in the serial monitor.

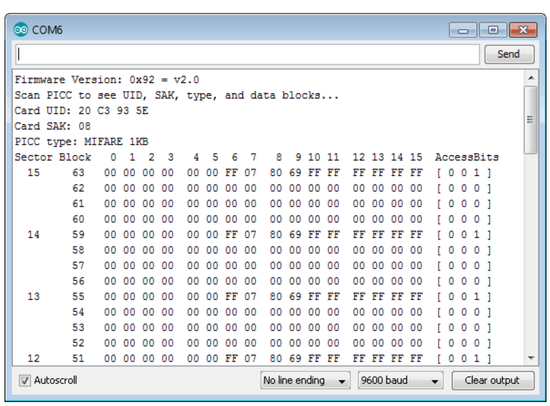


Figure 43. Screenshot of the Serial Monitor

11. The Serial Monitor displays all the useful information about the tag including tag's Unique ID (UID) and the memory size.

Result:

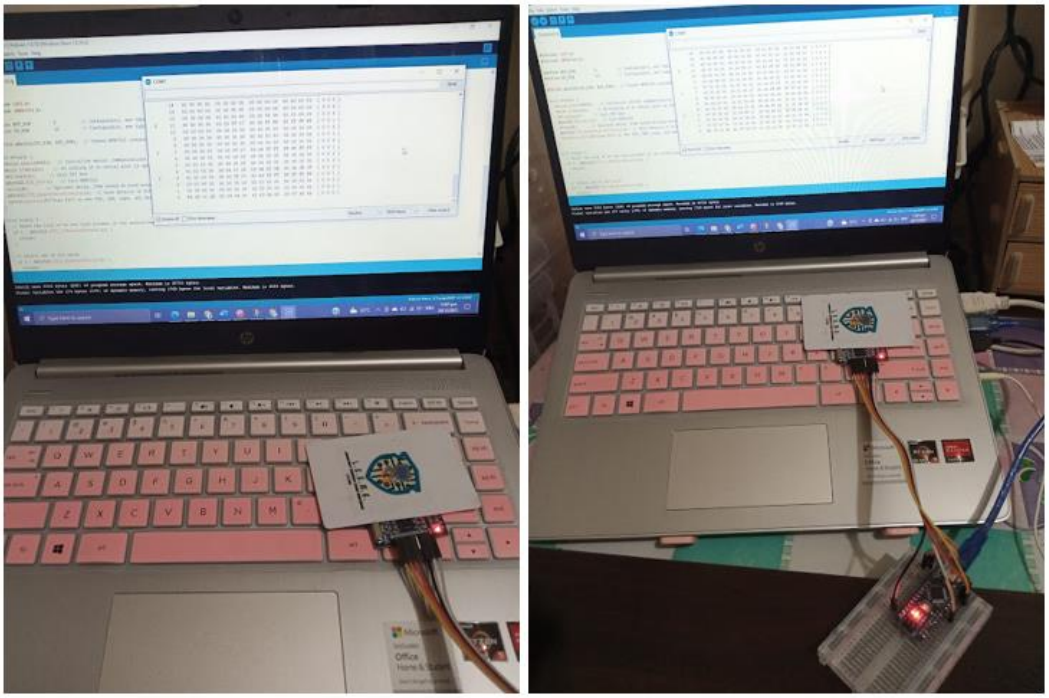


Figure 44. Result of the Testing of the RFID tag and reader

As shown in the figure, the complete information was displayed in the Serial Monitor, thus confirming that the entire reader and tag is functional.

B. TESTING OF THE PROJECT

B.1. Testing for the Time the System Reads the Tags in the Logging System (Custodian's Side)

The objective of this test is to determine the average time it takes the system to correctly read an RFID tag for the Logging System. The testing times were verified by three Fablab staff members. Twenty (20) trials were conducted to obtain a more adequate average time result. The results of the testing are shown in Table 16.

Table 16. Results for Average RFID tag Reading Time

Trial	Time an RFID tag was read	Trial	Time an RFID tag was read
1	0.79s	11	0.83s
2	1.03s	12	0.8s
3	0.9s	13	0.7s
4	0.89s	14	0.76s
5	1.39s	15	0.78s
6	0.99s	16	0.8s
7	0.76s	17	1.08s
8	1.4s	18	0.83s
9	0.78s	19	0.73s
10	0.64s	20	1.07s
AVERAGE TIME: 0.8975s			

As shown in the Table, the average time it takes for the system to read the UID Number and information in the RFID tag is about 0.8975 seconds. This implies that the reader is very capable to reduce the time spent by the custodian or students in manually writing down information regarding the use of the machines in the Fablab.

B.2. Testing of the Equipment Access System (FabLab Side)

The objective of this test is to check if the system can allow access to the equipment if the correct RFID tag is used and prevent access if an incorrect RFID tag is used. This test involved trying both correct and incorrect cards and testing if an equipment can be powered on. The results of the testing is shown in Table 17.

Table 17. Testing Result of the Equipment Access System

TRIAL	RFID CARD UID ASSIGNED TO THE MACHINE	RFID CARD UID USED	ACCESS STATUS
1	7I B8 E9 1B	7I B8 E9 1B	Enabled
2	7I B8 E9 1B	7I B8 E9 1B	Enabled
3	7I B8 E9 1B	02 IC 25 34	Disabled
4	7I B8 E9 1B	7I B8 E9 1B	Enabled
5	7I B8 E9 1B	02 IC 25 34	Disabled
6	02 IC 25 34	02 IC 25 34	Enabled
7	02 IC 25 34	02 IC 25 34	Enabled
8	02 IC 25 34	02 IC 25 34	Enabled
9	02 IC 25 34	7I B8 E9 1B	Disabled
10	02 IC 25 34	7I B8 E9 1B	Disabled

B.3. Testing of the GUI

The objective of this test is to verify if the created GUI is functioning correctly. This is done by ensuring that the RFID reader communicates with the GUI.

Results:

The GUI's functionality is proven by the code being able to communicate properly with the RFID card. The ability of the GUI to detect and declare a wrong card, thereby preventing any form of access to the logs is proof that the GUI is functional. Another proof is that the GUI is able to detect the Custodian RFID card and therefore unlock its features is also a way to verify that the GUI is functional and can perform the tasks that it is intended to do. The figure below shows a screenshot of the GUI showing its functionality to detect the RFID cards.

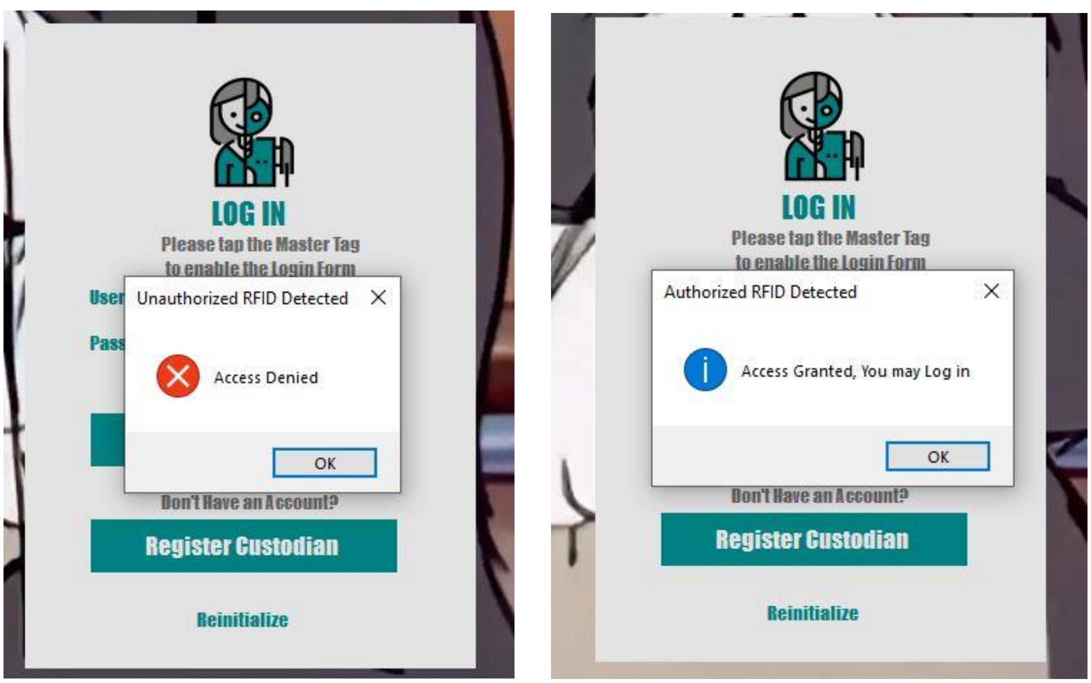


Figure 45. Screenshots of the initial access in the GUI

B.4. Testing of the System's Ability to Generate Log Reports

The objective of this test is to be able to verify the system's functionality of generating logs of the machines used.

Procedures:

1. In the GUI, select the record for printing. The custodian may choose to print the needed records only by using the filter function (see Figure 45 for sample screenshot.

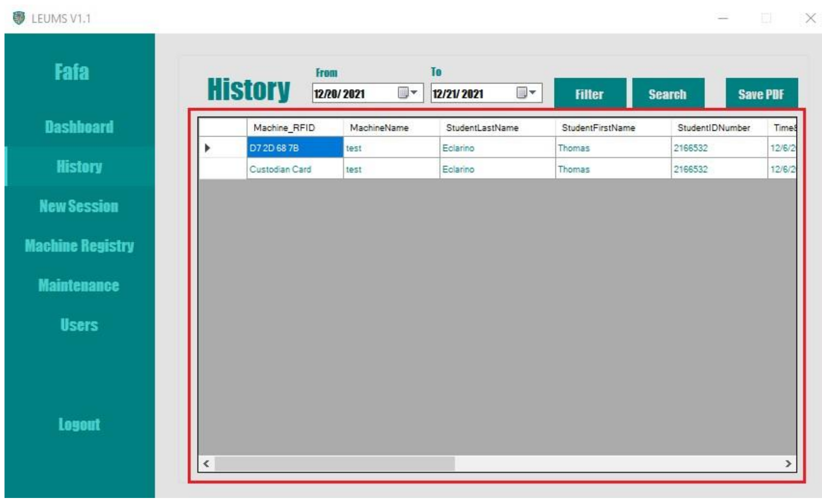


Figure 46. Sample Screenshot of History Reports

2. Tap the custodian card on the top of the RFID reader to be able to export the records into a pdf (ready to print) file format (see Figure 46)

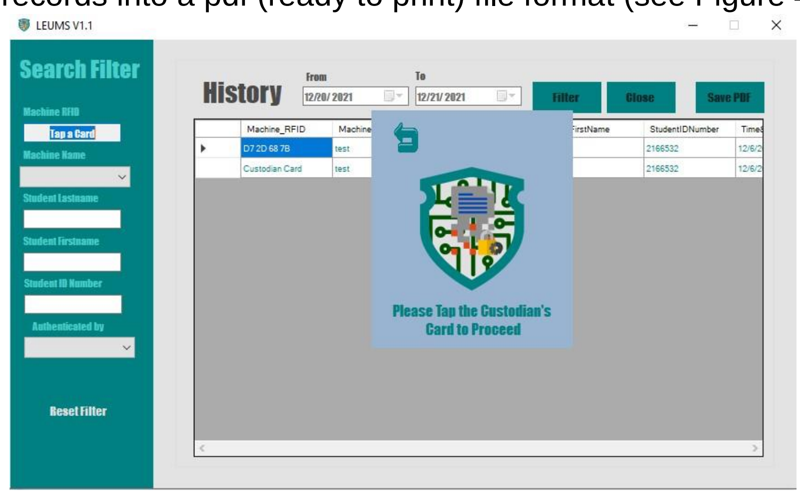


Figure 47. Screenshot of Instructions provided in the GUI

3. Save the pdf in the desired folder.
4. Open the file and it is now ready to be printed.

Machine_RF ID	MachineNa me	StudentLast Name	StudentFirst Name	StudentIDNu mber	Time&DateI n	Time&Date Out	Authenticate dBy	ProjectNumb er	ProjectDescr iption
Custodian Card	CNC	Eclarino	Thomas	2166532	1/30/2022 2:59:19 PM	1/30/2022 2:59:35 PM	Eden	ECE 526	Testing of GUI Functions
71 B8 E9 1B	Laser	Eclarino	Thomas	2166532	1/30/2022 2:58:23 PM	1/30/2022 2:59:44 PM	Eden	ECE 526	Testing of Functions
71 B8 E9 1B	Laser	Fianza	Eden Hope	2161748	1/30/2022 3:03:36 PM	1/30/2022 3:04:24 PM	Eden	ECE 526	Testing of GUI Function

Figure 48. Screenshot of how the pdf generated log is presented

Results

The system was able to generate reports and logs for all of its features.

B.5. Evaluation of the FabLab Staff

Evaluation was conducted to evaluate the acceptability of the system based on ISO 9126 software quality and the OECD Project Evaluation Checklist. The overall functionality of the project was tested and evaluated by the FabLab staff. Each respondent used and evaluated the system to determine the level of acceptability of the system. Respondents could answer 1 (Not acceptable) to 5 (Highly acceptable) to each question on the quality of the system.

Results

The project was tested and evaluated by three Fablab staff for its functionality with 3 machines, the Laser Engraver and Cutting Machine, the Die Cutter Machine and the drill press to ensure that the system is capable of allowing or preventing access to the machines whatever their specifications are. A checklist was provided for the staff to rate the project. The checklist allowed the respondents to answer using the Likert scale. The following table provides the result.

Table 18. Result for the Project Quality Metrics

Software and Project Quality	CRITERIA	SCORE
FUNCTIONALITY The capability of the software to provide functions which meet the stated and implied needs of users under specified conditions of usage (what the software does to meet needs)	The ability of the system to print reports The ability of the system to interact directly with the RFID module The ability of the system to grant authorized access and control The ability of the system to ensure accurate interaction between the modules of the system.	**5.00** **Highly Acceptable**
RELIABILITY The capability of the software product to maintain its level of performance under stated conditions for a stated period of time.	The ability of the system to provide consistent correct output The ability of the system to maintain the same level of performance when printing reports without errors, problems, crash, or service interrupts.	**5.00** **Highly Acceptable**
EFFICIENCY The capability of the software product to provide desired performance, relative to the amount of resources used, under stated conditions.	The ability of the system to provide accurate response and precise records upon user's requests The cost of the system is justifiable	**5.00** **Highly Acceptable**
USABILITY The capability of the software product to be understood, learned, used and provide visual appeal, under specified conditions of usage (the effort needed for use)	The system can be used as a tool in providing information to the user, specifically equipment usage information The system ensures authorized access to the machines in the FabLab. The results obtained from the use of the system will be useful to the FabLab staff and custodian.	**5.00** **Highly Acceptable**
MAINTAINABILITY The capability of the software product to be modified which may include corrections, improvements or adaptations of the software to changes in the environment and in the requirements and functional specifications (the effort needed for modification)	The system can be easily modified, tested and maintained. Through the user's manual, the users will be able to retain the project's usability even after the period of external assistance has ended.	**5.00** **Highly Acceptable**
PORTABILITY The capability of the software product to be transferred from one environment to another. The environment may include organizational, hardware or software.	The system can be easily moved to another environment and easily installed.	**5.00** **Highly Acceptable**

The results of the evaluation checklist accomplished by the three (3) evaluators show that the project has High Acceptability in all the aspects contained in the checklist. The researchers also obtained feedback from the evaluators and noted the following suggestions:

1. Suggestion for the system to be used also in the ECE laboratory and the other laboratory in the University.
2. Improvement of the casing. Maybe consider acrylic casing. This is cheaper and more durable as compared to 3d printed materials.

Documentation of the Testing and Evaluation at the FabLab

The succeeding figures show a documentation of the evaluation and testing done at the Fablab.

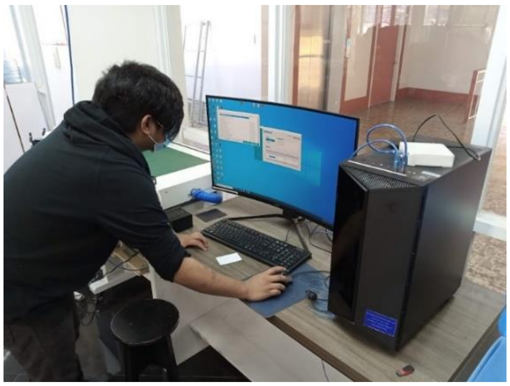


Figure 49. Documentation of Evaluation and Testing

Problems Encountered and Solutions Done

The table below is a documentation of the problems the researchers experienced in the duration of the project study and the solutions they made to be able to finish the project.

PROBLEMS ENCOUNTERED	SOLUTION
Digital Relay did not get enough power	The group added a 5V output charger module
The Arduino Program does not reset on its own.	The researchers needed to reboot the Arduino for each use that is why they added a switch that automatically turns off the Arduino when a card is not present on the slot.
Yellow Indicator Light, which represents that the system is ready to read a card, does not light up due to the Arduino being turned off having no power coming from the Arduino when a card is not inserted.	The group decided to have two 5v DC supplies, one to drive an analog relay by a switch that triggers when a card is inserted and one to supply power to whichever the relay directs it.
Normal PCB when etched yielded a messy result that can lead to short or open circuits	Used a pre-sensitized PCB instead
RFID reader detected RFID even if it was not placed directly inside the pocket of the system.	Coated the inside of the case with aluminum foil, this way the RFID reader cannot read signals coming from the outside of the casing.
Screws for assembly were too short for the designed casing	Used tempered metal strings and made a hook.
Messy Spliced Wiring	Use T-type splicer for cleaner and safer connections
Fitting all the components inside the Power Brick	Placed the components in a configuration where they would fit and used melted glue stick to make sure that the components stay in place and prevent shorting within the power brick.
Unoptimized GUI Program for low memory computers.	Optimized by using less memory straining methods and section them by Functions but this solution only improves the system by at least 20%.
Maintenance Scheduling for 2 or more machines does only register 1 machine which is the first to be processed.	By using a return function and making sure that no schedule has exactly the same time to the last second.

User Manual

L.E.U.M.S.

Laboratory Equipment Usage Monitoring System

User Manual

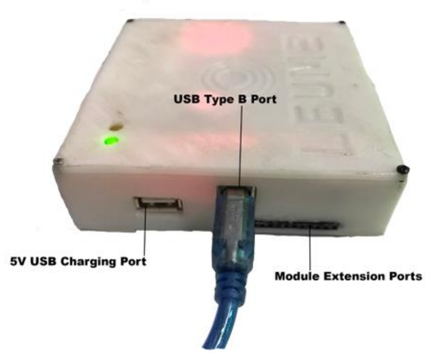
Package List

1 x LEUMS Custodian Hardware
1 x LEUMS Application Software (Windows)
3 x LEUMS Laboratory Equipment Hardware
3 x Power Cable
1 x Micro USB Cable
1 x USB Type B Cable
1 x User Manual

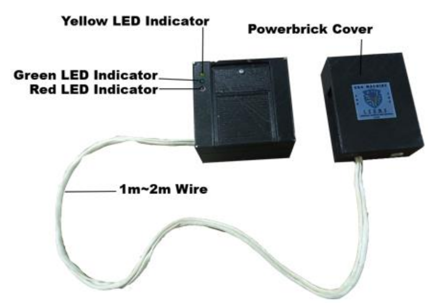
Product Overview

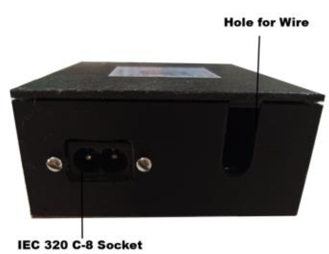
Top-Front Custodian Hardware:

Top-Side Custodian Hardware:



Top-Side Laboratory Equipment Hardware:





Card Reader Slot

IP40 Key Switch

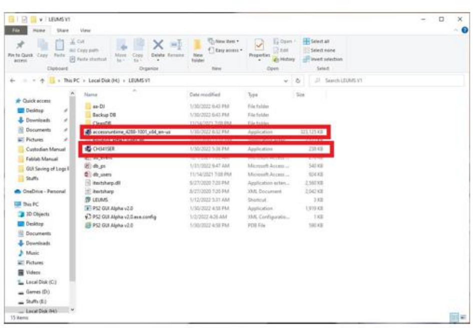
Specifications

LEUMS Application Software	
Minimum Requirements	
Operating System	Windows 10 (64-bit)
CPU	1GHz or faster processor
RAM	1GB (32-bit) or 2GB (64-bit) of RAM
Storage	500 MB of free disk space
NET Framework	.NET version 4.5 or above
LEUMS Custodian Hardware	
Compatibility	PC
Power Supply	+5v ⎓ 50mA
Microcontroller	ATmega328P @16MHz
SRAM	2 KB
EEPROM	1 KB
Flash Memory	32 KB
Read Range	Approx. 3cm with card
Data Transfer Rate	10Mbit/s
LEUMS Laboratory Equipment Hardware	
Power Supply	+5v ⎓ 19mA
Microcontroller	ATmega328 @16MHz
SRAM	2 KB
EEPROM	1 KB
Flash Memory	32 KB
Read Range	Approx. 3cm with card
Data Transfer Rate	10Mbit/s
Wire Length	1m ~ 2m

How to Connect LEUMS Custodian Hardware to PC

Connect via USB

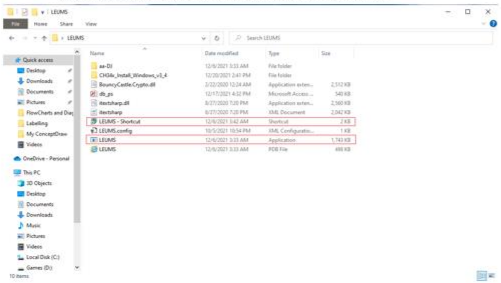
1. Navigate to the LEUMS folder. Open the CH341SER and accessruntime_4288-1001_x64_en-us. Install these files which are required in order to use the program.



2. Locate the USB type B on the Left Side of the LEUMS Hardware.

Connect the LEUMS Hardware to your PC with the USB type B connector. The Power Indicator LED (Green LED) should light up to indicate the connection was successful

3. Navigate to the LEUMS folder and Run the LEUMS Application.
(Note: The Shortcut may be placed on the desktop for easier access)



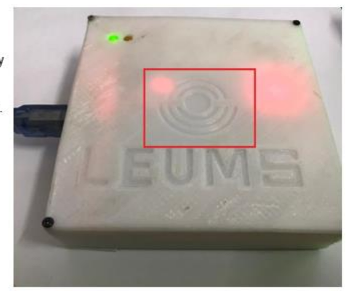
4. Upon running the application, the initializer will now list the detected serial communication ports that the LEUMS Hardware is connected to. If there is no communication port detected or if the correct communication is not on the list. Please make sure the connection of the USB type B from the LEUMS Hardware to the PC is properly connected and press the refresh button highlighted by the yellow square.
Once the correct communication port is selected you may click the Connect button.

5. Once Connected, a Disconnect button is will be present in case of further changes to the communication port. If the correct communication port is already selected. Click on proceed and the connection from the LEUMS Hardware and the PC is now established and will now be directed to the Login Page.

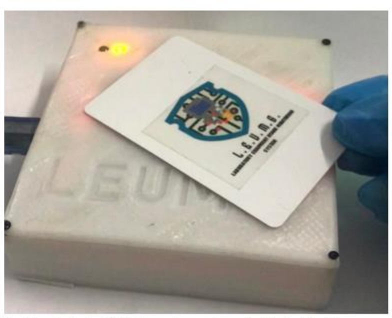
How to Scan RFID using the LEUMS Custodian Hardware

Tap the Card

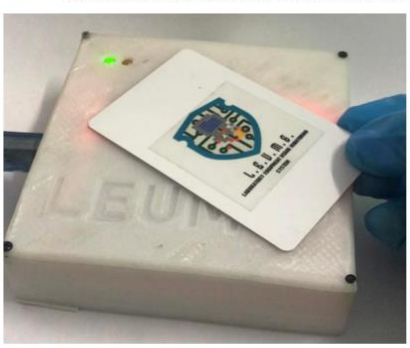
1. The location of the RFID scanner is directly under the embossed signal logo above the LEUMS embossed text. Which is where the user is designated to tap the card for a reliable scan.



2. Tapping a card or any RFID within the scanners frequency range on the scanner will temporary turn off the Power Indicator LED (Green LED) and turn on the Read Indicator LED (Yellow LED) indicating that the LEUMS Hardware have read the RFID data and has sent it to the GUI.



(Note: The turning off of the Power Indicator in this instance does not mean that the Arduino Uno is turned off, but is just an indicator that the LEUMS Hardware is in Read Mode)



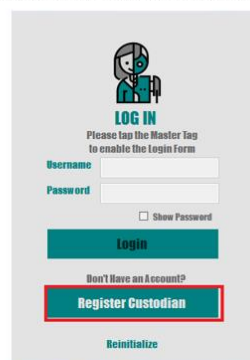
3. After an approximately 0.5s of tapping, the Power Indicator LED (Green LED) will turn back on and turns off the Read Indicator LED (Yellow LED) and will now be ready for another tap.

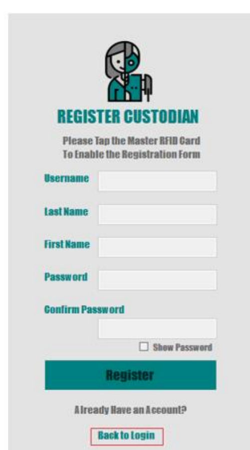
(Note: Leaving the card on top of the scanner is not considered a tap therefore the scanner will not read the card unless the user lifts the card away from the scanner range and tap again)

How to Register as a Custodian on the LEUMS Application Software

Register Custodian

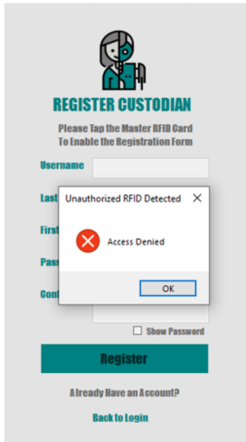
1. After proceeding the Initializer. The Login Page also contains the Register Custodian button. Click this button to register as a custodian in order to be able to Log in.

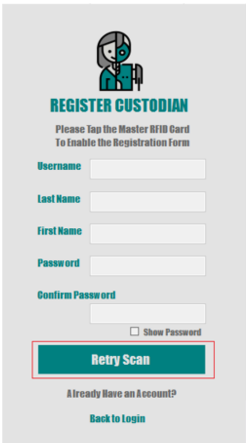


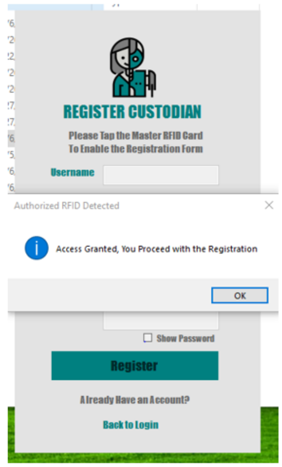


2. After loading the registration page. The user will be required to tap the Custodian RFID or also known as the Master RFID or Master Tag that is hard coded on the application. If the user is already registered and have an account clicking the **Back to Login** link will take the user back to the Login page.

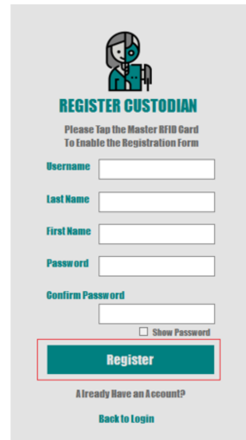
3. If the RFID card the user tapped on the scanner is not the Custodian Card/Master RFID/Master Tag the GUI will not give the user access to register and will have to click on the Retry button to tap the correct card/RFID tag which will show after the deny of access in place of the register button.







4. If the RFID card the user tapped on the scanner is the Custodian Card/Master RFID/Master Tag the GUI will detect it and will allow the user to register as a custodian.



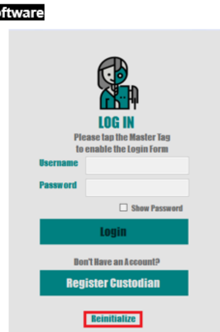
5. If the required fields are filled out correctly, click the Register button and the GUI will prompt the user that the custodian has successfully registered. The user will automatically be redirected to the Login after a successful registration.

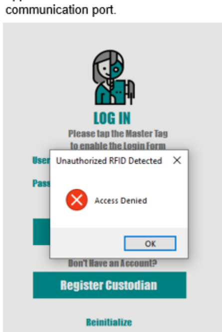
(Note: The GUI will inform the user if the chosen username is already in use.)

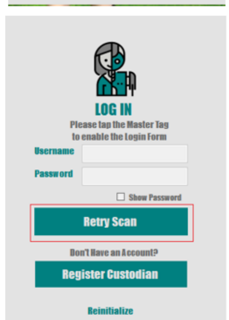
How to Log in on the LEUMS Application Software

Login

1. After loading the registration page. The user will be required to tap the Custodian RFID or also known as the Master RFID or Master Tag that is hard coded on the application.
2. If after tapping any card and the GUI does not detect any information about the card. It's advised to reinitialize and make sure the application is connected to the correct serial communication port.

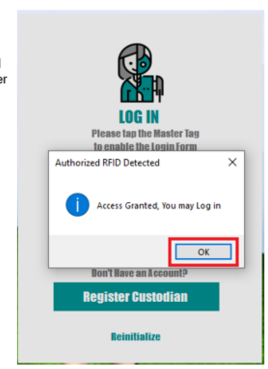


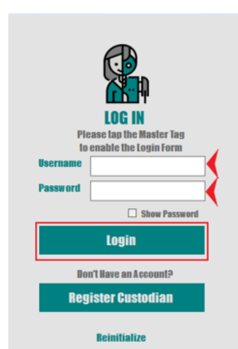




3. If the RFID card the user tapped on the scanner is not the Custodian Card/Master RFID/Master Tag the GUI will not give the user access to log in and will have to click on the Retry button to tap the correct card/RFID tag which will show after the deny of access in place of the login button.

4. If the RFID card the user tapped on the scanner is the Custodian Card/Master RFID/Master Tag the GUI will detect it and will allow the user to log in.



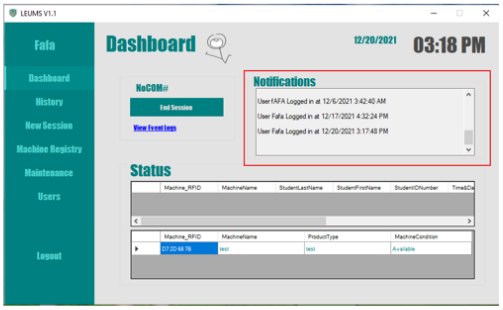


5. If the required fields are filled out correctly, click the Login button and will be able to proceed to the Dashboard.

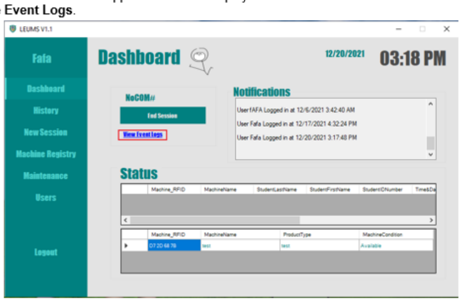
(Note: The GUI will inform the user if the written username & password combination is a registered custodian of this application.)

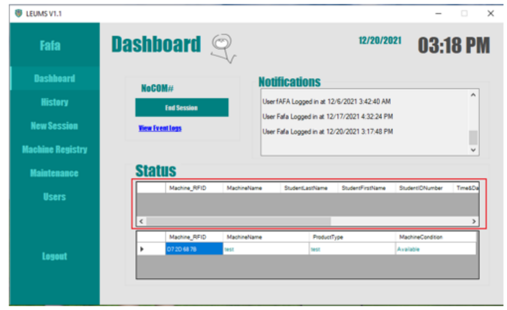
How to Navigate and Access the Main Features of the Dashboard

Dashboard Guide

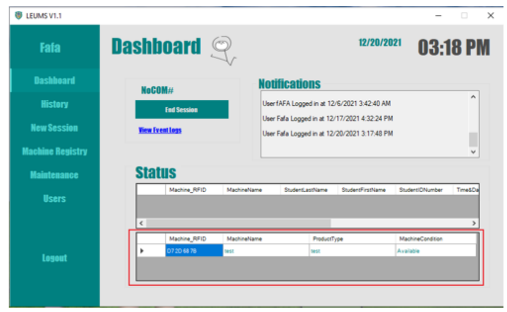


Within the dashboard is the Notifications Board which where all the actions and events that occurs within the application will be displayed and recorded which can be viewed in the **Event Logs**.

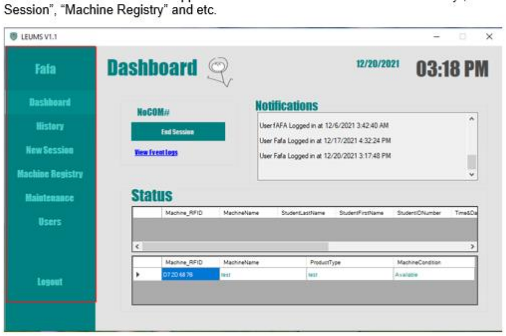




The dashboard contains the Status tables which displays the current session's information and also the list of machines and their brief information and conditions whether they are "In Use", "Under Maintenance", "Available" or "Out of Order".



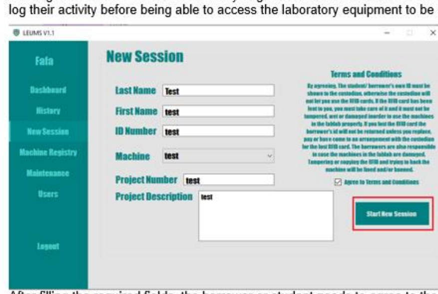
Lastly the bar tab is an extension of the dashboard which the user can navigate the different features the LEUMS Application Software can offer such as the "History", "New Session", "Machine Registry" and etc.



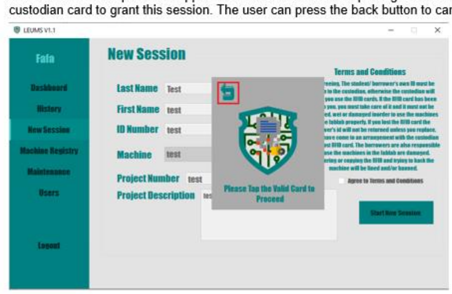
How to Start a New Session

New Session Guide

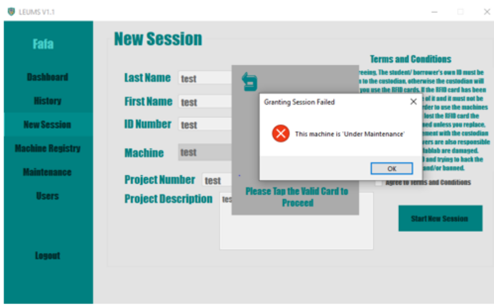
Starting a session is the custodian's way to grant access to a student or a borrower to log their activity before being able to access the laboratory equipment to be borrowed.

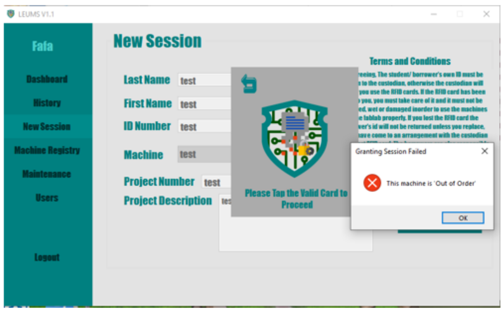


After filling the required fields, the borrower or student needs to agree to the terms and conditions set by the custodian before being able to click the "Start New Session" button then a confirmation panel will appear and the custodian will tap a registered card or custodian card to grant this session. The user can press the back button to cancel.



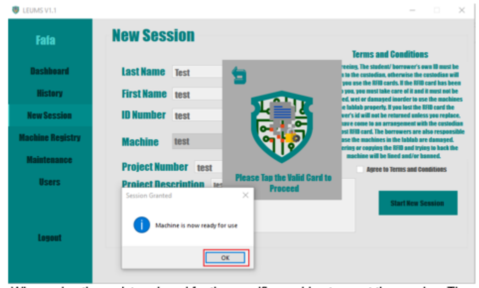
If the custodian taps an unregistered card or the incorrect registered card for the chosen machine filled out on the required field it will prompt that the session is not granted. Session can't also be granted if the selected machine is "In Use", "Out of Order" or "Under Maintenance" under any circumstances.



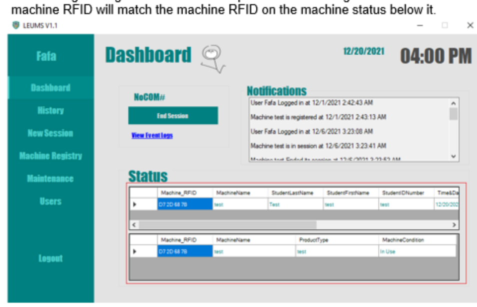


2 Ways to Grant a New Session

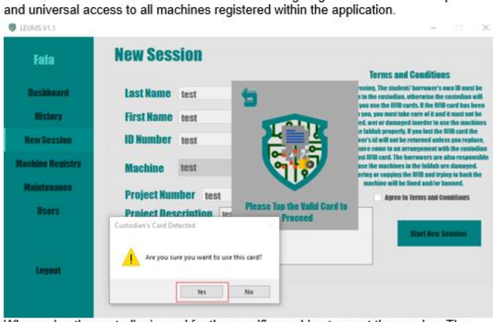
Using the Registered Machine Card – If the custodian taps the registered card for the chosen machine filled out on the required field it will prompt that the session is granted and the machine is now ready for use and already is updated on the status table and the machine status as "In Use".



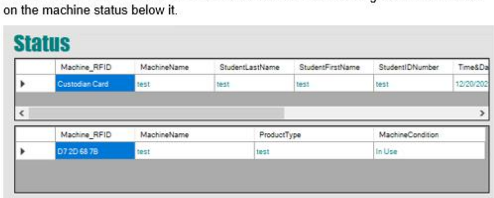
When using the registered card for the specific machine to grant the session. The machine RFID will match the machine RFID on the machine status below it.



Using the Custodian's Card - If the custodian taps the custodian's card which can be used on all existing machines registered within the application. It will prompt the custodian to confirm this action as this will result to giving a borrower/student special and universal access to all machines registered within the application.



When using the custodian's card for the specific machine to grant the session. The machine RFID will indicate "Custodian's Card" instead of matching the machine RFID on the machine status below it.

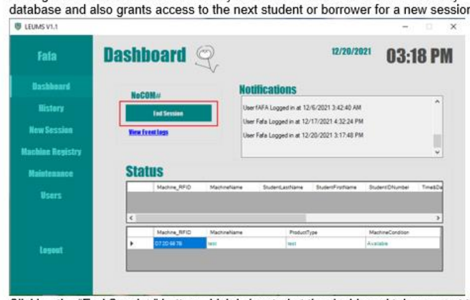


This will also be recorded to History to separate special granted sessions and regular granted session by the custodian.

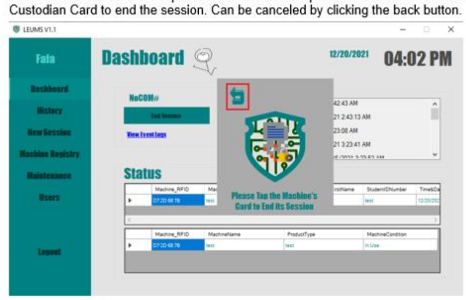
How to End a Session

End Session Guide

Ending a session is the custodian's way to record the transaction into the history database and also grants access to the next student or borrower for a new session.

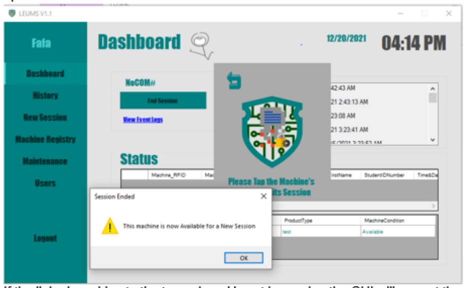


Clicking the "End Session" button which is located at the dashboard tab pops out the End Session Panel which requires the custodian to tap the returned Machine Card or Custodian Card to end the session. Can be canceled by clicking the back button.

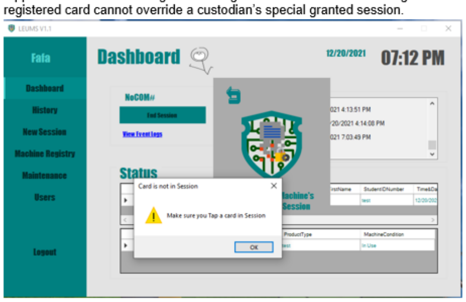


2 Ways to End a Session

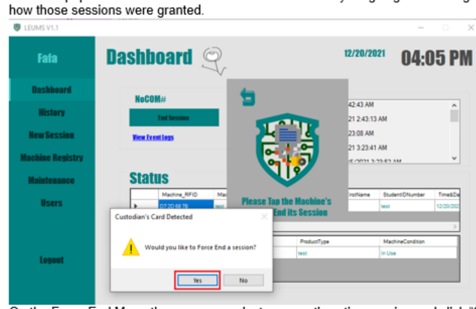
Using the Registered Machine Card - If the custodian taps the registered card, it will automatically end the session of the machine that is linked to the tapped card and updates the machine status to “Available”.



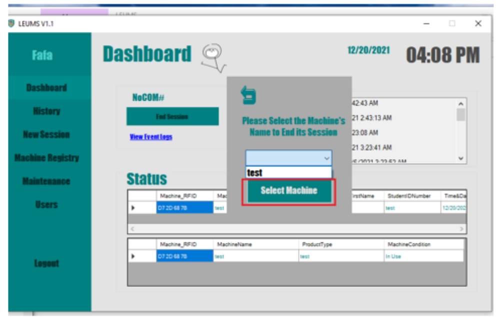
If the linked machine to the tapped card is not in session the GUI will prompt the user that the tapped card is not in session. This also shows up if the linked machine to the tapped card's session was granted using a custodian's card. Indicating that the registered card cannot override a custodian's special granted session.



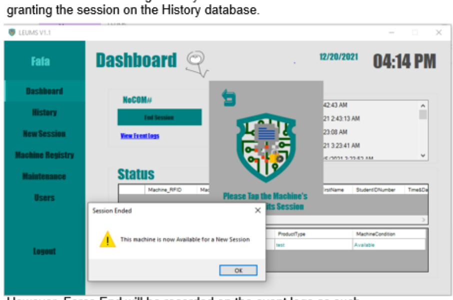
Using the Custodian's Card - If the custodian taps the custodian's card which can be used on all existing machines registered within the application. It will prompt a “Force End” and pops out the Force End Menu which can end any on-going session regardless how those sessions were granted.



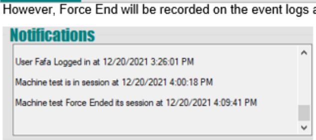
On the Force End Menu the user may select a currently active session and click “Select Machine” to force end the selected machine being used on the selected session.



Force ending also frees the machine from a session and will now be on “Available” status. The session is also recorded in the History database but whether the custodian ended the session the regular way or force end. It will still record the RFID used in granting the session on the History database.



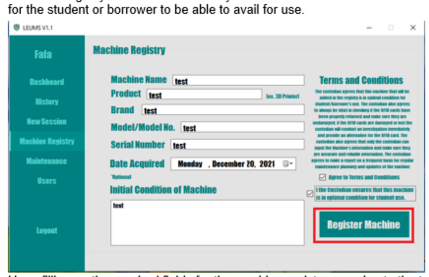
However, Force End will be recorded on the event logs as such



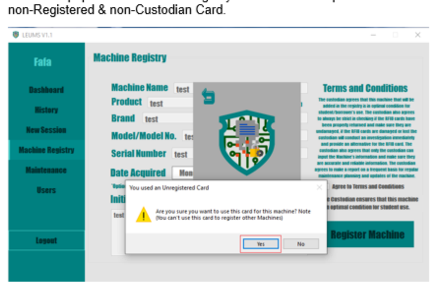
How to Register a Machine

Machine Registry

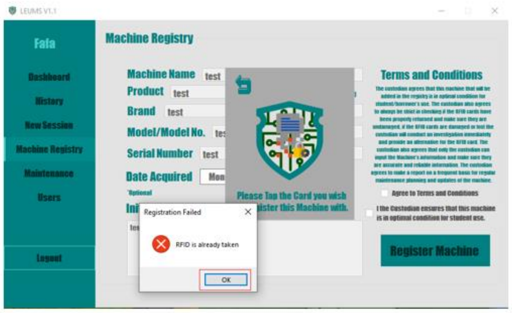
Machine Registry is the custodian's way to add a machine and link it to a card or RFID for the student or borrower to be able to avail for use.

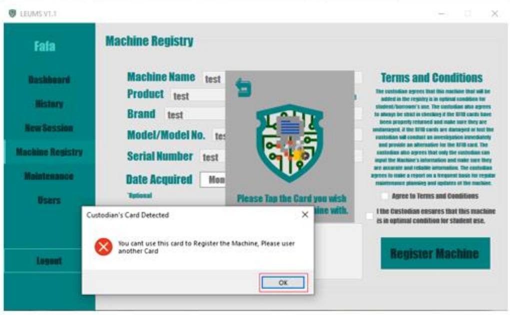


Upon filling up the required fields for the machine registry agreeing to the terms and conditions will enable the “Register Machine” button. Clicking the “Register Machine” button will pop out the Machine Registry Panel that will require the custodian to tap a non-Registered & non-Custodian Card.

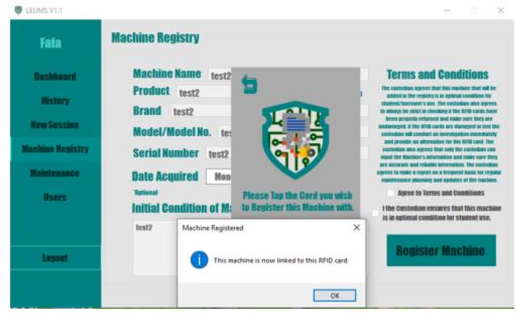


If the tapped card was a custodian's card the GUI will not link the Machine ongoing registration to it. Likewise if the tapped card already has a linked machine to it.

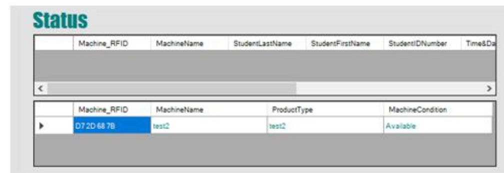




If the tapped card was neither an already linked card nor a custodian's card the machine will be linked to the tapped card.



After Registration it will automatically be added to the machine registry and machine status table.

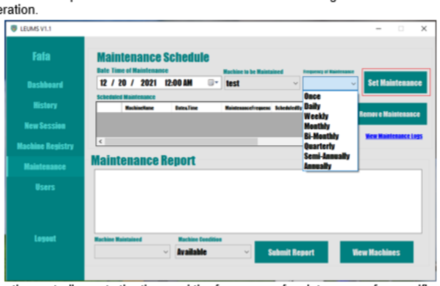


(Note: Accurate information filled out on the machine registry will make the maintenance for the machine smoother)

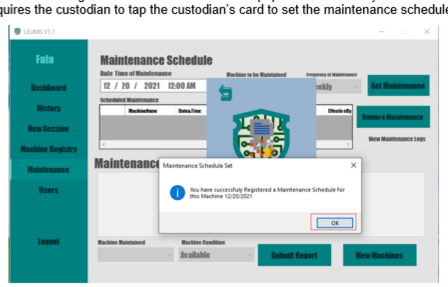
How to Make a Maintenance Schedule

Maintenance Schedule

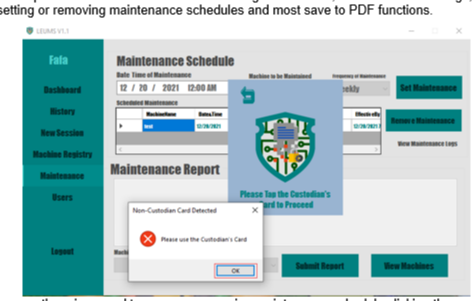
Maintenance Schedule is the custodian's way to make an automated reminder and ensures that the machine will not be in used during the maintenance time period until a maintenance report have been submitted that the machine is good to continue its operation.



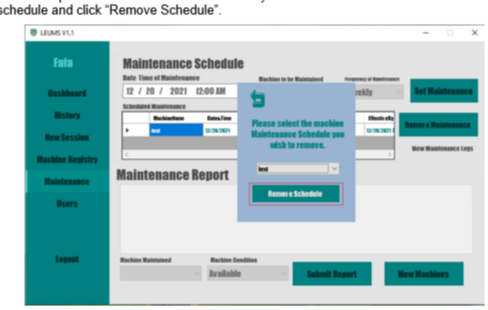
After the custodian sets the time and the frequency of maintenance of a specific machine. Clicking the "Set Maintenance" button pops out the Security Panel that requires the custodian to tap the custodian's card to set the maintenance schedule.



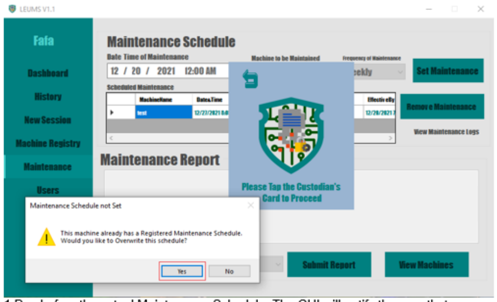
If the user taps a non-custodian's card for the Security Panel, It will deny any action that will require a custodian's card such as viewing of machines, view maintenance logs, setting or removing maintenance schedules and most save to PDF functions.



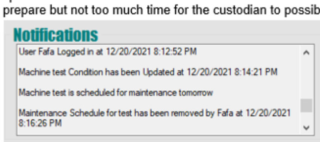
In case there is a need to remove a recurring maintenance schedule clicking the remove button and tapping the custodian's card will unlock the remove machine schedule options. Just choose which machine you would like to remove its maintenance schedule and click "Remove Schedule".



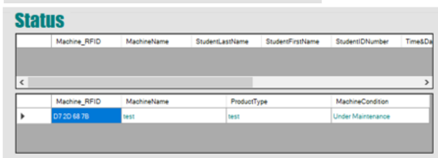
In case there's a need for overriding an already existing or a recurring maintenance schedule. By filling out the required fields and click "Set Maintenance" and tap the custodian's card. And this will replace the existing maintenance schedule.



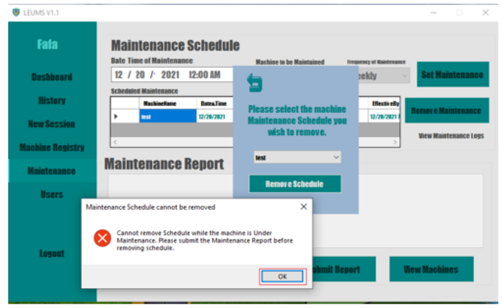
1 Day before the actual Maintenance Schedule. The GUI will notify the user that a specific machine is scheduled for maintenance tomorrow in order to have time to prepare but not too much time for the custodian to possibly forget.



Within the day of the actual maintenance schedule of the machine. The machine condition will automatically change to "Under Maintenance" during its scheduled time.



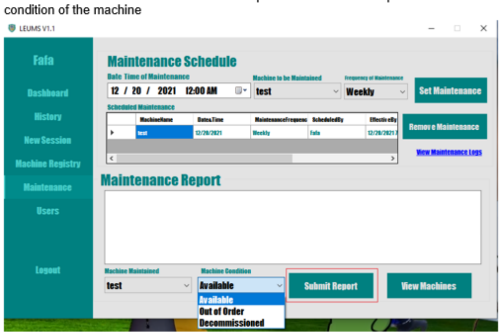
Overriding or removing the maintenance Schedule while the machine is "Under Maintenance" as such. Will not be allowed so the user must first submit a maintenance report to remove the under maintenance status of the machine.



How to Make a Maintenance Report

Maintenance Report

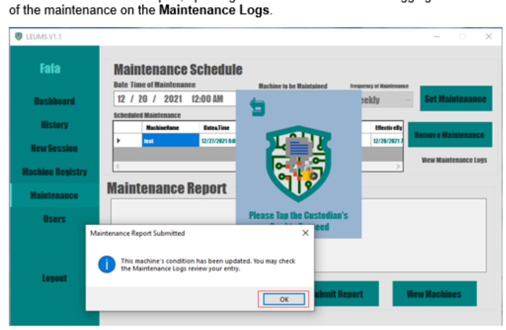
Maintenance Report is the custodian's way to make logs on maintenances done on scheduled or unscheduled manners. This helps the custodian to keep track on the condition of the machine



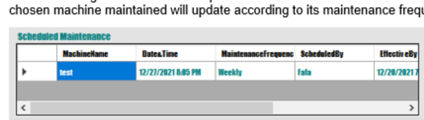
After choosing a Machine Maintained. The custodian now picks the summary of the machine condition after the maintenance. Whether if it's now **Available** for use or **Out of Order** due to still being unusable but can be fixed or will be fixed. **Decommissioned** machines however are for machines that are for write off due to being sold or being completely unusable. And accompanied by a detailed maintenance report on the provided textbox.

(Note: Accurate information filled out on the Maintenance Report will make the maintenance for the machine smoother in the future)

Clicking the Submit report button and tapping the custodian's card will successfully submit the maintenance report, updating the machine condition and logging the records of the maintenance on the **Maintenance Logs**.



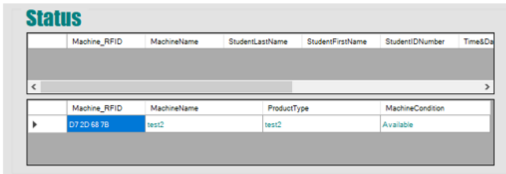
After submitting the maintenance report. The maintenance schedule tied with the chosen machine maintained will update according to its maintenance frequency.



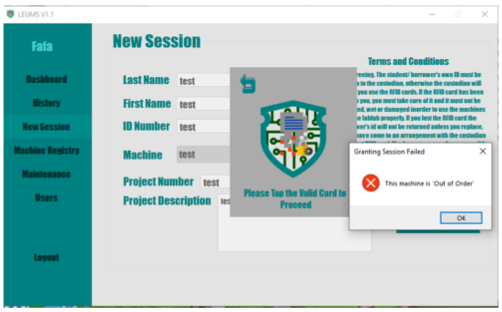
(Note: If a breakdown maintenance happened before a periodic maintenance and causes the maintenance schedule to change after submitting the report. The custodian can just override the changed maintenance schedule to keep the correct periodic maintenance for calibrations and etc.)

3 Machine Conditions

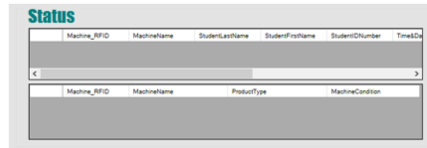
Available- If the submitted report contains this machine condition. It will make the machine maintained to be available for use again.



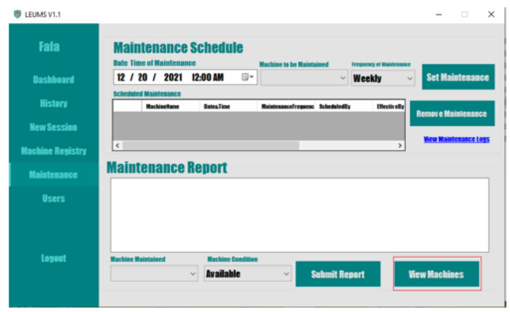
Out of Order- If the submitted report contains this machine condition. The machine will continue to be unusable for students or borrowers.



Decommissioned- If the submitted report contains this machine condition. The GUI will all registry of this machine except from the history tab and information of this machine will now be moved to the Decommissioned Machines Tab which is located on the Machine registry tab

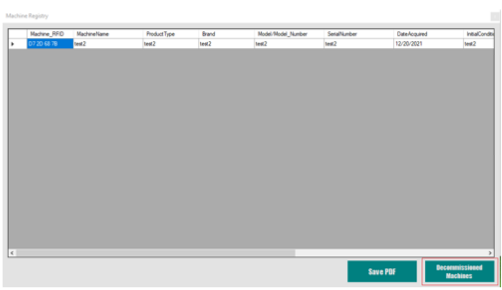


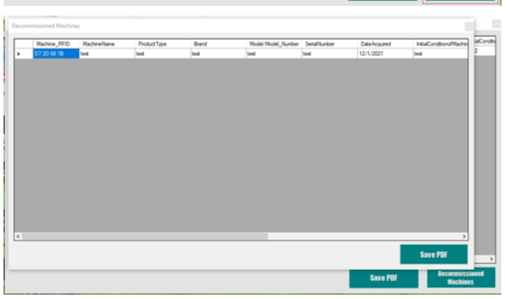
Click the "View Machines" and tap the custodian's card to access Machine registry



The machine registry contains the complete details of all the registered machines.

Clicking the Decommissioned Machines opens the information on all the former equipment that are tied and have been registered on this application.



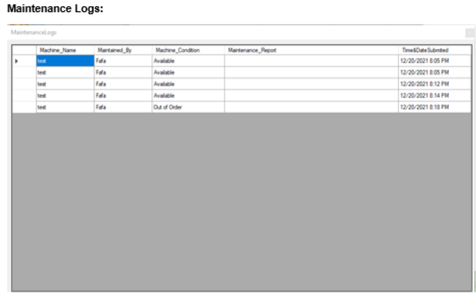


How to Use the Data Table Filter System

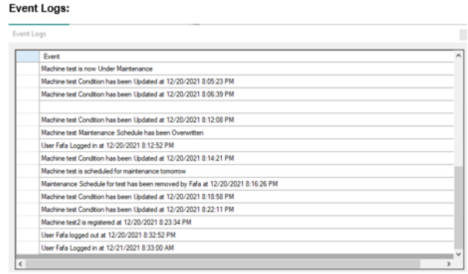
Search & Filter

Search & Filter is the custodian's way to make finding and analyzing all the logs and data from its usage be more efficient and easier to pull data from these tables such as:

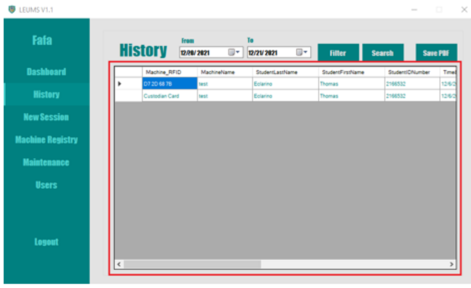
Maintenance Logs:



Event Logs:

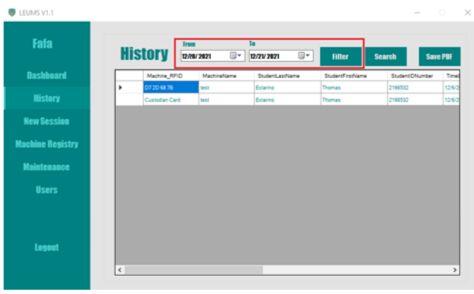


History Logs:

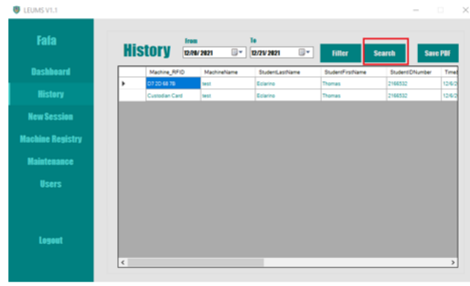


Using Search & Filter

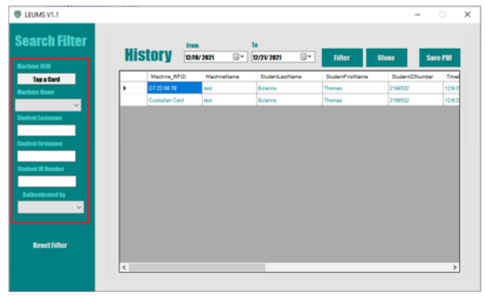
By selecting a range of date and clicking the "Filter" button. The user can filter the items on the table that fit the criteria.



By clicking the "Search" button. The search filter panel with take the place of the dashboard tabs until the user closes the search filter panel.



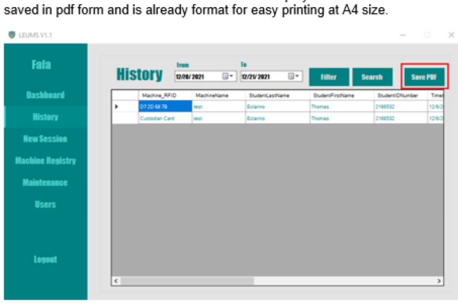
With this search filter panel the user can now filter the displayed data that satisfies all the search parameters for a more accurate result. Changing the search filter parameters will automatically search similarities in its database. But clicking the "filter button" will combine all the parameters to give a more specific sets of data.



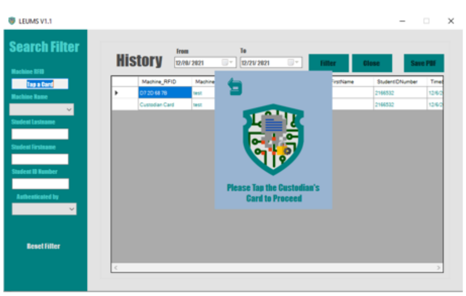
How to Save Data Table to PDF

Save to PDF

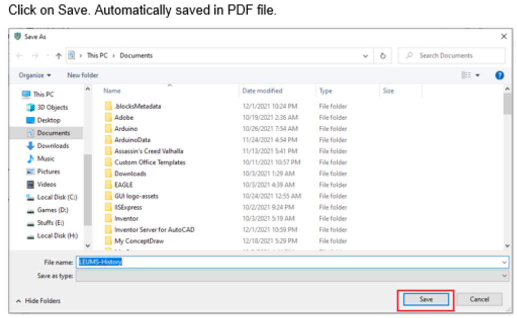
Click the Save PDF button. And whatever the displayed data on the data table will be saved in pdf form and is already format for easy printing at A4 size.



Tap the custodian's card to access the feature.



Click on Save. Automatically saved in PDF file.



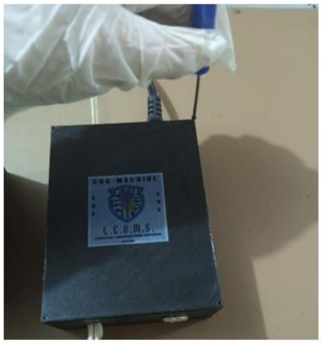
And will be saved as

Machine_RFID	MachineName	StudentLastName	StudentFirstName	StudentIDNumber	Time&DateIn	Time&DateOut	AuthenticatedBy	ProjectNumber	ProjectDescription
D7 2D 68 7B	test	Eclarino	Thomas	2166532	12/6/2021 3:23:41 AM	12/6/2021 3:23:52 AM	Fafa	ECE 517	Secret
Custodian Card	test	Eclarino	Thomas	2166532	12/6/2021 3:24:52 AM	12/6/2021 3:24:58 AM	Fafa	ECE 517	

How to Setup LEUMS Laboratory Equipment Hardware

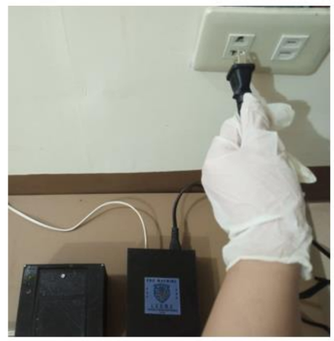
Setup

1. Unscrew and Remove the Power Brick cover



2. Plug the Machine to be powered by the LEUMS by plugging it into the TL2031 NEMA socket inside the LEUMS Laboratory Equipment Hardware Power Brick.

3. Screw in the Power Brick cover to secure the machine power plug.



4. Insert the EIC 320C-8 connector to the Power Brick socket and Plug in into 220V AC

How to Operate LEUMS Laboratory Equipment Hardware

Operation

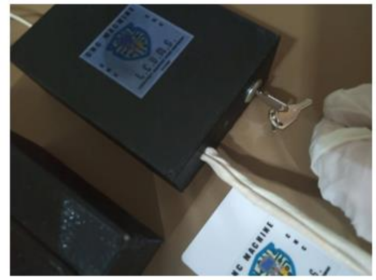
1. A yellow LED indicator should light up upon plugging in the Power Brick to 220V AC. This indicates the device is ready to receive and read a card.

2. Insert the card in the Reader Card Slot until you feel a clipping motion on the card and hear an audible click and the Yellow LED indicator will turn off.

3. If the Card inserted in the Reader Slot is the Custodian's Card or the registered Card that is hard coded on the Arduino. The green LED indicator will light up, hear an audible click and current is now flowing to the machine.

4. If the Card inserted in the Reader Slot is neither the Custodian's Card nor the registered Card that is hard coded on the Arduino. The red LED indicator will light up, hear no audible click and no current will be flowing to the machine.

5. In case of the absence of an authorized RFID card. A manual Bypass has been added. And can be accessed from the power brick with a key.



6. Turning the key will turn on the machine regardless the condition of the Arduino.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATION

This chapter presents the summary and conclusions as obtained from the previous chapters. Recommendations are also presented here for future researchers who wish to pursue the study.

SUMMARY

Automated monitoring systems are now becoming a trend in organizations, creating easier methods to identify items, tracking, monitoring and add on security values. Over recent years, a number of educational institutions have been adopting a quality process to improve the laboratory inventory management system. As a standard procedure in management, it is very crucial to have a record of all the inventories and usage available in laboratory. This is usually done with the help of logbooks and registers. This system was found to have a lot of weaknesses such as misuse of the equipment log records, losses of equipment, no in-out transaction record and misplace of equipment. The reliance on paperwork and data entry depends on the staff’s efficiency. Thus, viewed as a tedious and time-consuming method in monitoring and tracking the laboratory equipment as part of fulfilling the established quality process requirement.

The need to improve the existing laboratory equipment usage monitoring and management challenged the researchers to propose a project study on the design and construction of an RFID-based laboratory equipment usage monitoring system with the following capabilities: automatic logging of user information and time of usage. The data logged from the system will serve as a baseline for report generation on equipment utilization and maintenance schedules. The RFID-Based Laboratory Equipment Usage Monitoring System is a system that allows the laboratory custodian to monitor equipment usage logs in the FabLab. The project was divided into two systems since the custodian's office is separate from the FabLab, namely: the Logging System and the Equipment Access System.

CONCLUSIONS

The RFID-based laboratory equipment usage monitoring system was divided into two systems, namely: the Logging System and the Equipment Access System. It is a system capable of granting access to the designated machines and at the same time creating a digital log for documentation purposes. The system finds its application in laboratory inventory management systems. It was designed as a solution to more efficient, accurate and timely reporting challenges on equipment usage and monitoring in laboratories.

The logging system will be located in the custodian's office and the second system, the equipment access system will be located on the FabLab where the machines are housed. The designed system has the following capabilities: automatic logging of user information, time of usage and access granting to registered users. The Logging System is composed of the RFID module interfaced to the custodian’s computer. Specific RFID cards were assigned to each of the machines in the FabLab. These RFID cards are placed on a designated card slot inside the custodian’s office. The data logged from the system will serve as a baseline for report generation on equipment utilization and maintenance schedules. The custodian in charge will have to first register him or herself on the GUI. After an account is made, the custodian now has access to the GUI and a master ID. Once a student or staff requests access to the machines in the FabLab, the custodian makes a record on the GUI and taps the card of the machine which would be used. The log will include the time and date of scan and the machine used.

The software aspect of the project required programming of the Arduino microcontroller and the graphical user interface. The researchers in this project made use of two Integrated Development Environments (IDEs) for the programming of the microcontrollers and the construction of the Graphical User Interface (GUI). The open-source Arduino IDE software was used to program the microcontrollers and the Microsoft Visual Studio 2015 was used to create the graphical user interface for the custodian’s computer. The graphical user interface (GUI) shown in the custodian’s computer will allow the custodian to input the user information (student/user name), FabLab project to be done, and generate reports on machine usage. Reports can be generated as pdf only and filtered to the desired list of information to be present.

The testing process was initially iteratively conducted by the researchers for each module. Any encountered failures or breakdown during the test procedures were immediately considered and addressed for correction and improvement. Modifications of the program code were done to correct some of the system failures. Before the functionality test of the whole system was held, each component of the system has been tested separately to determine whether each component is working properly based on its expected specifications. The testing was done for both of the modules which were demonstrated to the FabLab staff.

The maintenance procedures required in both systems would involve visual and movement checks. Visual checks would involve ensuring that the devices are free from dust and moisture as well as ensuring that the modules are clean. Movement checks would involve checking for loose connections in both systems. The user's manual for both modules were included for the custodian to install, operate and maintain the system properly.

RECOMMENDATIONS

The researchers of this study recommend future researchers to improve the system by adding more features such as the ability of the logging system to communicate wirelessly with the equipment access system. The addition of an LCD in the RFID scanners to show card attempts or in-use would also be a good additional feature to the system. Furthermore, the researchers would also recommend future studies about the ability of the system to detect RFID strips in the University IDs so that the users do not need to input their personal information anymore, thus, making the system fully automated. Biometric features such as thumbprints or facial scanners may also be a good future improvement to the system. Another additional feature that can be incorporated in the system is file compression for old files. The system was not tested for its maximum capability of storage due to time constraints. Further research may be done to determine the system's maximum memory capacity. The use of cloud logging storage might also be an improvement to the system to allow all devices to be connected to a single main system.

APPENDICES

APPENDIX A. SAMPLE CODE LEUMS GUI

//Save to PDF Function Sample Code

```
private void SaveToPDF(DataGridView dgrid, string Filename)
        {
            if (dgrid.Rows.Count > 0)
            {

                BaseFont bf = BaseFont.CreateFont(BaseFont.TIMES_ROMAN, BaseFont.CP1250, BaseFont.EMBEDDED);
                PdfPTable htable = new PdfPTable(dgrid.Columns.Count);

htable.DefaultCell.Padding = 3;

htable.WidthPercentage = 100;

htable.HorizontalAlignment = Element.ALIGN_LEFT;

htable.DefaultCell.BorderWidth = 1;


iTextSharp.text.Font text = new iTextSharp.text.Font(bf, 10, iTextSharp.text.Font.NORMAL);

                foreach (DataGridViewColumn col in dgrid.Columns)
                {
                    PdfPCell hcell = new PdfPCell(new Phrase(col.HeaderText, text));

hcell.BackgroundColor = new iTextSharp.text.BaseColor(240, 240, 240);

htable.AddCell(hcell);

                }
                foreach (DataGridViewRow row in dgrid.Rows)
                {
                    foreach (DataGridViewCell hcell in row.Cells)
                    {

htable.AddCell(new Phrase(hcell.Value.ToString(), text));
                    }
                }

                var SavePDF = new SaveFileDialog();
                SavePDF.FileName = Filename;
                SavePDF.DefaultExt = ".pdf";
                bool ErrorMessage = false;
                if (SavePDF.ShowDialog() == DialogResult.OK)
                {


                        using (FileStream stream = new FileStream(SavePDF.FileName, FileMode.Create))
                        {

Document pdfdoc = new Document(PageSize.A4, 10f, 10f, 10f, 0f);

PdfWriter.GetInstance(pdfdoc, stream);

pdfdoc.Open();

pdfdoc.Add(htable);

pdfdoc.Close();

stream.Close();
                        }

                }
            }
            else
            {
                MessageBox.Show("No Record Found");
            }
        }
```

APPENDIX B. DATA SHEETS

A. RFID Module

8.1.2 Serial Peripheral Interface

A serial peripheral interface (SPI compatible) is supported to enable high-speed communication to the host. The interface can handle data speeds up to 10 Mbit/s. When communicating with a host, the MFRC522 acts as a slave, receiving data from the external host for register settings, sending and receiving data relevant for RF interface communication.

An interface compatible with SPI enables high-speed serial communication between the MFRC522 and a microcontroller. The implemented interface is in accordance with the SPI standard.

The timing specification is given in Section 14.1 on page 77.

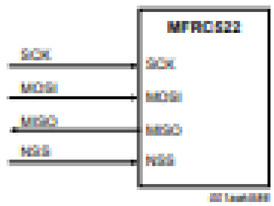


Fig 7. SPI connection to host

The MFRC522 acts as a slave during SPI communication. The SPI clock signal SCK must be generated by the master. Data communication from the master to the slave uses the MOSI line. The MISO line is used to send data from the MFRC522 to the master.

Data bytes on both MOSI and MISO lines are sent with the MSB first. Data on both MOSI and MISO lines must be stable on the rising edge of the clock and can be changed on the falling edge. Data is provided by the MFRC522 on the falling clock edge and is stable during the rising clock edge.

8.1.2.1 SPI read data

Reading data using SPI requires the byte order shown in Table 6 to be used. It is possible to read out up to n-data bytes.

The first byte sent defines both the mode and the address.

Table 6. MOSI and MISO byte order

Line	Byte 0	Byte 1	Byte 2	To	Byte n	Byte n + 1
MOSI	address 0	address 1	address 2	...	address n	00
MISO	X[1]	data 0	data 1	...	data n − 1	data n

[1] X = Do not care.

Remark: The MSB must be sent first.

B. Arduino Uno Microcontroller

Arduino® UNO R3

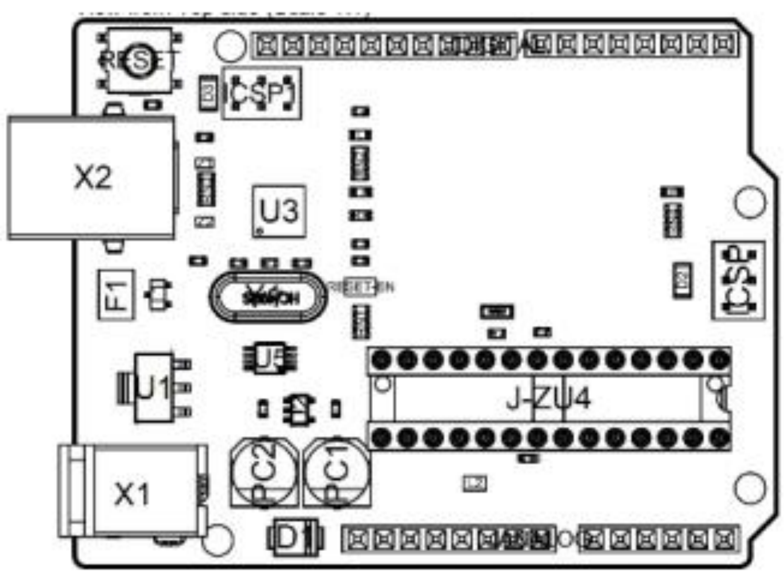
2.2 Power Consumption

Symbol	Description	Min	Typ	Max	Unit
VINMax	Maximum input voltage from VIN pad	6	-	20	V
VUSBMax	Maximum input voltage from USB connector		-	5.5	V
PMax	Maximum Power Consumption	-	-	xx	mA

3 Functional Overview

3.1 Board Topology

Top view



Board topology

Ref.	Description	Ref.	Description
X1	Power jack 2.1x5.5mm	U1	SPX1117M3-L-5 Regulator
X2	USB B Connector	U3	ATMEGA16U2 Module
PC1	EEE-1EA470WP 25V SMD Capacitor	U5	LMV358LIST-A.9 IC
PC2	EEE-1EA470WP 25V SMD Capacitor	F1	Chip Capacitor, High Density
D1	CGRA4007-G Rectifier	ICSP	Pin header connector (through hole 6)
J-ZU4	ATMEGA328P Module	ICSP1	Pin header connector (through hole 6)
Y1	ECS-160-20-4X-DU Oscillator		

C. Arduino Nano Microcontroller

Schematic and Design

Arduino Nano 3.0 (ATmega328): schematic, Eagle files.
Arduino Nano 2.3 (ATmega168): manual (pdf), Eagle files. *Note:* since the free version of Eagle does not handle more than 2 layers, and this version of the Nano is 4 layers, it is published here unrouted, so users can open and use it in the free version of Eagle.

Specifications:

Microcontroller	Atmel ATmega168 or ATmega328
Operating Voltage (logic level)	5 V
Input Voltage (recommended)	7-12 V
Input Voltage (limits)	6-20 V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	8
DC Current per I/O Pin	40 mA
Flash Memory	16 KB (ATmega168) or 32 KB (ATmega328) of which 2 KB used by bootloader
SRAM	1 KB (ATmega168) or 2 KB (ATmega328)
EEPROM	512 bytes (ATmega168) or 1 KB (ATmega328)
Clock Speed	16 MHz
Dimensions	0.73" x 1.70"

Power:

The Arduino Nano can be powered via the Mini-B USB connection, 6-20V unregulated external power supply (pin 30), or 5V regulated external power supply (pin 27). The power source is automatically selected to the highest voltage source.

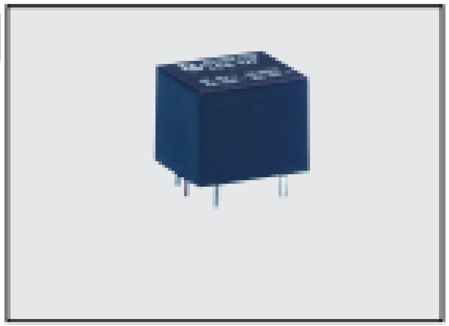
D. 5 leg SPDT 5VDC power relay

RAYEX ELEC.

LEG-F SERIES

FEATURES

- 15A cube relay
- 1 Form C (1PDT) contact arrangement
- Plastic material applied in high temperature and better chemical solution.
- Sealed type for washing procedure
- Using at domestic appliances, office machines, audio equipment, coffee pot , control units, etc.



ORDERING INFORMATION

LEG 1A — 12 F L

1 2 3 4 5

1. Type
2. Contact Arrangement
   Nil:1Form C(1PDT)
   1A:1Form A(1PST-NO)
3. Coil Nominal Voltage
4. Contact Rating
   F: 15A,0.36W
5. L:08W
   M:045W
   F :0.64W

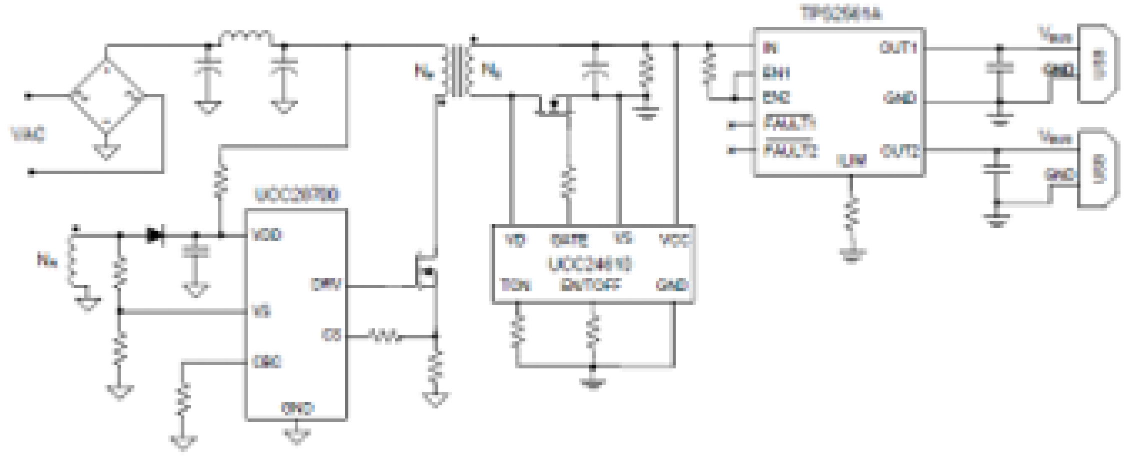
CONTACT RATING

Resistive (Cos.θ = 1)	AC 240V / DC 24V	15A

COIL DATA(0.36W,0.45W,0.8W,0.64W at 25℃)

Coil Nominal Voltage (VDC)	Resistance Tol.±10% (Ohms)				Nominal Current (mA)				Maximum Pick Up Voltage (V)	Minimum Drop Out Voltage (V)
	0.36W	0.45W	0.8W	0.64W	0.36W	0.45W	0.8W	0.64W		
3	25	20	11.3		120	150	285		2.1	0.3
5	70	55	31		72	90.9	161		3.5	0.5
6	100	80	45	56	60	75	133	107	4.2	0.6
9	225	320	101	127	40	50	89.1	70.8	6.3	0.9
12	400	720	180	225	30	37.5	66.6	53.3	8.4	1.2
24	1,600	1,280	740	900	15	18.5	32.4	26.7	16.8	2.4
48	6,400				7.5				33.6	4.8

E. 5V TWO OUTPUT CHARGER MODULE

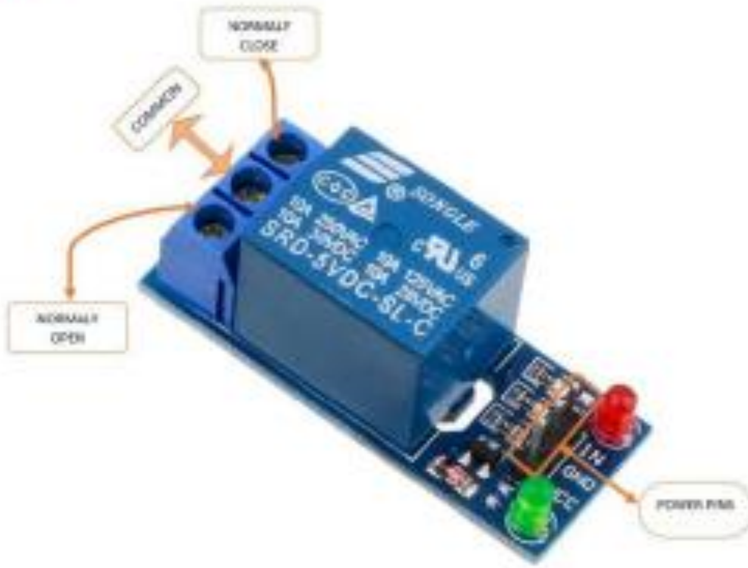


Output rating	5V / 3.1 A
Input AC Voltage Rating	100 – 240V
Frequency	50/60 Hz

F. 5V MODULE RELAY

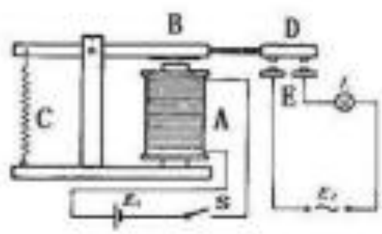
NOTE: The digital inputs from Arduino are Active LOW: The relay actuates and LED lights when the input pin is LOW, and turns off on HIGH.

Module Layout:



Operating Principle:

See the picture below: A is an electromagnet, B armature, C spring, D moving contact, and E fixed contacts. There are two fixed contacts, a normally closed one and a normally open one. When the coil is not energized, the normally open contact is the one that is off, while the normally closed one is the other that is on.



Supply voltage to the coil and some currents will pass through the coil thus generating the electromagnetic effect. So the armature overcomes the tension of the spring and is attracted to the core, thus closing the moving contact of the armature and the normally open (NO) contact or you may say releasing the former and the normally closed (NC) contact. After the coil is de-energized, the electromagnetic force disappears and the armature moves back to the original position, releasing the moving contact and normally closed contact. The closing and releasing of the contacts results in power on and off of the circuit.

Input:

VCC : Connected to positive supply voltage (supply power according to relay voltage)

GND : Connected to supply ground.

APPENDIX C. CURRICULUM VITAE

ALAIZAH MAE T. BATEG

SUMMARY

I am 22 (twenty-two) years old and a resident of San Carlos Heights, Baguio City. I am taking up Bachelor of Science in Electronics Engineering.

CONTACT

Address:
San Carlos Heights
Baguio City 2600

Email:
aalaizahmmae@gmail.com

Contact number:
+63950 323 5708

LANGUAGES

ENGLISH

FILIPINO

ILOCANO

EDUCATION

Year 2015 - Present - College Level

Saint Louis University

Year 2011 – 2015 – Secondary Level

Quezon Hill National High School

Year 2010 – 2011 – Elementary Level

Quezon Hill Elementary School

Year 2008 - 2010 - Elementary Level

Baguio Central School

Year 2007 – 2008 – Elementary Level

University of the Cordilleras Laboratory School

Year 2005 – 2007 – Elementary Level

Quezon Hill Elementary School

SKILL HIGHLIGHTS

- Creative
- Patient
- Optimistic
- Flexible
- Good interpersonal skills
- Enthusiastic

ESPER JOYMAE F. DALIT

SUMMARY

I am an electronics engineering student who already has a basic knowledge of electronics and it's application.

CONTACT

Address:
0810 Mangan vaca ,
Subic, Zambales

Email:
Esperjoymae1414@gmail.com

Contact number:
09292558344(smart)

LANGUAGES

ENGLISH

FILIPINO

EDUCATION

Year 2015 - Present – College Level

Saint Louis University

Year 2010 - 2014 – Highschool Level

Saint James School of Subic, INC.

Year 2004 – 2010 – Elementary Level

Saint Anne School of Subic

SKILL HIGHLIGHTS

-Basic knowledge in Arduino Programming

-AutoCAD 2D and 3D Design

-Designing PCB Circuitry

-Organized and efficient

-Ability to work independently or as part of a team

VANESSA R. DUNGCA

SUMMARY

I am an engineering student majoring in Electronics who has acquired knowledge of electronics and it's application.

CONTACT

Address:
No339 Palguyod, Pozorrubio, Pangasinan 2435

Email:
vanessa09dungca@gmail.com

Contact number:
09773483419

LANGUAGES

ENGLISH

FILIPINO

EDUCATION

Year 2015 - Present – College Level

Saint Louis University

Year 2010 - 2014 – Highschool Level

Mary Help of Christians Boarding School for Girls Inc.

Year 2005 – 2011 – Elementary Level

Palguyod Elementary School

SKILL HIGHLIGHTS

- computer literate
- good with written and oral communications
- multi tasking abilities

THOMAS DAVID G. ECLARINO

SUMMARY

Bachelor of Science in Electronics Engineering. Took up Instrumentation Electives.

Minor experience in C++, C#, Java and Python programing as well as Machine Learning and Pen testing. Experienced in electronics, software and gadget repair and diagnostic.

CONTACT

Address:
197 Upper Bonifacio st., Baguio City , Benguet,

Email:
2166532@slu.edu.ph
tdeclarino@gmail.com

Contact number:
09165905440

EDUCATION

Year 2015 - Present - College Level

Saint Louis University

Year 2013-2015 - Highschool Level

Saint Vincent's Academy

Year 2006 - 2013 – Elementary Level

Holy Word Academy

Year 2004 – 2006 – Pre – elementary Level

Holy Word Academy

SKILL HIGHLIGHTS

- Adept Computer and Gadget Repair/Diagnostic
- Intermediate C++, C# and Java Programming
- Adept Python Programming
- Basic Machine learning and Penetration testing
- Video & Photo Editing
- Sketch Drawing
- Basic Photography

LANGUAGES

ENGLISH

FILIPINO

EDEN HOPE F. FIANZA

SUMMARY

Bachelor of Science in Electronics Engineering. Took up Instrumentation Electives inside and outside of the University.

Small background in minor electronics repair and troubleshooting.

CONTACT

Address:

11D M.Roxas Street,
Baguio City 2600

Email:

2161748@slu.edu.ph
ehffianza@gmail.com

Contact number:

09498158048
(074) 442-5149

LANGUAGES

ENGLISH
ILOCANO
FILIPINO

EDUCATION

Year 2015 - Present – College Level

Saint Louis University

Year 2013 - 2015 – Highschool Level

Good News Academy

Year 2006 - 2013 – Elementary Level

Good News Academy

Year 2004 – 2006 – Pre – elementary Level

Baguio Baptist Learning Center

ACHIEVEMENTS

Honor Student 2006 - 2012

Speaker of the Year – 2011

Silver Medal - Taekwondo Poomsae Competition – 2011

Bronze Medal - 4 by 100meter dash race – 2012

1st Runner Up Arnis Duelo & Anyo Belting Ceremony – 2013

SKILL HIGHLIGHTS

- Basic Appliance and Gadget Repair

- Basic C++ Programming

- Video Making

- Poetry Writing

- Dramatic Mono/Dialogue

- Musically Inclined

JETHRO WILSON H. HANGDAAN

SUMMARY

Bachelor of Science in Electronics Engineering. Took up Instrumentation Electives. Finished One-year Electrical Installation and Maintenance.

Minor experience in basic C++ programing. Basic knowledge in minor electronics and gadget repair and troubleshooting.

CONTACT

Address:
570 Purok 3, Gibraltar
Baguio City 2600

Email:
wilson.servant73@gmail.com

Contact number:
09460815493

LANGUAGES

ENGLISH FILIPINO ILOCANO

EDUCATION

Year 2019 - Present - College Level

Saint Louis University

Year 2017 - 2018 - College Level

King's College of the Philippines

Year 2013 - 2017 - College Level

Saint Louis University

Year 2009-2013 - High School Level

Southern Hingyon National High School

Year 2003 - 2009 – Elementary Level

Mompolia Elementary school

Year 2002 – 2003 – Pre – elementary Level

Mompolia Elementary School

ACHIEVEMENTS

Dean's Lister First Semester, 2014-2015

SKILL HIGHLIGHTS

- Basic Appliance and Gadget Repair
- Basic C++ Programming
- Electrical Installation and Maintenance

AKINO BRIEN O. REYES

SUMMARY

I am a graduating electronics engineering student who already has a basic knowledge of electronics also I have basic knowledge and skills, such as coding and programming.

CONTACT

Address:
#154 Rizal Ave., San Carlos City, Pangasinan 2420

Email:
akinoreyes211gmail.com

Contact number:
09661382074

LANGUAGES

ENGLISH
FILIPINO

EDUCATION

Year 2015 - Present – College Level

Saint Louis University

Year 2010-2014 – Highschool Level

Mary Help of Christians Seminary

Year 2001 - 2010 – Elementary Level

Ednas School

ACHIEVEMENTS

-High school honor student

SKILL HIGHLIGHTS

-Computer literate

-Fundamental knowledge of Scilab

-Basic knowledge in AutoCad

CHARLES LORBIL H. SALAMANCA

SUMMARY

A graduating BSECE-Electronics engineering student at Saint Louis University with a basic knowledge and skills in electronics and communication that I have acquired all throughout my college year. Seeking for a greener pasture that will help me in continuing to learn and develop my skills in electronics and communication engineering.

CONTACT

Address:
Rizal street, Poblacion Sur, Mayantoc, Tarlac

Email:
lorbilsalamanca76@gmail.com

Contact number:
09776750485

EDUCATION

Year 2015 - Present

Saint Louis University

Year 2013-2014

Tarlac Agricultural University

Year 2009-2010

Mayantoc Central Elementary School

Year 2004

Angelicum School

ACHIEVEMENTS

- Baseball Varsity in Elementary
- Honor Student in high school
- Baseball Varsity in College

SKILL HIGHLIGHTS

- Fundamentals knowledge of Scilab
- Multi-tasking
- Basic knowledge in AutoCad
- orientation in basic Microsoft Office application
- Communication

LANGUAGES

ENGLISH

FILIPINO

ILOCANO

GICELLE TRIZZIA C. PALUYO

SUMMARY

Objective:
To work in a company where in I can apply my knowledge and abilities and to fully utilize my skills and to provide a steady and dependable workforce.

CONTACT

Address:
Block 2 Lot 4 Tierra Bonita Subdivision, Dasmariñas, Cavite 4114

Email:
gicellepaluyo.99@gmail.com

Contact number:
09150946229

LANGUAGES

ENGLISH

FILIPINO

EDUCATION

Year 2016 - Present

Saint Louis University

Year 2015

San Quintin National High School

EXPERIENCES

- Guidance Center Student Assistant

SAINT LOUIS UNIVERSITY, BAGUIO CITY

A. Bonifacio Street, Baguio City, Benguet

January 2019 – April 2019

SKILL HIGHLIGHTS

- Analytical skills to follow logic of electronic circuits and interface with software
- Essential Computer Skills
- Knowledgeable in Programming Language (C, C++, JAVA), Arduino Programming and AutoCAD
- Hardware and Software Troubleshooting
- Proficient in Microsoft Office Applications
- Has good oral and written communication and interpersonal skill.
- Capable of Multitasking
- Highly collaborative and capable of working independently when required

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