



Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE)

**Design and Implementation of a Smart Device for Real-Time
Medical Equipment Inventory Record Management**

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DECLARATION

I, Maurice UWIMANA declare that this dissertation entitled “**Design and Implementation of a Smart Device for Real-Time Medical Equipment Inventory Record Management**” is my original work based on research and prototype and has not been submitted for any other degree or professional qualification.

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CERTIFICATE

This is to certify that the project entitled “**Design and Implementation of a Smart Device for Real-Time Medical Equipment Inventory Record Management**” is a record of original work done by **Maurice UWIMANA** (Reference number: 220020568), a MSc. Degree student in Biomedical Engineering.

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ABSTRACT

The effectiveness of medical equipment management is crucial for Healthcare Technology Management (HTM) services. Inventory as one of the main aspects of HTM can lead to better clinical workflows when practiced well unless; it can result in unused or unfit equipment without a purpose resulting in the loss of resources and patients' life. Medical equipment records in developing countries are paper-based or/and computer-based systems where records are entered with unjustified /or incomparable resources (cost and time). Apart the highlighted issues, the access of recorded data is a big problem ensuing the maintenance mismanagement. In Rwanda, the use of the Medical Equipment Management and Maintenance System (MEMMS); a sophisticated software by which updated records are entered quarterly, is an online access database that results in many questionable outcomes like records duplication and errors. Internet of Things, ATMEGA 328P, and sensors together with other electronics components simulated through Proteus and other software helped to get a monitoring device that can stream real-time data (location, temperature, working time, and alerts for maintenance and security purposes) from medical equipment at any based institution. The device sends equipment records in a web login dashboard database constructed using hypertext pre-processor (PHP), hypertext mark-up language (HTML), Cascading Style Sheets (CSS), My Structured Query Language (MySQL), and Javascript. The research resulted in a designed system made by a small device linked to a web login dashboard. The monitoring device that is permanently attached to the equipment is built by various microcontroller-based sensors with push buttons and they detect and stream the equipment's functional data. The desired real-time data are detected and are also downloadable via the login dashboard. Through the dashboard, the system can also display the equipment performance while comparing the streamed data. This new inventory system is an innovative real-time inventory as it provides medical equipment's timely effectiveness, timely maintenance management, and optimized cost with an easy access database.

Keywords: Medical equipment, Inventory System, IOTs, web dashboard, Maintenance.

LIST OF ACRONYMS AND ABBREVIATIONS

AVR: Alf and Vegard's RISC processor

BI: Business intelligence

BT Bluetooth

BT: Bluetooth

CEBE: Centre of Excellence in Biomedical Engineering and e-Health

CMHS: College of Medicine and Health Sciences

CMOS: Complementary Metal Oxide Semiconductor

CND: National Classification of Medical Devices

CPU: Central Processing Unit

CSS: Cascading Style Sheets

ECRI: Emergency Care Research Institute

E-LMIS: electronic-Logistics Management Inventory System

EMDN: European Medical Device Nomenclature

ESI: Equipment Smart Inventory

GHz: Giga Hertz

GMDN: Global Medical Devices Nomenclature System

GPS: Global Positioning System

HTM: Healthcare Technology Management

HTML: Hyper Text Mark Up Language

ICU: Intensive Care Unit

ID: Identification

IEEE: Institute of Electrical and Electronics Engineers

IOTs: Internet Of Things

ISM: industrial, scientific, and medical

ISM: industrial, scientific, and medical

MEMMS: Medical Equipment Management Maintenance System

mm: millimeter

MRI: Magnetic Imaging Resonance

MySQL: My Structured Query Language

N/A: Non Applicable

PCB: Printed Circuit Board

PHP: Hypertext Preprocessor

Qty: Quantity

SMS: Short Message Service

System Programmable (ISP) Flash

TDD-based LTE-Hi

TDMA: Time Division Multiple Access

UDI: Unique Device Identifier

UMDNS: Universal Medical Devices Nomenclature System

USD: United States Dollar

UWB: ultra-wideband

UWB: ultra-wideband

V: Voltage

WHO: World Health Organization

WLANs: wireless local area networks

WLANs: wireless local area networks

XAMPP: cross-platform, Apache, MySQL, PHP, and Perl

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CHAPTER I. HEALTHCARE TECHNOLOGY MANAGEMENT

1. INTRODUCTION

Development in digitalization is drastically influencing everyday life all over the world, Internet of Things is a pillar that is changing work time and mass production. Across all sectors, good management is essential for daily workflows while having updated information about what to do and when to do it. In the health sector; the Internet of Things is changing that sector in better services but in developing countries, timely delivery, digitization, and lack of adequate infrastructures are affecting everyday healthcare technology management. Within the scope of Healthcare Technology Management (HTM), a real-time inventory is the most important tool to provide a techno-economic appraisal of the technology on hand while giving details of the type and quantity of equipment available. The IOT-based inventory results in effective asset management, including facilitating preventive maintenance scheduling and tracking of maintenance, repairs, alerts, recalls, and equipment history files [1].

1.1. What is the inventory practice

World Health Organization (WHO) highlights that inventory management is a paper-based or computer-based system depending on the resources available but emphasizes that a computer-based inventory system is preferred to have up-to-date records about the status and easy access to healthcare technology [2]. Despite that, the real-time inventory may be much better for medical equipment's timely effectiveness because updated records for any equipment helps monitor the equipment status especially for maintenance and lifetime use information.

1.2. Medical equipment inventory

An **inventory of medical equipment** is essential in fulfilling management routes for monitoring and control of medical equipment through their records in an electronic format for any health institution. Medical devices/equipment inventory records are fundamental to clinical workflows, financial, and to effective patient care. Access to medical equipment and a record in a short time help to have better distribution and effective use inventory in hospitals [3]. A medical inventory management system enables staff to monitor inventory in retail and sends out alerts for items' lifespan (expiry) or when they're in a need of maintenance.

In general medical equipment is complex equipment designed to aid in the estimation of body potentials, blood values, imaging and laboratory equipment, to aid in monitoring body parameters and analysis of the hospital environment, and to be used with radiation energy, prosthetic and orthopedic equipment.

Medical equipment can also be used for special treatment and surgical support including the gas supply system, or treatment of medical routine for patient care. Medical Equipment may be used for medical academic purposes.

1.3.What is equipment Maintenance?

A good medical inventory results in better equipment Maintenance which help to keep equipment in optimum working condition and consists of periodic inspection, preventive maintenance, and corrective maintenance. Any equipment use in any health institution will always depend on local, regional or national policy and healthcare conditions needs; including but not limited to the type of health facility where the equipment are to be used, the health work force available and the burden of disease for treatment [4].

1.4. Medical equipment in Rwanda

For Rwanda some health institutions use paper based inventory difficult to perform or to access and others users computer based inventory like MEMMS but still having the problem of showing updated inventory data due to no accountability/training capacity of some workers or even the hardness of system being used resulting in unfair use and distribution of medical equipment [5]. The manual data entry or traditional filing of medical equipment in healthcare institutions is one of the big complication issues affecting the quality of healthcare practices as well as imposing resource expenses. Having the ameliorated inventory based Internet of Things (IOTs) would result in an up-to-date inventory which is very crucial because of the real time records showing the status of medical equipment. Beside traditional inventory and recent research on inventory innovations, still an improvement for inventory is needed so that any information can obtained through online or remotely [5].

2. PROBLEM STATEMENT

The role of inventory management is an important factor for workflows in Healthcare Technology management. A smart inventory can reduce operations while ensuring the effectiveness in services delivery from medical equipment. From the point of view, ‘a smart inventory for medical equipment is the good management for medical equipment through any health institution. Inventory management practices varied widely in different health facilities; inadequate education and ineffective training for equipment management with inaccurate inventory management lead to the improper inventory plan, saying like stock damage and expiration with inappropriate maintenance, and can also cost patients’ life [6][7].

Medical devices and equipment's inventory in Rwanda is still a long journey to accomplish as many pieces of equipment are unused or unfit without purpose. For medical equipment inventory in Rwanda, at District hospital level; Medical Equipment Management Maintenance System (MEMMS) and electronic-Logistics Management Inventory System (e-LMIS) are relied on, and all; are the computer based systems for inventory records and reports that can be accessed from website [5]. Rwandan Health Institutions are generally only relying on those systems for inventory adding paper-based inventory which are not regularly capturing and updating data without mentioning their incurred high cost. It is observed that through MEMMS, there is no equipment identification system and no way to show the equipment's functional status. Again; according to the published audit report in 2019, users have no adequate training for the available software resulting in many errors and sometimes equipment duplication from the database [8][9]. In addition to the highlighted issues, the system doesn't generate real time data or equipment updates regularly, and being a sophisticated software, it requires regular training for the users. This system also cannot deliver immediate alerts for maintenance or a rapid service. To access recorded data, it is not immediate. Thus, it is very indispensable to have a real time inventory system for equipment management to maximize clinical workflows and maintenance activities while reducing/eliminating unnecessary investments inventory.

3. OBJECTIVES

3.1.General objective

To improve the inventory system of medical equipment in Rwanda by prototyping a web-accessible device for a real-time inventory.

3.2.Specific objectives

To design and prototype a system that can stream real-time functional data from equipment.

To design a conceptual website dashboard for viewing and monitoring the streamed data through the online updated database.

To simulate and analyze the access of equipment records information through a web system

4. RESEARCH QUESTION

- What is the purpose of this research?
- Can the real time database improve the inventory of medical equipment?
- Will the designed device stream effectively real time data?
- Will the proposed inventory system improve the maintenance management of medical equipment?

5. SCOPE AND LIMITATION OF THE STUDY

This research focused on designing and prototyping of a device which is sealed on medical equipment and stream real time data; accessed through a login web dashboard. The medical equipment addressed are the ones that require maintenance.

Data used were collected according to the rules of the addressed health institutions. Only researchers involved in this study has access to the records and transcripts. This paper did not assess supply chain and it proposed medical equipment inventory system at district hospital level.

6. MATERIALS AND METHODS

A device associated with a web-based dashboard system for medical equipment functional records system was developed, the device can be attached on medical equipment. It is registered with full information about medical equipment identification and programmed to give important functional data like maintenance (scheduled or curative) alerts.

The system user can get information through a web login dashboard where he/she can register new equipment or a new health institution, search, access, and generate a report for any medical equipment through download formats from the dashboard.

The real-time equipment functional status (in operation, for maintenance, or disposed) from the hospital/institution is streamed for cloud records storage by the developed device.

Data were collected through a questionnaire from Kibagabaga District Hospital. Information about the actual medical equipment inventory is filled by a biomedical engineer/technician or a logistic for getting the full information of the current inventory practice of medical equipment at the District Hospitals Level.

A polymer/metallic box, ATMEG microcontroller based together with other electronic components and sensors were used to design the device. The prototype is GPRS-GSM and GPS-enabled for data transmission and equipment localization.

The equipment in operation, interrupted, disposed of/out of service together with location is accessed through a web-based dashboard. The data from device are simulated using Arduino IDE, Proteus. To design the web dashboard, the PHP, HTML, CSS and JavaScript were used to design the web dashboard and MySQL for database.

7. SIGNIFICANCE OF THE RESEARCH

The designed device when attached permanently on a medical equipment can deliver the updated functional data of medical equipment. It can help in improving the equipment codification at the organization level.

The use of real time inventory provides a better monitoring of medical equipment through cloud database.

The combination of IOT and the existing equipment's nomenclature improves monitoring identification and can help naming equipment through website.

8. ANTICIPATED OUTPUTS

The designed system is a smart inventory system that result in a web accessible file (records and history of use) from regular streaming of equipment functional status. The records are real time data. With the push buttons from the attached monitoring device, upon equipment failure or security issues, immediately the alert is sent to the competent person. The device also can remind the equipment's regular maintenance at the time set. Equipment is registered with nameplate information. When the equipment entered in service, the attached device starts to send functional data accordingly. Reporting from any functional data can be downloaded in various forms. The system can be transformed application, it can be viewed from a link introduced in MEMMS as it is a web accessed system. Again, it is easily possible to add in the system other modules like spare parts and the module of medical devices that don't require maintenance so that it can replace MEMMS totally.

The new system offers effective healthcare services delivery and helps in expenditure regularization for inventories (cost reduction). Time consuming operating procedures are reduced releasing off the challenges encountered in inventory management (matching database records and maintenance).

9. ORGANIZATION OF THE THESIS

The thesis has six chapters, chapter 1 talks about the overview of HTM and what is inventory in general. It mentions also inventory of medical equipment and how it is done in Rwanda. The general and specific objective of the study, summary on materials and methods used and the relevancy of the research are also described in this chapter.

Chapter 2 presents the general literature review about inventory in healthcare management and a brief description of medical equipment inventory with its role while applying a good maintenance for equipment. The best practices of medical equipment inventory with the involvement of digitization are highlighted.

Chapter 3 describes about the methods and materials that have been used in this thesis. Method of data collection about the current situation was presented. Materials used to design the device were presented and assessed. Software used to develop the web-based system to analyze and design the system.

Chapter 4 presents the overview of the project implementation. Design and simulation were done. A small device was designed and a web-based system was also developed. Physical device and real time data streaming were simulated.

The results obtained were analyzed using the prescriptive methods are explained in chapter 5. The results obtained were compared with the assessment of the current medical equipment inventory in government-owned hospitals (Kibagabaga district hospital). The manner and time of which information are recorded and accessed are compared with the solution from the developed system. Finally, chapter 6 presents the conclusion and proposes recommendations for future work.

CHAPTER II. LITERATURE REVIEW

1. INVENTORY MANAGEMENT

Purchased equipment should be monitored to check their status in regard to the expiry. By a good inventory practice, the intended services from the equipment are assured and also the investment cost in inventories might be saved.

A good inventory practice must keep equipment in better condition with sufficient information on records about the use and storage where various audits are necessary to be sure that the database status is matching with the expected equipment available [10].

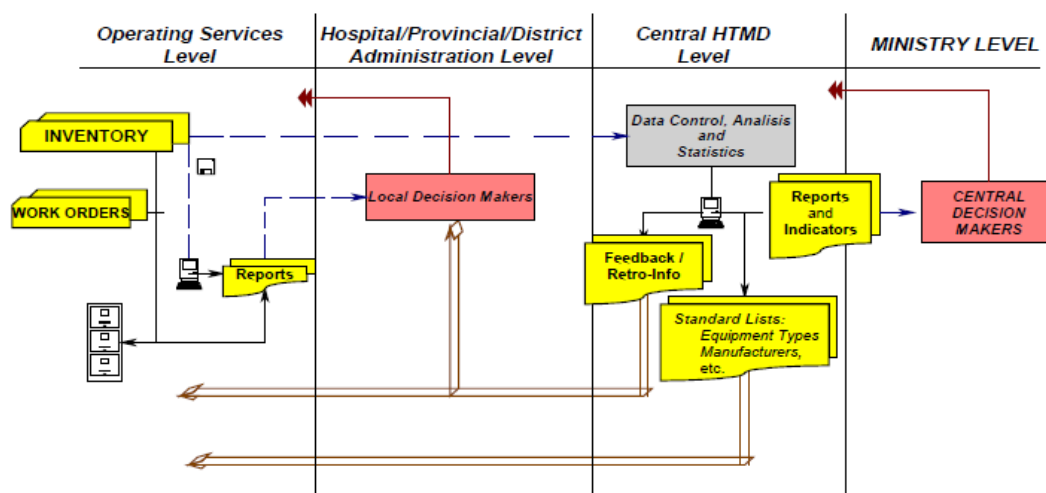


Figure 2.1: Inventory management level

Various methods are used for equipment inventory like files based, computer based but still real time inventory that can provide up-to-date records, the location of the products, the actual status is a problem specifically in developing countries. The good record system for equipment's inventory resulting in good maintenance always relies on a better inventory coding system that classifies and identifies the equipment in any institution. While maintaining the WHO guidelines, every country may possess its own standardized nomenclature system[11] .

2. ROLE OF INVENTORY MANAGEMENT

The way inventory management is practiced determines the effectiveness of stock of goods. It helps also to manage the life conditions of products stored or in services. The better is the management, improves service quality, operation costs, the usage of facilities and cost saving. Inventory management takes a crucial in assuring a good management while helping stakeholders to perform a fruitful service in healthcare industries. Inventory control is concerned with maintaining the correct level of stock through recording its movement and maintenance of goods/equipment as well as operational requirements.

Inventory is the last part for the supply chain, its cost is the most important aspect of an organization so a qualified professional who understands inventory management techniques should be hired or a proper and affordable inventory system should be put in place for any organization as it is the utmost importance [12].

3. REQUIREMENTS FOR EFFECTIVE INVENTORY MANAGEMENT

While a competent, capable, and expert team of staff members is the backbone of any facility, having up-to-date and functional equipment can make it easier to provide extraordinary patient care. Technologically advanced equipment not only improves patient satisfaction; but also increases staff efficiency - both of which lead to more revenue. Planning helps to oversee and maintain medical equipment to safe and readily available standards.

Any institution should have a products/equipment management plan. The plan must accomplish the following initiatives:

- A system/software to keep track of the inventory on hand and on order.
- A reliable forecast of demand that includes an indication of possible forecast error.
- Knowledge of lead times and lead time variability.
- Reasonable estimates of inventory holding costs, ordering costs, and shortage costs.[13].

With the help of equipment service software, these essential parts of a strong equipment management plan can be easily implemented, so the confident in the practice's ability to keep the business, and everything safe.

4. INVENTORY MANAGEMENT IN HEALTH SECTOR

Another thing is that the insufficient of staff can be reason to lack the accountability for updating Medical inventory [14]. Inventory management practices are being used to achieve efficiency and effectiveness in its supply chains and daily workflows. There is a rapid growth in the demand of drugs and diagnostic systems within the healthcare industry. The biggest challenge for healthcare supply chains is to manage inventory efficiently and keep up the satisfactory service level at the same time. A better efficient and effective inventory must be improved and optimized for an active healthcare products monitoring.

The current managerial practices and conflicts among different stakeholders in health care supply chains are directly associated with the issue of inventory management [15].

Better healthcare technology inventory can eliminate frequent failures of hospital equipment and can also reduce the cost of services when applied appropriately[16]. Inaccuracies in inventory and the lack of a consistent inventory mechanism with procedures for medical equipment monitoring results in shortages of essential clinical services [17].

It is likely to prevent or treat most illnesses by using economical techniques that provide medical equipment information needed in the right time [18]. The problem of medical equipment maintenance is persistent, this is because many factors such as professional qualification; practical knowledge; work professionalization; supervision focused on evaluation, development, results and continuous improvement; professional updating and technical support; individual accountability and adequate infrastructure. Application of equipment management planning is also an important factor in addressing the effectiveness of the management of medical equipment [19].

5. MEDICAL EQUIPMENT MANAGEMENT

5.1. Medical equipment planning

From any health organization, it is imperative to ensure both staff and patient safety while using medical equipment. This means that planning is imperative while emphasizing on routine equipment inspections, testing, and maintenance efforts to properly address any and all medical equipment risk.

Common initiatives in medical equipment management plan include:

- To reach all necessary requirements of accreditation established by any regulatory agencies like the Joint Commission.
- To establish patient, employee, practitioner, and visitor protection and safety during medical equipment use.
- To ensure all medical equipment used within the facility is maintained to specific standards to allow safe operation and immediate readiness.
- To assess and uphold medical equipment performance to necessary standards.
- To encourage safe and effective use of medical equipment by staff and practitioners within the health facility. [19]

5.2. Conduct an Equipment Inventory

A better plan for medical equipment management will need to highlight the quantity and the use of medical equipment, this help to have a good approach on any equipment life use details.

It will result in knowing the available equipment and their status while helping to what are for maintenance. Serial numbers, equipment location details, and specific maintenance information should be filed. By collecting and routinely updating these details and doing required maintenance and testing sessions, this is properly an inventory management [20].

Having a medical equipment safety standard within the inventory, generally identifying all high-risk medical equipment, such as equipment in ICU. The malfunction and failure of these life-sustaining pieces of equipment can cause severe injury or death, so it's imperative you use a ranking system to highlight these machines' importance within your inventory [21]. By acknowledging all high-risk equipment within your facility, you can better prioritize maintenance and safety testing to effectively uphold a strong safety standard.

5.3.Equipment Maintenance

The management of medical equipment is somehow difficulty when there is a huge amount of equipment but when all updated data are available, their maintenance is easy to handle [7]. The inventory is an everyday performed activity for biomedical department or logistic in any health institution. A good database that have to deliver any stored information on the equipment including but not limited to the identification number, location of use, installation date, number of events (for troubleshooting), total time of use for maintenance either corrective or preventive maintenance [22]. A good data reporting procedures is closely linked to better maintenance, despite that it can cause loss [23].

Based on the equipment manufacturer's recommendations and accreditation requirements, develop a maintenance schedule for each piece of equipment.

While addressing each equipment piece, be sure to also include any details regarding required equipment testing. Those data helps in better maintenance plan in terms of equipment use and clinical application [24].

Information regarding both maintenance and testing procedures should always be recorded within your maintenance plan, especially in regards to high-risk equipment. These details must include problem descriptions, performed repairs, maintenance actions, technician details, department location, and completion dates. When constructing this plan, remember to acknowledge access information for the maintenance management system being used to organize these details as well. Maintenance has three major forms which are design-out maintenance, preventive maintenance that includes systematic (periodic) maintenance and condition-based maintenance and Corrective maintenance in case of emergency alerts.

The effectiveness for medical equipment results from the better maintenance management of medical equipment while improving quality of care and cost-effective health services. Hence it is necessary to have a proper method that assess and real information data [2] [25].

Medical equipment maintenance is a daily task for clinical engineers, but it may prove difficult to easily extract relevant information from the large amount of data from computerized maintenance management systems or with acceptable maintenance history and ages [24].

6. INTERNET OF THINGS (IOT)

An IoT system is a system of entities (including cyber-physical devices, information resources, and people) that exchange information and interact with the physical world by sensing, processing information, and actuating. In essence, the components (things) of an IoT system interact with each other to fulfill the goal for which the system has been designed like autonomously control or monitoring [26][27].

6.1. Internet of thing performance /Real time data streaming

Internet of Things technology could be one of the trustworthy automated systems, for the proper management of the medical equipment particularly in healthy institutions while reducing the trouble for the system identification for equipment with update information delivery [28].

The solution for real time data streaming was proved by the performance evaluation system based on online monitoring of Internet of things technology, taking medical imaging equipment as an example. Build the performance management platform of the Internet of things through four aspects: data acquisition, network architecture, CPU, and display output [29] [30].

For real-time monitoring of electrical equipment early warning for safety, shorten troubleshooting time and emergency command, a variety of key technologies of the Internet of Things, such as sensor technology, network communication technology, and cloud computing technology, data, information exchange, and communication between electrical equipment and Internet technology are carried out to prevent power equipment failure and other problems [31].

IOT is crucial in streaming data generally in the intelligent power monitoring system by combining 4G technology, the Android operating system, and other technologies closely related to the Internet of things. This results in the optimization of process parameters of electronic assembly that can accurately redirect the information to attain the aim of smooth link and information exchange between things and people [32].

6.2.IOT challenges and solution for data streaming

IoT has been disrupting in data streaming by providing an unprecedented approach for a (potentially large) number of distributed components connected over a network to collect data, collaborate, and perform tasks with almost no human intervention.

A secure data stream is important for the real time communications. Communication security is a requirement and a secure data stream is significant for the communications of the IoT.

Because the communication of the IoT is in real time, a stream cipher with the characteristics of simplicity and high speed is suitable in the real-time communications of IoT for its security. It plays an important role in modern cryptography, especially, in IoT, mobile and wireless communications [33]. In Internet Of Things, devices performance are often mobile and battery powered thus their communication requires fast and energy efficient solutions for this problem the use of multi-interface communication for fast and energy efficient communication would be the good solution [34]. Lack of visibility into real-time inventory poses a problem for not only in equipment availability but also for the performance of inventory-based service equipment.

To deal with optimization of input data for wireless IoT devices with database handled by cloud framework, a combination of accumulation data in IoT device to multi-value packet with noise elimination solved by advanced interpolation results in reducing noise and increase of data frequency stored in cloud platform for next knowledge data mining [35].

With the mass use of mobile internet access, mobile applications contribute to traffic explosion in telecommunication networks, TDD-based LTE-Hi is a prospective solutions to future mobile broadband systems as it can offer better performance in hotspots and indoor environments from the exploration of wider transmission bandwidth in higher frequency band(s) and being seamlessly integrated with conventional LTE macro-cells [36]. The use of wireless systems using 2.4 GHz industrial, scientific and medical (ISM) band such as IEEE 802.11 wireless local area networks (WLANs) and Bluetooth (BT), ZigBee, and ultra-wideband (UWB) results in minimizing the interference with a small additional delay in the data transfer in the proximity as those devices have spread-spectrum modulation techniques to make their systems less susceptible to interference from other in band ISM signals [37].

6.3.The role of IOT in inventory management

An online programmed system with desired conditions and configuration through IOTs embedded help in obtaining regular updated database. The website interface is easy to use and can shows desired data anytime [38]. Beside traditional inventory and recent research on inventory innovations, still an improvement for inventory is needed so that any information can obtained through online or remotely [5].

The use of wireless or Bluetooth devices can together with IOTs make possible the remote monitoring. Upgraded data can be transmitted over a distance carrying settled conditions and also highlighting not only the innovation but also improve and address the real needs for users. Based on this, a firmware and software prototyping can be done in order to make the most of device performances [39]. Different technology for data streaming in short or long distance such mesh network using Bluetooth with its impact, ZigBee Solution, LTE (Long Term Evolution) solution, IOT solution or the combination of LTE with IOT solutions [40][41]. IOT has been very familiar in industry inventory management emphasizing in supply chain, stock management and pricing [42].

6.4.Web-Cloud based Inventory solution

IoT offers better visibility of inventory, and managers are more likely to have the right items, in the right place, at the right time than manual inventory. With real-time data, online database and items location, users can avoid human errors of inventory in hand without failing to meet the needs of the customers [43]. With a Cloud-Based Solution, IoT brings with it a scope of real-time systematic abilities through PHP and MySQL application. Data streamed from programmed components and even social media can be assimilated with cloud-based BI systems [44]. Through web dashboard, a system user can manage and monitor the inventory management from protected log in. Using the system/application the user can enter, view or edit information relating to updated inventories and maintenance of registered equipment [45].

7. INVENTORY MANAGEMENT OF MEDICAL EQUIPMENT IN RWANDA

In any country, there is a defined procedures of medical devices/ equipment management. This is crucial because the healthcare services everywhere are based on good management. In Rwanda's health sector, the purpose is to ensure that any medical equipment is safely handled, managed, and maintained in an appropriate manner to serve its intended expediencies and to ensure staff and patient safety.

Generally, the management of medical equipment is done through MEMMS and the Ministry of health has clear statements about medical equipment management which are the followings:

- The hospital shall ensure that medical equipment is appropriately managed and effectively used by qualified and trained staff.
- The hospital shall utilize the Medical Equipment Management and Maintenance System (MEMMS) to ensure all biomedical equipment activities are effectively and efficiently managed and documented.

Any health institution in Rwanda having medical equipment should have the department in charge of medical equipment. In the department there a technician, an engineer or a logistic in charge of medical equipment management. The key person must ensure that he/she conducted an inventory of all biomedical equipment and records in MEMMS [6]. Through inventory practice, he/she assigns an inventory number to each piece of equipment. The registered biomedical equipment should be updated quarterly. Biomedical Technician keeps equipment installation schedule, and equipment maintenance, avails guidelines and user manual for proper use, trains staff on proper use, equipment check-up, tag the inspection date and next check-up date to ensure equipment is in proper condition, to ensure appropriate planning and effectively implements maintenance and management plan, updates accordingly in MEMMS, and avails a maintenance report [46].

8. NOMENCLATURE OF MEDICAL EQUIPMENT

Medical Device nomenclature is a complex system of rules, codes, and definitions employed by healthcare systems or organizations to identify sets of medical devices. The main nomenclature systems are the Universal Medical Devices Nomenclature System (UMDNS), the National Classification of Medical Devices (CND), the European Medical Device Nomenclature (EMDN), the Global Medical Device Nomenclature (GMDN), the Universal Medical Device Nomenclature System (UMDNS), and the Unique Device Identifier (UDI) [47][48][11][49][50]. Rwanda uses the UMDNS system through Emergency Care Research Institute (ECRI) membership. There is a codification method that associated to the said nomenclature for identifying each equipment in regard to the department where it is assigned.

9. SUMMARY

The works review presented provide an understanding of theories concerning how inventory management is done. Healthcare technology management inventory contributes to the health care delivery especially in biomedical department. Many studies argue types of inventory practice and their importance in healthcare services. The management level of medical equipment is an important index to appraise the modernization grade of hospitals and it is also the basic element of medical and scientific research work, which plays a key role in the development of medical clinical services. From the papers reviewed, the gaps missing are real time functional data from medical equipment and a proper maintenance management. Those problem can be addressed by the use of embedded devices together with IOTs resulting in having updated functional data from equipment; an innovative inventory system.

CHAPTER III. RESEARCH METHODOLOGY

1. INTRODUCTION

The primary research method for monitoring and control a Web-Based Medical Equipment Inventory Record Management is the literature review and the theoretical modeling. For literature review, the survey of scholarly sources on a specific topic that provided an overview of current knowledge and systems was used, allowing the identification of relevant theories, methods, and gaps in the existing system for monitoring and control of medical equipment.

Theoretical frameworks were often used to define concepts and explained phenomena of this system like working system of medical equipment, sensor, microcontrollers, gateway device and other related to this IoT system. For the implementation, we used literature review model and theoretical modeling in order to implement the monitoring and the control system of a Smart Device for Real-Time Medical Equipment Inventory Record Management

In designing; the first step was to connect calibrated and calculated sensors (GPS module, current sensor, and vibration and temperature sensors) to the Medical Equipment. It means all sensors measure real value and send data to microcontroller. To achieve the objectives, a comparative analysis of the current scenario of medical inventory system in Kibagabaga District Hospital was done by using the prescriptive and descriptive methods.

A good understanding of the current situation through hospital workers interviews and questionnaire of selected professionals in a district hospital (Kibagabaga District Hospital) lead to the best analysis with the designed system.

A monitoring device to be attached permanently on medical equipment in service, was designed. The device streams data that are accessed through a dashboard. The real time data of medical equipment functional status (in operation, for maintenance or disposed) from the hospital/institution should be streamed for cloud storing through GPRS-GSM installed in the prototyped device. The device was programed in the way that it sends alerts to the competent person in case of maintenance need either for emergency or for scheduled maintenance. The device is linked to i-cloud which receives regular updates for database. For emergency alerts; with the conditioned push button on the device, a simple push by the equipment user can generate an alert. The device has another pushbutton for security purpose, once the device is removed from Medical Equipment without authorized access; this is taken as a breach of security and data are beyond the accepted limits (abnormality) for more than 2 seconds a decision to notify that the medical equipment has been displaced without authorization.

The corresponding notification of the fault happened is sent immediately to authorized person for urgent intervention. The sampling rate or frequency for sensing technical parameters data (geo location, functional status, temperature, time of use and alerts) and streaming them in the cloud is 5 seconds.

2. RESEARCH PROCESS

The system of monitoring and control the Smart Device for Real-Time Medical Equipment Inventory Record Management identifies and acts clearly on the problem of monitoring and controlling daily working of medical equipment problems: real time database, emergency alerts, working status (time of use), and vandalism that caused in the healthy institutions carelessness. Generally Medical Equipment parameters such as working temperature, working time, geo-location status, and safety are monitored.

The systematic process of conducting this project was:

- **Problem definition:** Understanding the situation and gaps to be addressed.
- **Project planning and gathering needed information:** Addressing how to complete a project in a certain timeframe, usually with defined stages and designated resources.
- **Data collection:** For feasibility analysis and requirements specifications
- **Design conception:** The core idea driving the design of a product, explained via a collection of sketches, images, and a written statement. Translates the requirements specifications into the model.
- **Coding and Implementation of the prototype:** Creation of the actual prototype.
- **Simulation of the designed system:** linking the physical device with the web dashboard.

The implementation system gives the following solutions:

- When there are unconditional faults from the equipment, there is a push button to be pressed by any equipment user; the notification is sent to the authorized inventory managing person.
- For security issues, there is a hidden push button. The system alert automatically when there is someone trying to remove attached medical equipment from its position in order to protect against theft of displacement infrastructures and the alarm system to let the offender be intimidated and inform neighborhood whenever there is an emergency.
- The system takes decision automatically according to data available and it is done by analyzing real time stored data in database.

- Authorized person in the institution will be able to monitor and register all different medical equipment in different location by using dashboard on cloud.
- System can generate report and graphs of monitored data when needed.

Design and Implementation of a Smart Device for Real-Time Medical Equipment Inventory Record Management comprises of two subsections, which are hardware part and software part. This research was concerned with three major issues: Effective real time data streaming, Ease access of recorded data and maintenance management.

Effective real time data streaming: The designed device system has the electronic components modules. These components are fixed on microcontroller and are used for detecting functional data and any alerts then stream them to the online database.

Ease of access: The data can be effectively accessed using the cloud, it can be observed and controlled using the web application. Through website it is possible to register a new equipment and download reports based on functional service.

Maintenance management: When a fault occurred on Medical Equipment; the system send a sms notification to an authorized person.

3. RESEARCH DESIGN MATERIALS

The developed IoT system automatically detects technical parameters of on Medical Equipment (geo-location, status of use, temperature and alerts notification) and checks if they are in the admissible operating limits. Once one or all of those technical parameters are becoming abnormal, and go beyond the accepted limits during 5 seconds, then the system on Medical Equipment alert for maintenance or security, send the corresponding short message service (sms) to the authorized persons. Security push button detects removal of the system on Medical Equipment when there is vandalism of Medical Equipment. A Buzzer gives an alert warning on the site as well.

The device system has four modules, which are power module, sensors (input) module, controller module, output module. It is built using current sensors, GPS, and temperature sensor with ATMEGA 328P Microcontroller to collect and process data from sensors connected to Medical Equipment system. GSM/GPRS module uploads all the data sensed to the cloud storage, displays them on web application and sends sms to authorized persons. Software like Arduino IDE, EasyEDA and Proteus have been used in hardware design and processing.

A web-based dashboard application was developed using PHP, HTML, CSS, and Java Script as the user interface for information visualization. The database for storing sensed data was developed using MySQL and this application was hosted to on **www.machine.iot.rw**.

This Web-Based Smart Inventory System for Medical Equipment, its hardware system is powered by a rechargeable battery once the AC power source is off.

4. BLOCK DIAGRAM

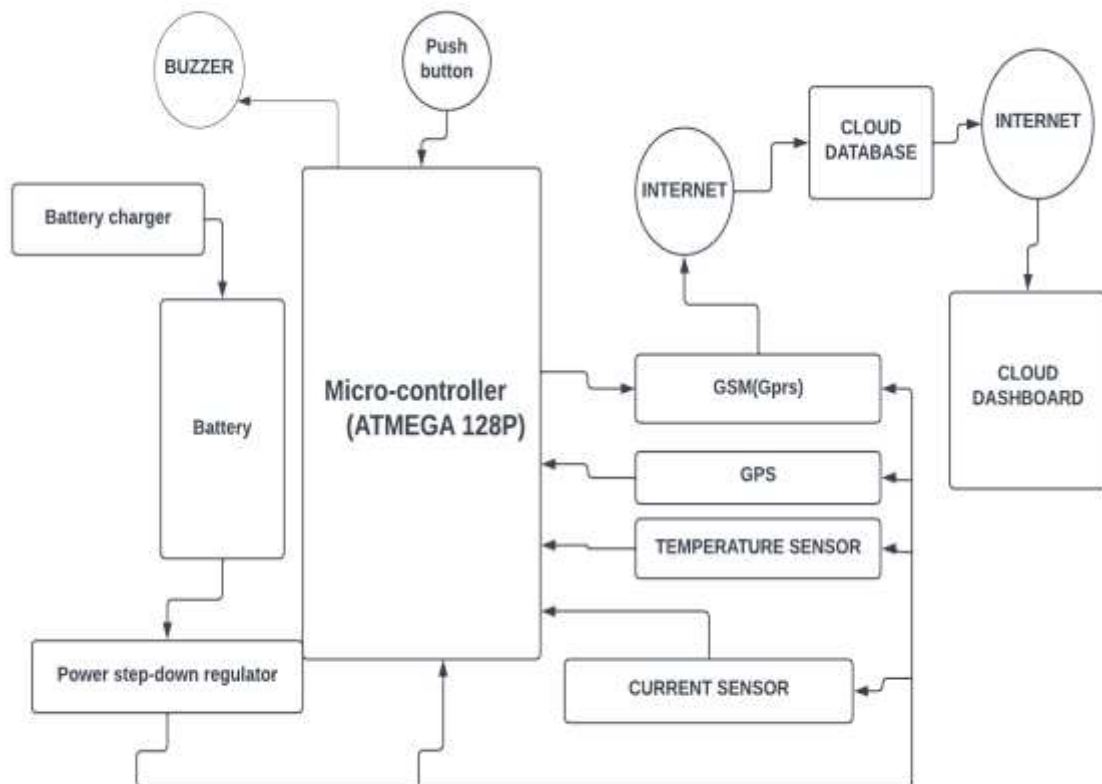


Figure 3.1: Block diagram

Power module: The power module has a Rectifier as AC to DC converter and battery power bank. The battery is used to keep constant power supply when there is no main power. A power supply is there to give the capacity to scale sensor and controller modules, which will work at 5V. The device can be powered by a lithium battery or by the power sourced from the medical equipment input power. The need of using the parallel adaptor at the input.

Sensor module: The sensor module comprises by current sensors, GPS module and waterproofed Temperature sensor. These sensors are connected with microcontroller as input part and are used for detecting the power utility parameters from time to time.

Controller module: ATmega 328P microcontroller is considered as brain of this architecture, GPRS as gateway device.

The GPRS system sits on top of the TDMA and GSM networks to provide subscribers uninterrupted data connection instead of a dial-up connection. This gives subscribers the ability to access data without the need to dial up and authenticate.

A packet control unit is present in a GPRS cellphone. This control unit provides a bridge for data to travel across mobile networks and the Internet by making use of radio channels.

Output module: Monitoring and control system of medical equipment has web application as the first output part by using her/his mobile phone, tablet or computers, the authorized person in control station will receive SMS notifications, collected data and output as decision made after data analysis.

Storage module: we have clouds storage as server, it is a service model in which data is transmitted and stored on remote storage systems before and after data analysis, where it is maintained, managed, backed up and made available to users over a network, and it will store all data collected and transmitted by GPRS module.

5. COMPONENTS USED

5.1.PCB



Figure 3.2: printed circuit board

A **printed circuit board** is a medium used in electrical and electronic engineering to connect electronic components to one another in a controlled manner. Ideal for point to point soldering, used to fix all components together.

5.2.AT mega 328P Microcontroller

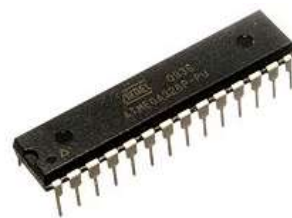


Figure 3.3: ATmega328P

A compact integrated circuit designed to govern a specific operation in an embedded system. ATmega328P is a high performance yet low power consumption 8-bit AVR microcontroller that's able to achieve the most single clock cycle execution of 131 powerful instructions thanks to its advanced RISC architecture. It can commonly be found as a processor in Arduino boards such as Arduino Fio and Arduino Uno.

The ATmega328 is a low-power CMOS 8-bit microcontroller based on the AVR® enhanced RISC architecture with 32 KBytes in System Programmable (ISP) Flash.

Features:

1.8-5.5V operating range

Up to 20MHz

Part: ATMEGA328P-AU

32kB Flash program memory

1kB EEPROM

2kB Internal SRAM

2 8-bit Timer/Counters

1 16-bit Timer/Counter

RTC with separate oscillator

6 PWM Channels

8 Channel 10-bit ADC

Serial USART

Master/Slave SPI interface

2-wire (I2C) interface

Watchdog timer

Analog comparator

23 IO lines

Data retention: 20 years at 85C/ 100 years at 25C



Figure 3.4: Arduino uno

Arduino uno is open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It is intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments.

Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The microcontroller on the board is programmed using the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing).

Arduino projects can be stand-alone or they can communicate with software running on a computer (e.g. Flash, Processing, Max/MSP).

Features

Microcontroller: ATmega328

Operating Voltage: 5V

Input Voltage (recommended): 7-12V

Input Voltage (limits): 6-20V

Digital I/O Pins: 14 (of which 6 provide PWM output)

Analog Input Pins: 6

DC Current per I/O Pin: 40 mA

DC Current for 3.3V Pin: 50 mA

Flash Memory: 32 KB (ATmega328) of which 0.5 KB used by boot-loader

SRAM: 2 KB (ATmega328)

EEPROM: 1 KB (ATmega328)

Clock Speed: 16 MHz

5.3. Current sensors

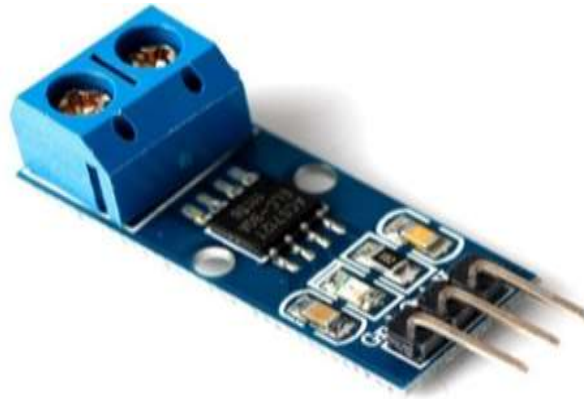


Figure 3.5: Current Sensor Module

30A range Current Sensor Module ACS712 Module COM44, R17

This ACS721 current module is based on ACS712 sensor, which can accurately detect AC or DC current. The maximum AC or DC that can be detected can reach 30A, and the present current signal can be read via analog I / O port of Arduino.

The module can measure the positive and negative 30 amps, corresponding to the analog output $66\text{mV} / \text{A}$

Pin 5V power supply, on-board power indicator

Using gold plated circuit boards

No test current through the output voltage is $VCC / 2$

Size: 31 x 13mm

5.4. GSM module



Figure 3.6: SIM 800L GSM module

Smallest SIM 800L GPRS GSM BRD56, R11. It allows my hardware part to connect to the internet, send and receive SMS, using the GSM library. LoNet 800L is a mini-GSM module that offers 2G GSM and GPRS data. It features small size and low power consumption.

Twice size as a coin and the working current low to 1mA when in sleep mode. It uses a serial port communication, supports 3GPP TS 27.007, 27.005 and SIMCOM enhanced AT Commands. Also, it supports A-GPS technique that help get indoor position by the mobile network. Works compatible with Arduino Uno, Arduino Mini, Raspberry Pi. It comes with a mini-GSM antenna, and also an external power supply is required.

Features:

Quad-band 850/900/1800/1900MHz

GPRS multi-slot class12 connectivity: max. 85.6kbps (down-load/up-load)

GPRS mobile station class B

3GPP TS 27.007, 27.005 and SIMCOM enhanced AT Commands

Real Time Clock

Power voltage 3.4V ~ 4.4V DC

A-GPS (Assisted Global Positioning System)

Supports 2.8V to 5.0V logic level

Low power consumption, 1mA in sleep mode

Compact size 23mm x 35mm x 5.6mm

Standard SIM Card

5.5. Temperature sensor



Figure 3.7: Temperature sensor

Waterproof Digital Thermal Probe LM35DZ Temperature Probe sensor Module SEN53, R13

These are precision integrated-circuit temperature devices with an output voltage linearly-proportional to the Centigrade temperature.

The LM35 device has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from the output to obtain convenient Centigrade scaling.

Technical Specification:

Operating voltage: 4V – 30V

Sensor Model: LM35DZ

Signal Output Type: Analog

Temperature measuring range: 0°C – 100 °C

Measuring accuracy: 0.5 °C

Linear scale factor: +10 mV / °C

Low power consumption, less than 60uA

Low output impedance, 1mA current through only 0.1 ω

5.6. Buzzer



Figure 3.8: Buzzer – 5V COM22, R33

This is a Buzzer device that you can embed into your project for audio signalling, Apply 5V to this buzzer module and you’ll be rewarded with a loud noise.

FEATURES

Input Voltage (Max.): 5V

Resistance: 90 Ω

Resonance Frequency: 2048 Hz

Sound pressure (dB(A)/10cm) min.: 80

Body Size: 12 x 9.5mm

Pin Pitch: 6mm

External Material: Plastic;

Color: Black

5.7. Jumper wires



Figure 3.9: Jumper wires

Male to male jumper wires. Female to male jumper wires. Female to female jumper wires

Jumper wires are used to connect two points in a circuit. All Electronics stocks jumper wire in a variety of lengths and assortments. Frequently used with breadboards and other prototyping tools in order to make it easy to change a circuit as needed

5.8. Power supply



Figure 3.10: AC-DC Power Supply

AC-DC Power Supply – 5W 1A (220V/5V) BRD42, R11

We get 5V to supply all parts of the system sensor, controller modules and gateway module at 5V. This is a AC to DC power Supply with 220V AC input and 5V DC output. This is a power source for the isolation industrial-grade built-in power supply module, temperature protection, and short circuit protection, AC85 ~ 265 v input voltage, wide 431 precision voltage stability DC5V output, with mounting holes, with input and output EMI filter circuit, small volume, stable performance, cost-effective.

Features

Mounting dimensions: 51mm x 23mm

Input voltage: 90V to 240V AC 50HZ/60HZ

Input Current: 0.065 (AC 110V) 0.032 (AC 220V) (full load)

Input surge current: 20A (full load)

Output voltage: DC 5V ($\pm 0.2V$)

Output Current: 1A

Output power: 5W

5.9. ARDUINO IDE

Arduino IDE is an open-source software that is mainly used for writing and compiling the code into the Arduino module. This software makes code compilation too easy.

It is easily available for operating system like MAC, Windows, LINUX and runs on the Java platform that comes with inbuilt functions and commands that play a vital role for debugging, editing and compiling the code in the environment. The main code, also known as a Sketch created on the IDE platform will ultimately generate a Hex file, which is transferred and uploaded in the controller on the board.

The Arduino Integrated Development Environment or Arduino Software (IDE) - contains a text editor for writing code in C++, a message area, a text console, a toolbar with buttons for common functions and a series of menus used to program microcontroller.

5.10. PROTEUS

The Proteus design suite is a proprietary software tool suits primarily for electronic design automation. Mainly electronic design engineers and technicians to create schematics and electronic print for manufacturing printed circuit boards use the software.

Proteus is used to simulate, design and drawing of electronic circuits. The Lab Centre Electronics invented it. Proteus is a complete development platform product concept to design completion.

Its advantage are intelligent principle layout, hybrid circuit simulation and accurate analysis, single chip software debugging, and peripheral circuit co- simulation, PCB automatic layout and wiring.

CHAPTER IV: SYSTEM DESIGN AND SIMULATION

1. INTRODUCTION

This chapter describes the implementation of the System Prototype, meaning the design of device prototype and the design of a web dashboard. Data are streamed via the device attached to medical equipment and finally displaying the results of the device and rationalization of finding and the graphs of effects.

2. FLOWCHART

Shows the Flowchart of the developed system.

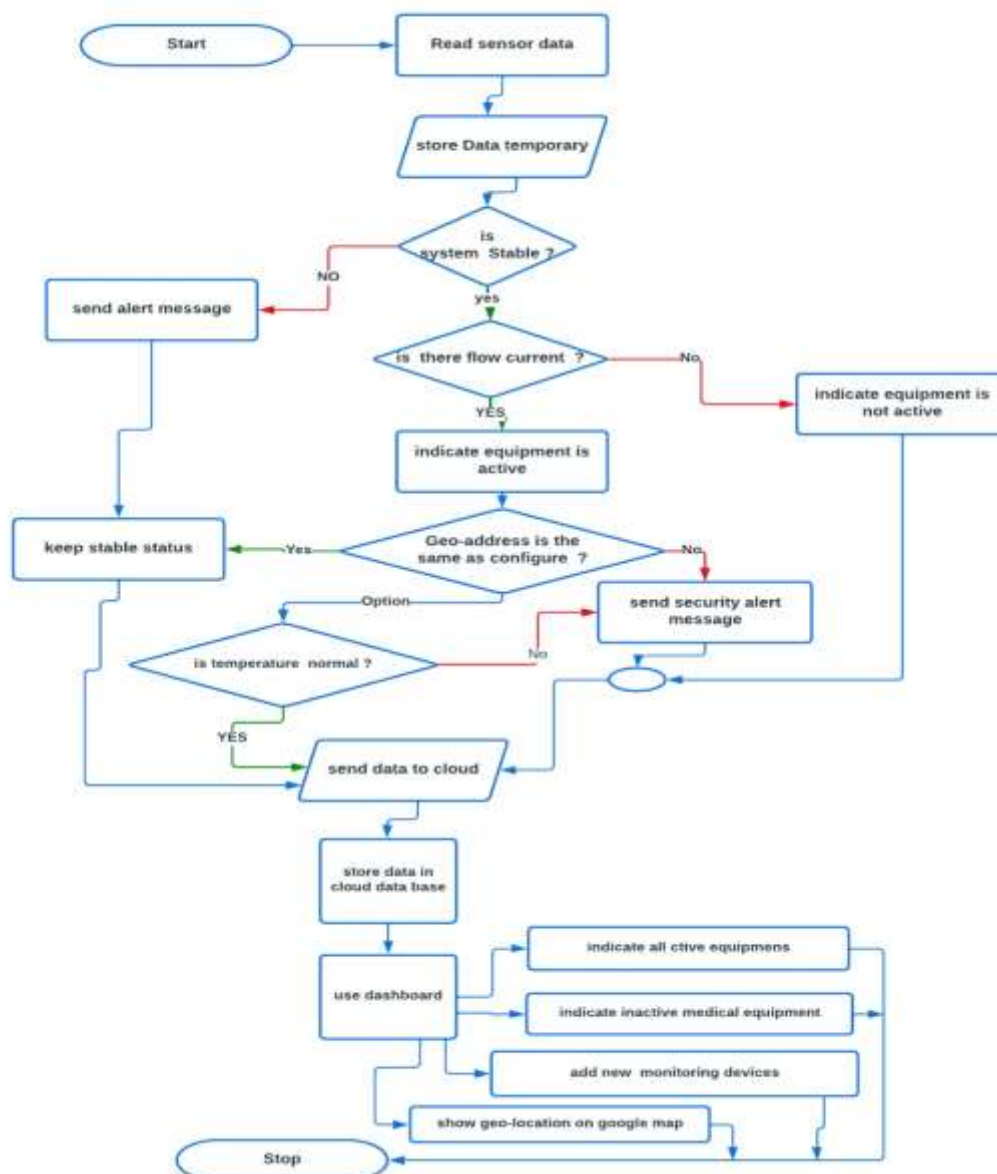


Figure 4.1: Developed system flowchart

The figure above provides a detailed structure of functionality of the system and how data follows also by indication of condition followed in making decision in the whole system.

A web-based application was developed using PHP, HTML, CSS, and Java Script as the user interface for information visualization. The database for storing sensed data was developed using Mysql and this application was hosted.

3. PHYSICAL DEVICE DESIGN AND SIMULATION

The “Design and Implementation of a Smart Device for Real-Time Medical Equipment Inventory Record Management” is a cross platform tool to detect the use, faults and theft of medical equipment by indicating the location of medical equipment on google map in way of tracking which goes with security monitoring and by considering the functionality parameters of each equipment the system tell user when maintenance is required. Remotely user can be able to view or informed when the device displaced, powered off, active and interrupted. While registering the information about scheduled maintenance, the equipment is registered and programmed with exact maintenance schedules date to generate alerts when the time set in on.

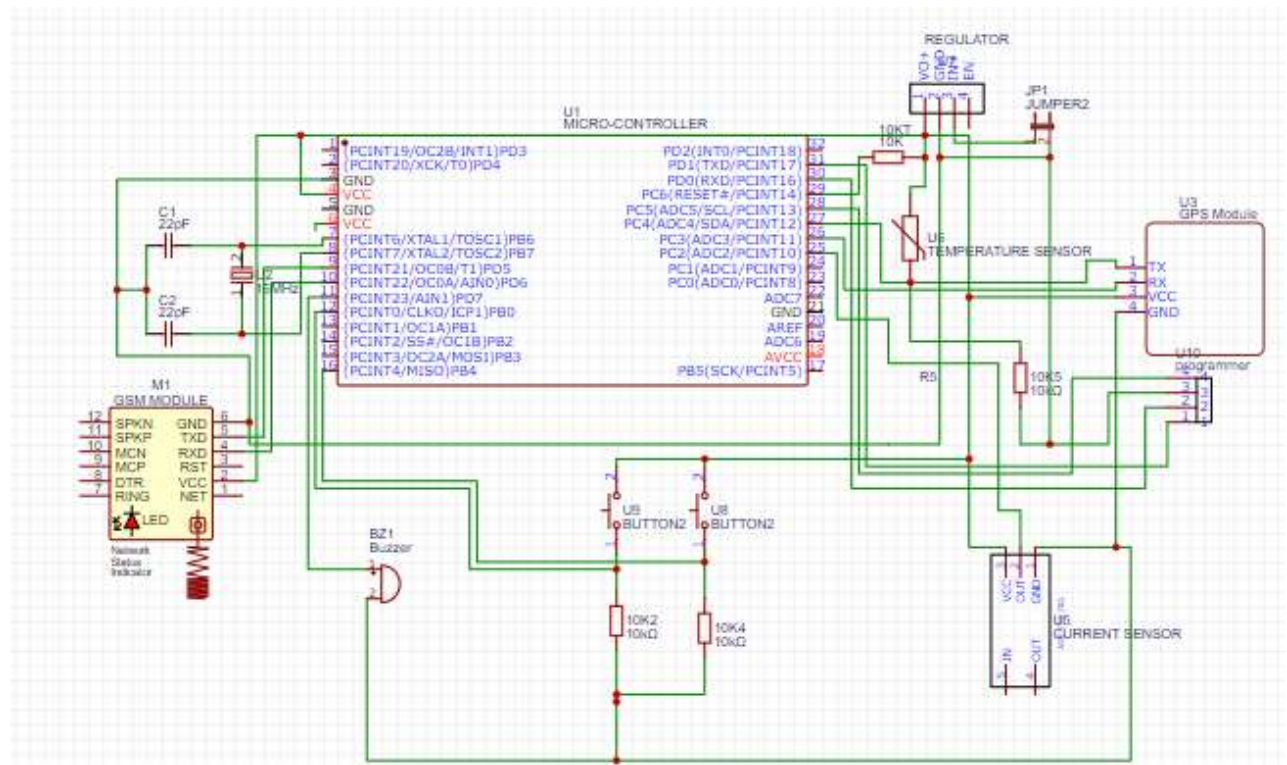


Figure 4.2: Physical hardware simulation

The figure above shows the circuit diagram and how each electronic part is connected to other to form a system. The simulation was done through Proteus. Each component is calculated basing on parameters for better simulation.

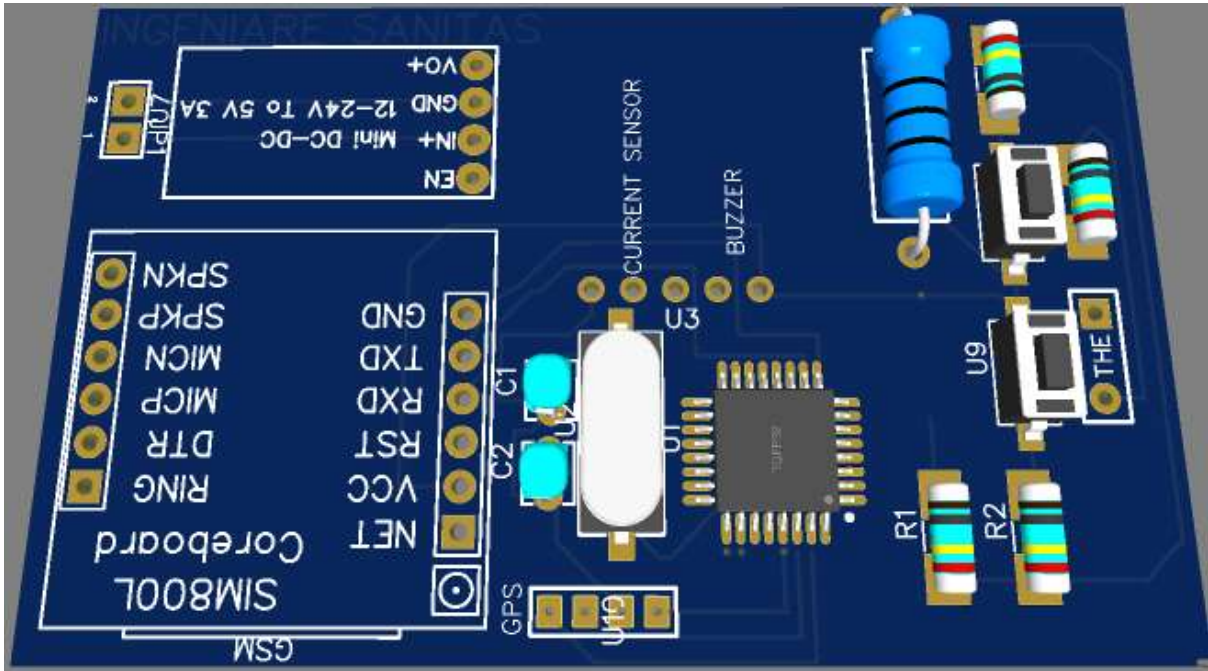


Figure 4.32: The device PCB with different components

The figure above shows the PCB board designed to show how each electronic part is connected together and it will be printed using PCB making machine to get good motherboard of this system. The simulation was done through EasyEDA

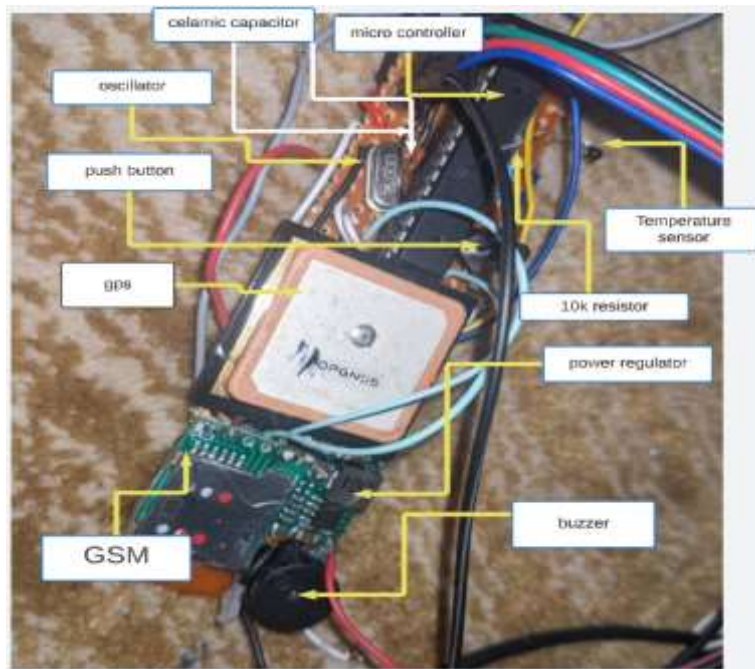


Figure 4.4: Hardware prototype

The figure above shows the design implementation of the prototype where all electronic components are connected to form a working prototype which is mounted to the PCB board.

4. WEB DASHBOARD AND SIMULATION

The implemented system keeps data stored in the cloud, and different analyses can be accessed by providing the username and password the followings sign in form.

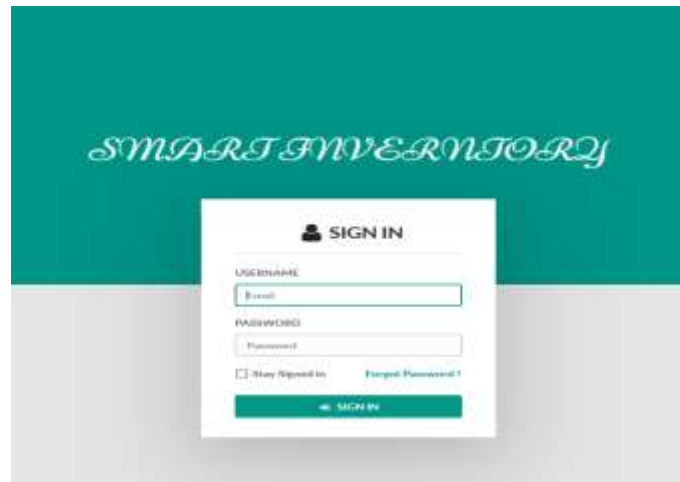


Figure 4.5: The login page

The above login page allows a registered user to access the application by entering their username and password. The user ID must conform to a limited length, such as eight characters, and the password must contain at least one digit and not match a natural language word, which makes our system more secure.

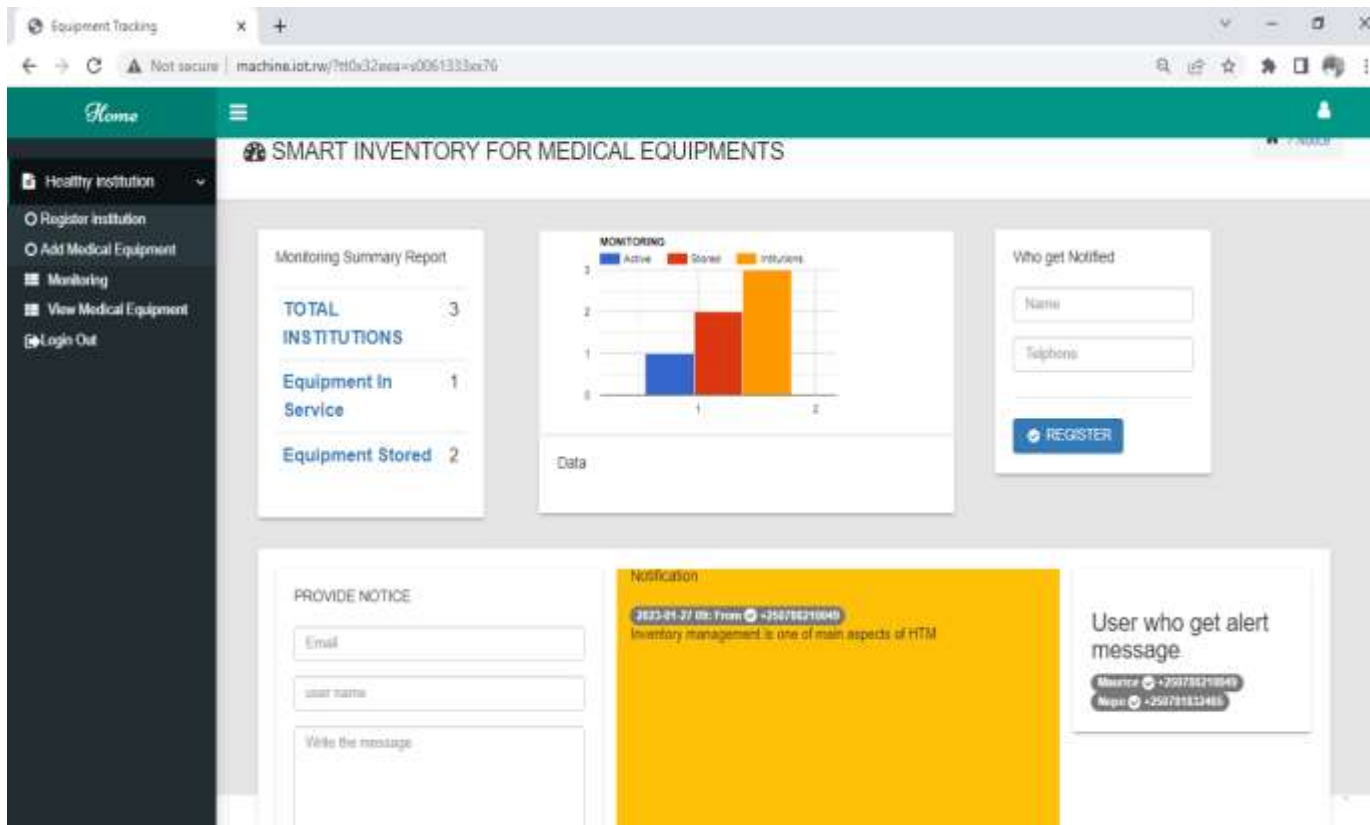


Figure 4.6: The dashboard's main page

The above figure shows the dashboard of the current statistics for the information (i.e., total institutions, total in service equipment, total stored equipment, and total disposed equipment) that are currently stored in the system. This dashboard is called the "Home dashboard."

The main page has a small window to provide important information message and another window to display the information communicated from any user. There is also the window for users who get notified.

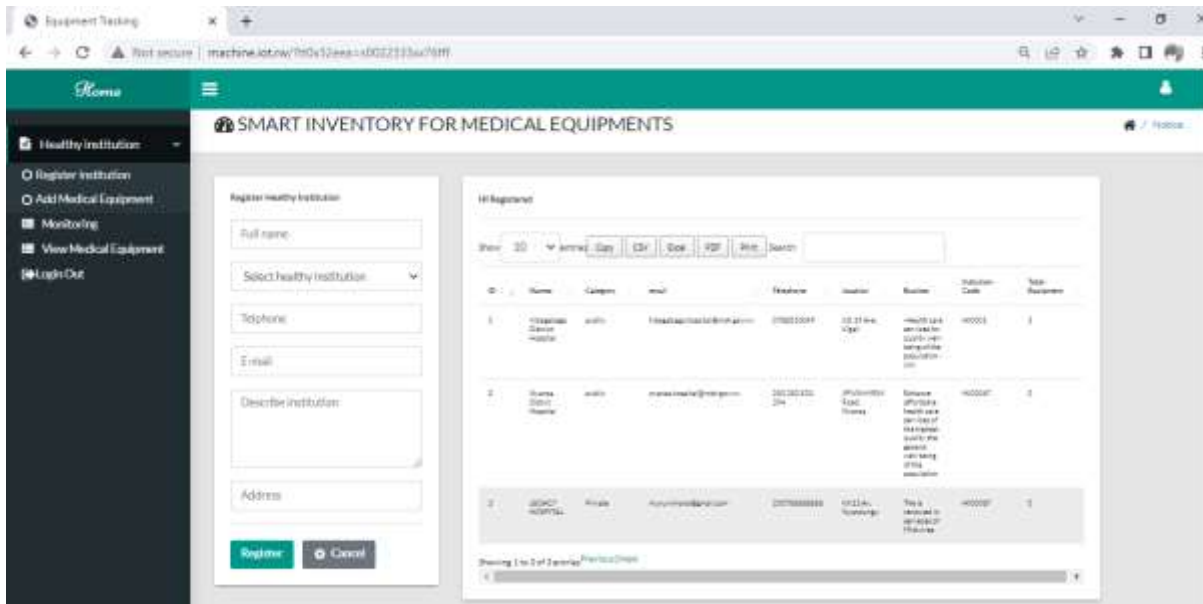


Figure 4.7: Institution registration page

The above figure shows the form that allows the administrator to register a new healthy institution with the following form fields (name of institution, institution category which may be public or private, telephone, email, and other related information).

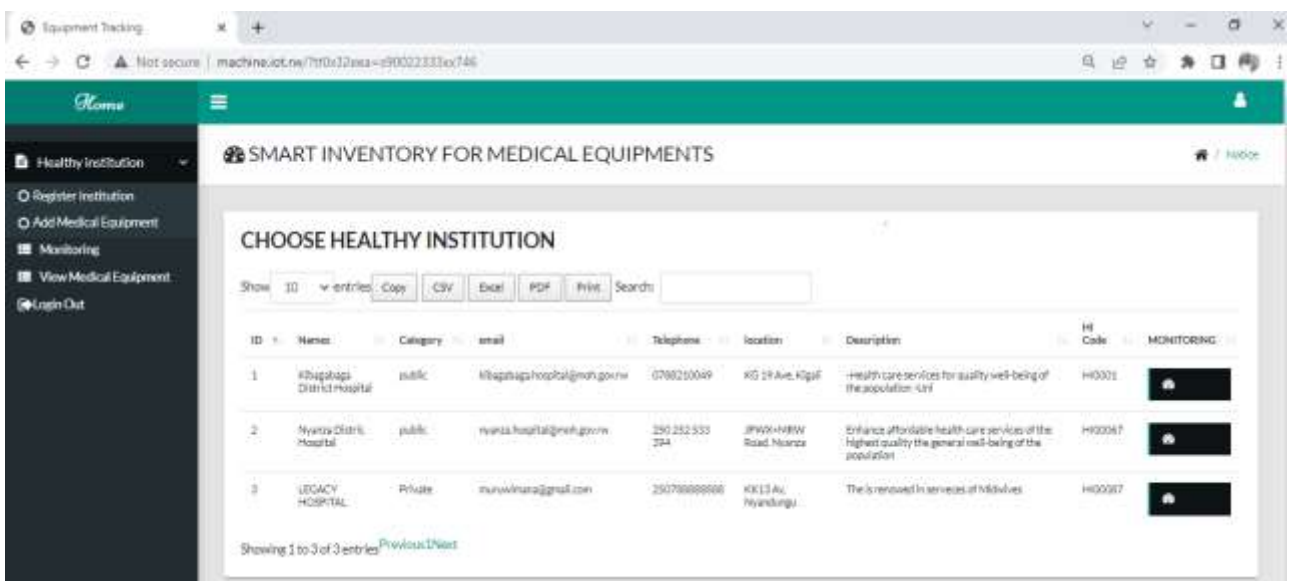


Figure 4.8: Health institutions display page

The above page allows a view and navigation into health institutions, from this side the user can access the list of all registered these institutions. For each institution, it displays the name, category (private or public), location, important service from the institution, identification code and the number of registered medical equipment.

The screenshot shows a web application interface for managing medical equipment. On the left is a dark sidebar with navigation options: 'Home', 'Healthy institution', 'Register institution', 'Add Medical Equipment', 'Monitoring', 'View Medical Equipment', and 'Login Out'. The main content area is titled 'SMART INVENTORY FOR MEDICAL EQUIPMENTS' and contains a form titled 'Add New Device'. The form includes the following fields: 'HI ID Code', 'Enter Serial Number', 'Equipment name', 'Enter Manufacturer', 'Enter equipment model', 'Manufacture date' (with a date picker showing 'mm/dd/yyyy'), 'UMDNS-CODE' (a dropdown menu), 'SET LOCATION' (with 'latitude' and 'longitude' sub-fields), 'maintainance Schedule' (with a date picker showing 'mm/dd/yyyy'), and a large text area for 'Describe The Functionaties of Device'. At the bottom of the form are two buttons: a green 'Register' button and a grey 'Cancel' button.

Figure 4.9: Health institutions display page

The above figure show the form that allow the user to register new medical equipment that will be used to monitor the medical equipment with the following form fields (institution id, serial number, equipment name, the manufacturer,model of medical equipment and other related information).

Afer receiving the equipment from the supplier, the equipment will be registered for store with its full information according to the manufacturer nameplate and the allowed nomnencature.

When the medical equipment enters in service, developed device will be attached on it and this device will have the device ID which will be authomatically assigned to the equipment replacing the current institution codification. This will help to identity the equipment from others through the systematic inventory system.

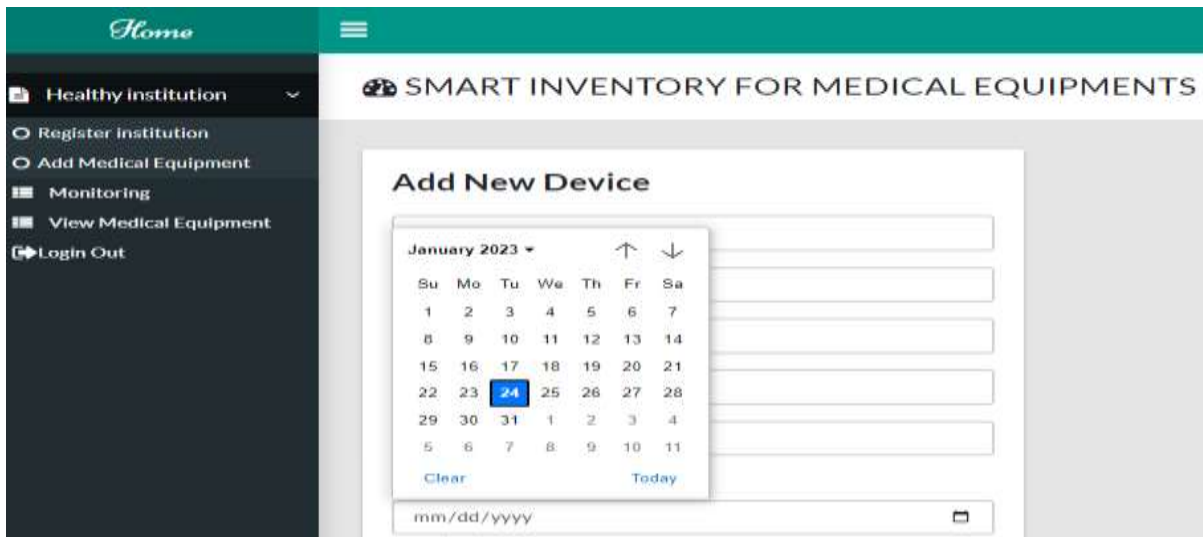


Figure 4.10: Equipment registration page with date insertion

While registration the manufacturing date, the maintenance schedule dates is registered also.

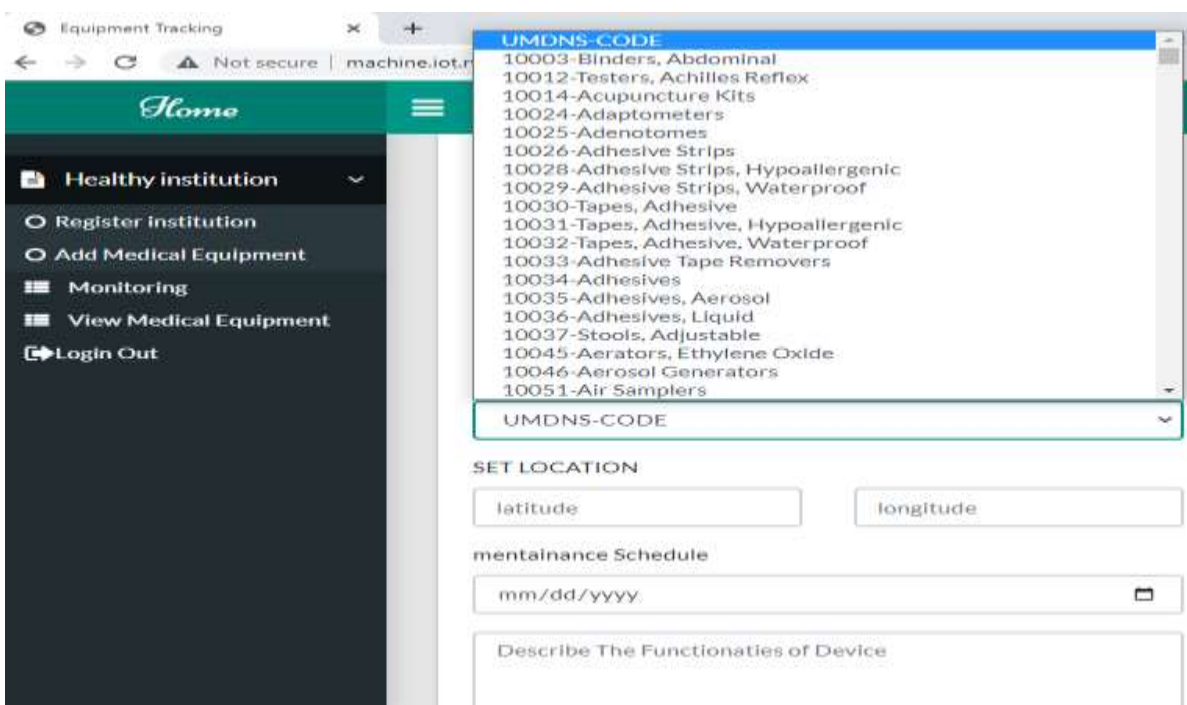


Figure 4.11: Equipment registration page with drop UMDNS Code

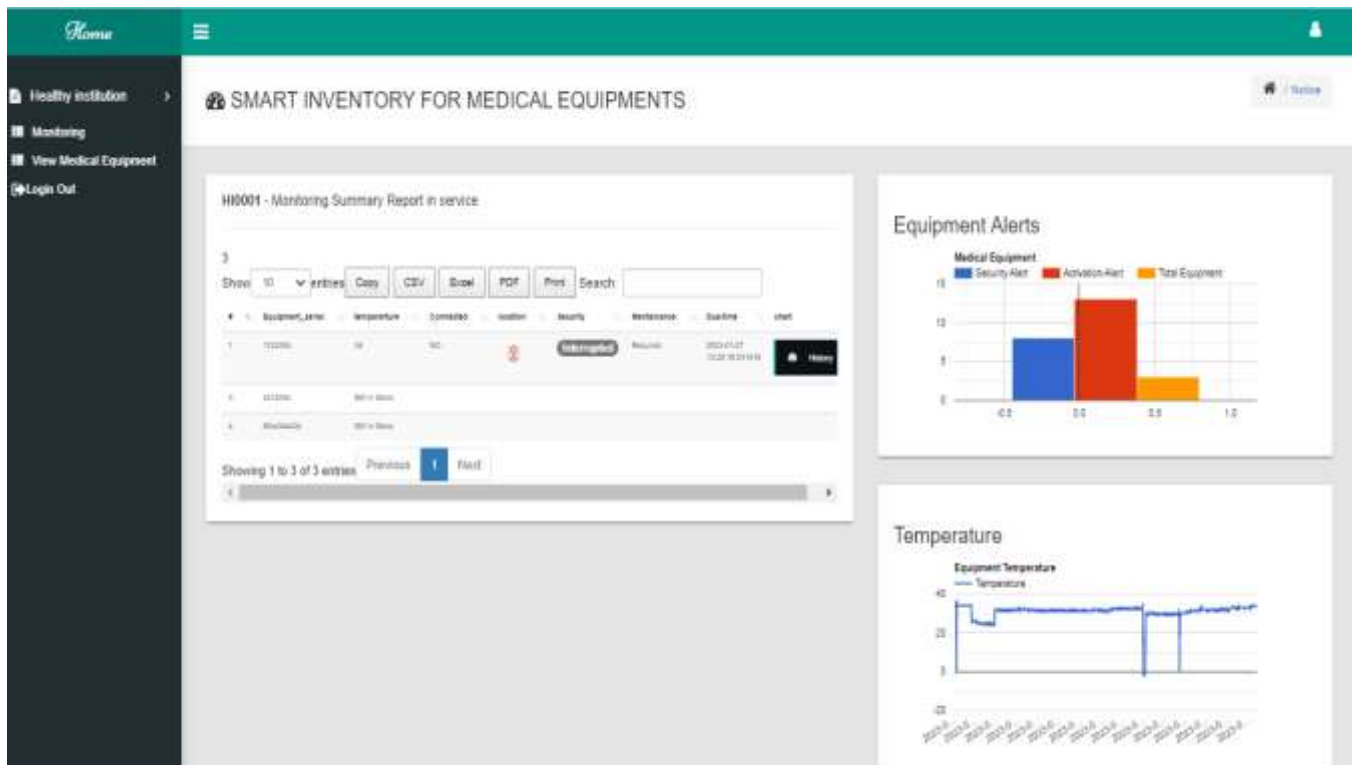


Figure 4.12: Medical equipment records page

The above figure shows the real time information of each medical equipment in a specific healthy institution where current functional status of equipment is showed in easier way and emergency notifications are given in a friendly way. The security alerts notification will be sent based on location change or on removal of the attached device from the equipment. It display temperature and the maintenance status. The figure shows also If the equipment is working/active (powered) or not.

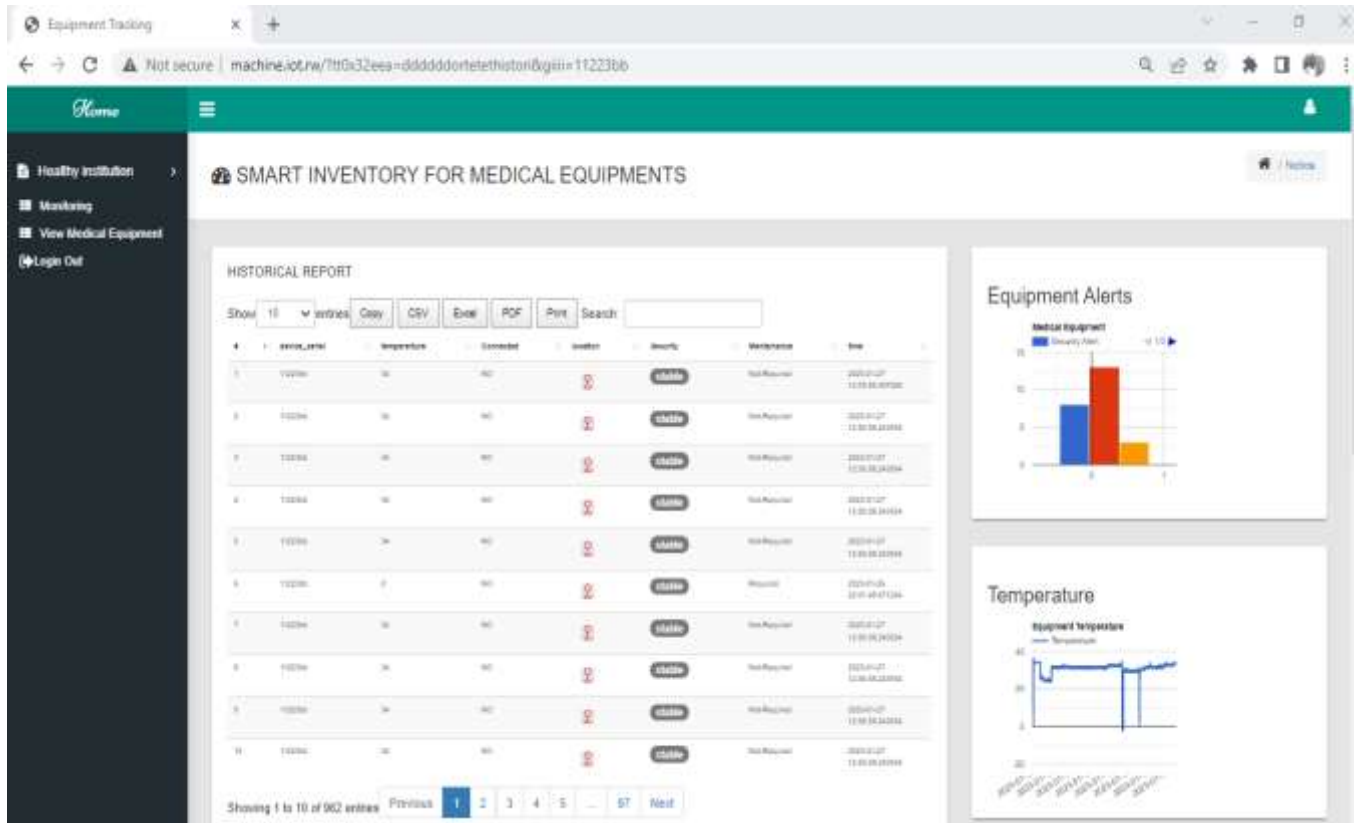


Figure 4.13: Equipment history records page

ALL DATA



Figure 4.14: Graphical displays for monitored data

This above figure represents data in graphical format where all are combined together with the purpose of interpretation in real time monitoring of temperature, security, status (Active) and maintenance alerts of medical equipment at given healthy institution.

Temperature

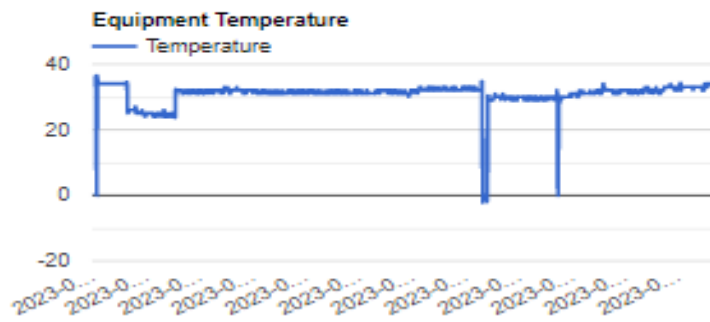


Figure 4.15: Graphical display for temperature

The best way to see changes is monitoring of temperature can be seen by on the above figure temperature changes are according to time data was taken.



Figure 4.16: Equipment google map location

The figure above shows us how to find the exact location of our medical us GPS service on google map.

5. SUMMARY

Hardware and software simulation were performed. From various components, the device was designed and simulated using Proteus and Arduino. The web login dashboard was designed, various datasheets created from CSS. By PHP and MySQL languages, programming was applied for viewing the data loaded from the designed device. Streamed data can be viewed, plotted and even downloaded.

CHAPTER V. RESULTS ANALYSIS AND DISCUSSION

1. EXISTING SYSTEM

Currently the inventory management of medical equipment is not full digitalized [43]. This has a bad impact to health care services and on the cost of inventories because they are done without using high technology and this leads to improper inventory of equipment. A lot of methods are used for inventory like paper based, computer based and barcode technology[3][44]. There is a large number of hospitals in Rwanda and those healthy institutions are storing data using bio-medical equipment on a large scale and the inventory practice is through MEMMS. [1]



Figure 5.1: MEMMS functionality

The above figure shows the existing system where medical equipment are registered by the user and regular updated data are entered manually through the computer in the available system inventory. The user can view all registered equipment and report instance manually because as highlighted, there is no monitoring device to deliver updated from any medical equipment[9].

Generally, the gap is the missing of real time functional data and the ease access of recorded data that results in equipment maintenance mismanagement, hence the loss of services effectiveness, loss of resource and patient's life.

2. DEVELOPED SYSTEM

With the attached device on medical equipment, the system automatically detects the abnormality/fluctuations of technical parameters of medical Equipment (geo-location address, current, security, temperature, time of use and alerts) and stream them to i-cloud. The device must be connected at the equipment powering outlet. Once one or all of those technical parameters are becoming abnormal, and go beyond the accepted limits during 5 seconds, then the system sends the corresponding short message service (SMS) to the authorized persons.

Security push button when there is vandalism of medical Equipment Buzzer gives an alert warning on the site as well. With developed system, the user at the installed equipment location; can make a technical assistance request from technical team about the hazard fault on medical equipment. By navigating the cloud dashboard, the system gives a clear identification of a health institution concerned and medical equipment inventory statistics with a live monitoring report which describes the number of active medical equipment, interrupted, inactive and disposed medical equipment.

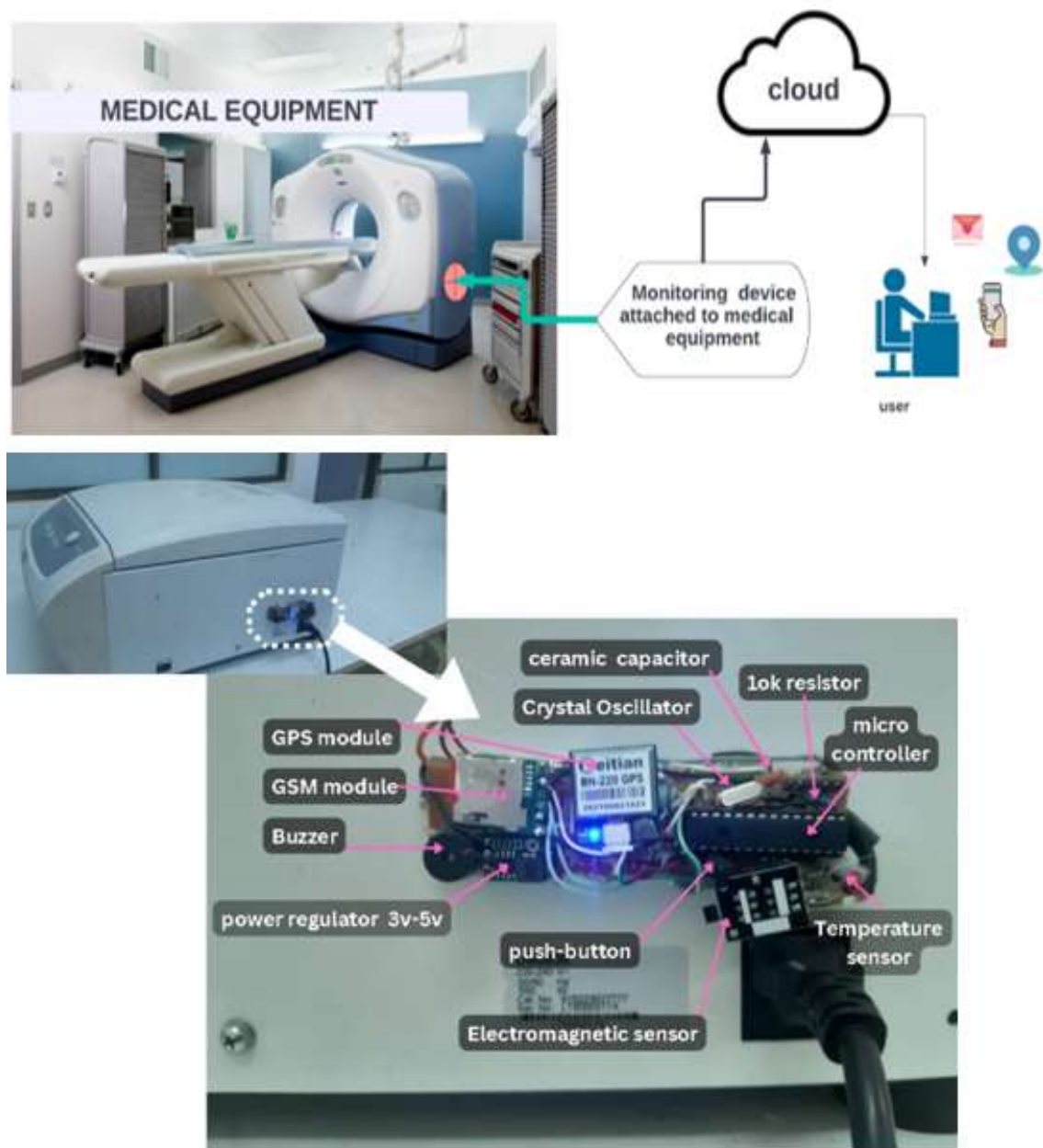


Figure 5.2: Medical equipment with a prototype connected (MRI)

The above figure gives the short description of how the monitoring device should be attached to medical equipment allowing remote monitoring and management of medical resources from taken information. The developed device is attached near the equipment power outlet.

3. COMPARISON ON EXISTING WITH THE DEVELOPED INVENTORY

Table 5.1: Analysis of existing and new inventories

Existing inventory system		The developed system	
Type	Associated problem	Type	Associated solution
<ul style="list-style-type: none"> File based Offline Computer based (Barcode or data entry) Cloud based (Periodical updates) 	Delay in dispatched data and require manual monitoring	<ul style="list-style-type: none"> IOT based (Monitoring device + cloud database)	Easy control (In services, Disposed and expiry updates)
	Complex clinical workflows and high cost		End to end workflow management
	Prone to human errors within existing system		Lower risk errors due to used friendly system
	Periodic reporting		Real time data and reporting
	Sophisticated system (where software are used); training required		Easy access (online, application) and multiple access at once.
	Duplication of data and high cost associated to inventory practice		Low cost and reliable inventory system
	Complex regular maintenance planning and Regular checking for better functionality		Real time alerts for equipment use optimization

4. RESEARCH OUTPUTS

This developed inventory system improves reliability and efficiency of medical equipment in health institutions through security alerts, management of clinical workflows, and a proper maintenance due to availability of equipment history of use.

- Due to real time data from the prototyped device, functionality status of medical equipment maybe viewed as needed. This will help medical diagnostic treatment because when a Medical Doctor needs to transfer a patient for further treatment to any other hospital, he/she will need first to check if the service is available from that institution through the web dashboard.
- With the push buttons, upon device failure any equipment user can press on the device, immediately the alert/alarm is sent to the competent person. The device also reminds regular maintenance at the time set. This serves to have a clear maintenance management for all equipment from the institution because of the instant availability of history of use for any equipment
- By regular delivery of equipment functional status, an inventory database records (history reports available) is available anytime, resulting in a proper management of medical equipment while obtaining effective healthcare services delivery and expenditure regularization on inventories investment (cost reduction).

- Monitoring alerts (preventive & breakdown maintenance, incidents) from equipment while comparing them with number of institution's equipment is the quality indicator of performance evaluation.
- Reporting hazard notices and recalls (manufacturer suggested schedules maintenance) and updated information for equipment reduce the risks associated with equipment failures; and ensure the function and reliability of medical equipment.

5. SUMMARY

The designed inventory system shows that data are streamed immediately from the attached device and would be viewed immediately. From prescriptive and descriptive analysis, the web accessible files (records and history of use) are effective and can be downloaded in various forms. The system confirms the innovation (digitization and automation) of medical equipment inventory, allowing a better decision-making for equipment management workflows.

CHAPTER VI. CONCLUSION AND RECOMMENDATION

1. CONCLUSION

This research sightsees the use of the Internet of things for medical equipment inventory. The manual and computer-based inventory system are used in Rwanda's healthcare institutions. So, Healthcare Technology Management (HTM) still need to be improved.

A monitoring device build by sensors and electronics components together with a Microcontroller was designed to detect and process functional data from medical Equipment. GSM/GPRS module uploads all the data processed from the device to cloud storage which displays them through a developed web application and also sends SMS for alerts to authorized persons. The database for storing sensed data was developed using MySQL and this application was hosted to the designed dashboard (www.machine.iot.rw).

With IOTs, challenges encountered in inventory to match database records and maintenance alerts are minimized /or eliminated. Real time alerts record from the designed system help in expanding monitoring, timeliness, and assistance within the healthcare institution. The designed smart inventory would assist healthcare systems management while improving the quality of clinical workflow services and maintenance activities. This system can replace MEMMS by adding the modules of spare parts and the module of medical devices which don't require maintenance in the developed dashboard. It can also be added in MEMMS and accessed through a link

2. RECOMMENDATION

This project was conducted while using a single developed device. The prototype gave accurate results but it is necessary to use many devices from different health institutions for a better performance analysis.

In this research, it is difficult to find a cell battery power the prototype permanently, a charging system is needed for availing permanently full independent device. The real time updates from GPS makes the system consumes more power and a bit expensive; so further research needs to be addressed to get a self-powered and affordable device.

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APPENDICES

1. DATA COLLECTION ACCEPTANCE LETTER

REPUBLIC OF RWANDA

Kibagabaga 19 /10/2022

No. ~~ACS~~ HOP. KIBAG/2022



MINISTRY OF HEALTH

KIBAGABAGA LEVEL2 TEACHING HOSPITAL

Po. Box: 6062, KIGALI

Email: kibagabaga.hospital@moh.gov.rw

To: Uwimana Maurice

University of Rwanda

Dear applicant,

RE: Your request for data collection

Reference made to your letter requesting for permission to collect the data within Kibagabaga District Hospital for your Research Proposal entitled *“Design of a Web-based Smart Inventory System for Medical Equipment in Rwanda”* Based on the approval No: /KBGH_EC/2022 from research Ethic committee, we are pleased to inform you that you are accepted to collect data within Kibagabaga Level2 Teaching Hospital. Please note that your study findings must be shared/presented to research committee of the hospital before its dissemination.

Sincerely,

Dr Ernest MUNYEMANA

Lt. Col

Director General of Kibagabaga Level2 Teaching Hospital



REPUBLIC OF RWANDA



MINISTRY OF HEALTH
THE CITY OF KIGALI
GASABO DISTRICT
KIBAGABAGA LEVEL2 TEACHING HOSPITAL
P.O Box 6260 KIGALI
Kibagabaga.hospital@moh.gov.rw

KIBAGABAGA LEVEL2 TEACHING HOSPITAL ETHICS COMMITTEE (KBGH_EC)

Date: 19/10/2022

Name of the applicant:

Uwimana Maurice

University of Rwanda

Approval Notice: No/Kibagabaga Hospital Ethics Committee/ 2022

Your project entitled "*Design of a Web-based Smart Inventory System for Medical Equipment in Rwanda*" has been evaluated by Kibagabaga Level2 Teaching Hospital Ethics committee members



2. QUESTIONNAIRE

Hospital Name: Date of Visit:

.....

Medical Equipment Inventory management questionnaire

1. Who is responsible for inventory for medical Equipment?

Clinical Officer 1	Biomedical Engineer 2	Biomedical technician 3	Medical assistant 4	Nurse 5	Other; specify:
--------------------	-----------------------	-------------------------	---------------------	---------	--

2. How often is a physical inventory carried out?

Once a week Yes..... No.....	Once in a month? Yes..... No.....	Once in 3 months Yes..... No.....	Once in 6 months? Yes..... No.....	Once a year? Yes..... No.....	Other; specify:
------------------------------------	---	---	--	-------------------------------------	--

3. Is there any cost associated with the inventory carried out?

Yes..... No.....	Specify:
---------------------	----------------------------------

4. How the stock data information is gotten?

Manual Filing records Yes..... No.....	Manual data entry in computer records Yes..... No.....	IOTs real time data records
--	--	---

5. Do you fill out the following logistics tools for inventory practice?

Stock cards Yes..... No.....	Daily register Yes..... No.....	Computer based records Yes..... No.....	Real time records Yes..... No.....	Other; specify:
------------------------------------	---------------------------------------	---	--	--

6. How do you determine/access the data from inventory?

Stock Filing	Computer database	Online database	Online Real time database	Other; specify:
Yes.....	Yes.....	Yes.....	Yes.....	.....
No.....	No.....	No.....	No.....	.....

7. On average, how long it takes to access the recorded data?

In seconds Specify .....seconds	In minutes Specify .....seconds	Other; specify:
------------------------------------	------------------------------------	-----------------------------------

8. How is effective to access the inventory database by the any user?

Stock cards	Daily register	Computer based records	Real time records	Other; specify:
Yes.....	Yes.....	Yes.....	Yes.....	.....
No.....	No.....	No.....	No.....	.....

9. How is effective to access the medical equipment location by the user?

Physical check up	GPS location (Lagging time)	Real time GPS location	Fixed coordinates records associated to IOTs	Other; specify:
Yes.....	Yes.....	Yes.....	Yes.....	.....
No.....	No.....	No.....	No.....	.....

10. How do you determine temperature conditions from medical equipment?

Site measurement Yes.....How..... No.....	Sensing methods Yes.....How..... No.....	Other; specify:
---	--	-----------------------------------

11. Is or can be the storage database secured?

Stock Filing	Computer database	Online database	Online Real time database	Other; specify:
Yes.....	Yes.....	Yes.....	Yes.....	.....
No.....	No.....	No.....	No.....	.....

12. Inventory is appropriately labelled.				
By generic name	Stored under correct label station	Well labeled in database?	Other; specify:	
Yes.....	Yes.....	Yes.....	.....
No.....	No.....	No.....	.....
13. Is there any way to get inventory notification for expiry date?				
Manual check up	Email notification	Alarm notification	Message notifications	Other; specify:
Yes.....	Yes.....	Yes.....	Yes.....	.....
No.....	No.....	No.....	No.....	.....
14. How the inventory practice is linked to medical equipment preventive/and scheduled maintenance?				
By manual check up	By Email notification	By Alarm notification	By Message notifications	Other; specify:
Yes.....	Yes.....	Yes.....	Yes.....	.....
No.....	No.....	No.....	No.....	.....
15. Medical equipment preventive/scheduled maintenance notification.				
Manual check up	Email notification	Alarm notification	Message notifications	Other; specify:
Yes.....	Yes.....	Yes.....	Yes.....	.....
No.....	No.....	No.....	No.....	.....
16. Medical equipment emergency maintenance notification.				
Manual check up	Email notification	Alarm notification	Message notifications	Other; specify:
Yes.....	Yes.....	Yes.....	Yes.....	.....
No.....	No.....	No.....	No.....	.....
17. What are the most frequent problems faced in medical equipment inventory?				
Please specify:				
.....				
.....				
18. What are the most frequent problems faced to access the recorded data?				
.....				
.....				

3. DEVICE SIMULATION CODES

```
#include <TinyGPS++.h>
#include <SoftwareSerial.h>
/* Create object named bt of the class SoftwareSerial */
SoftwareSerial GPS_SoftSerial(6,7);/* (tx, Rx) *//* (Rx, Tx) */
/* Create an object named gps of the class TinyGPSPlus */
TinyGPSPlus gps;
volatile float minutes, seconds;
volatile int degree, secs, mins;
SoftwareSerial GsmSerial(8,9);//(Tx,Rx)
int flag1=0;
int flag2=0;
int sensorPin1 = A1;
int sensorPin2 = A2;    // select the input pin for the potentiometer
int sensorValue1 = 0;  // variable to store the value coming from the
sensor
int sensorValue2 = 0;  // variable to store the value coming from the
sensor
    double lat_val, lng_val, alt_m_val;
    const int sensorIn1 = A5;
int mVperAmp1 = 500;
double Voltage1 = 0;
double VRMS1 = 0;
double AmpsRMS1 = 0;
String active;
int therm1Pin = A3;
int therm1 = 0;
float R1T1 = 6000;
float logR2T1, R2T1, TT1,TcT1;
float c1 = 1.009249522e-03, c2 = 2.378405444e-04, c3 = 2.019202697e-07;
void setup() {
    GsmSerial.begin(9600);
    GPS_SoftSerial.begin(9600);
    //GsmSerial.begin(9600);
    Serial.begin(9600);
}
void loop() {
    therm1 = analogRead(therm1Pin);
    R2T1 = R1T1 * (1023.0 / (float)therm1 - 1.0);
    logR2T1 = log(R2T1);
    TT1 = (1.0 / (c1 + c2*logR2T1 + c3*logR2T1*logR2T1*logR2T1));
    TT1 = TT1 - 273.15;
    TT1 = (TT1 * 9.0)/ 5.0 + 32.0;
    TcT1 = (TT1-32)*5/9;
    Serial.print("Temperature One: ");
    Serial.print(TcT1);
    Serial.println(" C");
    Voltage1 = getVPP1();
    VRMS1 = (Voltage1/2.0) *0.707;
    AmpsRMS1 = ((VRMS1 * 1000)/mVperAmp1);
    Serial.print("AmpsRMS1=");
    Serial.print(AmpsRMS1);
    Serial.println(" Amps RMS");
    if(AmpsRMS1>0,05){active="YES";}
    else{active="NO";}
    smartDelay(1000); /* Generate precise delay of 1ms */
    unsigned long start;
    lat_val, lng_val, alt_m_val;
    uint8_t hr_val, min_val, sec_val;
```

```

bool loc_valid, alt_valid, time_valid;
lat_val = gps.location.lat(); /* Get latitude data */
loc_valid = gps.location.isValid(); /* Check if valid location
data is available */
lng_val = gps.location.lng(); /* Get longitude data */
alt_m_val = gps.altitude.meters(); /* Get altitude data in
meters */
alt_valid = gps.altitude.isValid(); /* Check if valid altitude
data is available */
hr_val = gps.time.hour(); /* Get hour */
min_val = gps.time.minute(); /* Get minutes */
sec_val = gps.time.second(); /* Get seconds */
time_valid = gps.time.isValid(); /* Check if valid time data
is available */
if (!loc_valid)
{
    Serial.print("Latitude : ");
    Serial.println("*****");
    Serial.print("Longitude : ");
    Serial.println("*****");
}
else
{
    DegMinSec(lat_val);
    Serial.print("Latitude in Decimal Degrees : ");
    Serial.println(lat_val, 6);
    Serial.print("Latitude in Degrees Minutes Seconds : ");
    Serial.print(degree);
    Serial.print("\t");
    Serial.print(mins);
    Serial.print("\t");
    Serial.println(secs);
    DegMinSec(lng_val); /* Convert the decimal degree value into
degrees minutes seconds form */
    Serial.print("Longitude in Decimal Degrees : ");
    Serial.println(lng_val, 6);
    Serial.print("Longitude in Degrees Minutes Seconds : ");
    Serial.print(degree);
    Serial.print("\t");
    Serial.print(mins);
    Serial.print("\t");
    Serial.println(secs);
}
if (!alt_valid)
{
    Serial.print("Altitude : ");
    Serial.println("*****");
}
else
{
    Serial.print("Altitude : ");
    Serial.println(alt_m_val, 6);
}
if (!time_valid)
{
    Serial.print("Time : ");
    Serial.println("*****");
}
else
{

```

```

        char time_string[32];
        sprintf(time_string, "Time : %02d/%02d/%02d \n", hr_val,
min_val, sec_val);
        Serial.print(time_string);
    }
    sensorValue1 = analogRead(sensorPin1);
    sensorValue2 = analogRead(sensorPin2);
    Serial.println(sensorValue1);
    Serial.println(sensorValue2);
    delay(100);
    if(sensorValue1<60){
        flag1=1;
        Serial.println("ok11");
    }

    else{Serial.println("no11");
    flag1=0;}
    if(sensorValue2<60){
        flag2=1;
        Serial.println("ok22");}

    else{Serial.println("no22");
        flag2=0;}
    gprscodel();
}

void gprscodel()
{
    GsmSerial.println("AT+CREG?");
    delay(100);
    GsmSerial.println("AT+SAPBR=3,1,\"CONTYPE\", \"GPRS\"");
    delay(1000);//2000
    GsmSerial.println("AT+SAPBR=3,1,\"APN\", \"internet.tigo\"");
    delay(1000);//2000
    GsmSerial.println("AT+SAPBR=1,1");
    delay(1000);//2000
    GsmSerial.println("AT+HTTPIPINIT");
    delay(1000);//2000//device_serial`, `temperarture`, `vibration`,
`active`, `location`, `stable`

GsmSerial.print("AT+HTTTPARA=\"URL\", \"machine.iot.rw/indata.php?");

Serial.print("AT+HTTTPARA=\"URL\", \"machine.iot.rw/indata.php?");
    GsmSerial.print("device_serial=");
    Serial.print("device_serial=");
    GsmSerial.print("NOS23HJ");
    Serial.print("8999");
    GsmSerial.print("&");
    Serial.print("&");
    GsmSerial.print("temperarture=");
    Serial.print(TcT1);
    GsmSerial.print(TcT1);
    Serial.print("99");
    GsmSerial.print("&");
    Serial.print("&");
    GsmSerial.print("vibration=");
    Serial.print("vibration=");
    GsmSerial.print("OK");
    Serial.print("340");
    GsmSerial.print("&");

```

```

Serial.print("&");
  GsmSerial.print("active=");
  Serial.print("active=");
  GsmSerial.print(active);
  Serial.print("100");
    GsmSerial.print("&");
    Serial.print("&");
  GsmSerial.print("location=");
  Serial.print(lat_val, lng_val);
  GsmSerial.print("100");
  Serial.print("100");
    GsmSerial.print("&");
    Serial.print("&");
  GsmSerial.print("stable=");
  Serial.print("stable=");
  GsmSerial.print("100");
  Serial.print("100");
  GsmSerial.println("\");
  Serial.println("\");
delay(1000); //2000
// set http action type 0 = GET, 1 = POST, 2 = HEAD
  GsmSerial.println("AT+HTTPACTION=0");
delay(1000); //5000
// toSerial();
// read server response
  GsmSerial.println("AT+HTTPREAD");
delay(500); //
// toSerial()
  GsmSerial.println("");
  GsmSerial.println("AT+HTTPTERM");
// toSerial();
// delay(300);
  GsmSerial.println("");
delay(1000); //10000
  GsmSerial.println("AT+CIPSHUT");

}
void gprscode()
{
GsmSerial.println("AT+CREG?");
delay(100);
GsmSerial.println("AT+SAPBR=3,1,\"CONTYPE\", \"GPRS\");
delay(1000); //2000
GsmSerial.println("AT+SAPBR=3,1,\"APN\", \"internet.tigo\");
delay(1000); //2000
GsmSerial.println("AT+SAPBR=1,1");
delay(1000); //2000
GsmSerial.println("AT+HTTPINIT");
delay(1000); //2000
GsmSerial.print("AT+HTTTPARA=\"URL\", \"solar.iot.rw/in.php?");
Serial.print("AT+HTTTPARA=\"URL\", \"solar.iot.rw/in.php?");
//https://solar.iot.rw/in.php?sn=hfd4554&v=11&c=200&l=34&t=34
GsmSerial.print("sn=");
Serial.print("sn=");
GsmSerial.print("7NA900");
Serial.print("7NA900");
GsmSerial.print("&");
Serial.print("&");
GsmSerial.print("v=");
Serial.print("v=");

```

```

GsmSerial.print("12");
//Serial.print(vIN);
//mySerial.print("9");
GsmSerial.print("&");
Serial.print("&");
GsmSerial.print("c=");
Serial.print("c=");
GsmSerial.print("12");
//Serial.print(AmpsRMS1);
//mySerial.print("2");
GsmSerial.print("&");
Serial.print("&");
GsmSerial.print("l=");
Serial.print("l=");
GsmSerial.print("12");
//Serial.print(l1);
GsmSerial.print("&");
Serial.print("&");
GsmSerial.print("t=");
Serial.print("t=");
GsmSerial.print("6");
//Serial.print(t);
GsmSerial.println("\n");
Serial.println("\n");
// Voltage: 199.90V
//Current: 0.14A
//Power: 28.10W
//Energy: 0.020kWh
//Frequency: 49.6Hz
//PF: 1.00
//`sn`, `v`, `c`, `l`, `t`
  delay(1000);//2000
  // set http action type 0 = GET, 1 = POST, 2 = HEAD
  GsmSerial.println("AT+HTTPACTION=0");
  delay(1000);//5000
  // toSerial();
  // read server response
  GsmSerial.println("AT+HTTPREAD");
  delay(500);//
  // toSerial()
  GsmSerial.println("");
  GsmSerial.println("AT+HTTPTERM");
  // toSerial();
  // delay(300);
  GsmSerial.println("");
  delay(1000);//10000
  GsmSerial.println("AT+CIPSHUT"); }
static void smartDelay(unsigned long ms)
{
  unsigned long start = millis();
  do
  {
    while (GPS_SoftSerial.available()) /* Encode data read from GPS
while data is available on serial port */
      gps.encode(GPS_SoftSerial.read());
    /* Encode basically is used to parse the string received by the GPS
and to store it in a buffer so that information can be extracted from
it */
  } while (millis() - start < ms);
}

```

```

void DegMinSec( double tot_val)    /* Convert data in decimal degrees
into degrees minutes seconds form */
{
    degree = (int)tot_val;
    minutes = tot_val - degree;
    seconds = 60 * minutes;
    minutes = (int)seconds;
    mins = (int)minutes;
    seconds = seconds - minutes;
    seconds = 60 * seconds;
    secs = (int)seconds;
}
float getVPP1(){//this will caculate the peak to peak of sensor1
float result1;
int readValue1;           //value read from the sensor1
int maxValue1 = 0;        // store max value here
int minValue1 = 1024;     // store min value here
uint32_t start_time = millis();
while((millis()-start_time) < 1000) //sample for 1 Sec
{ readValue1 = analogRead(sensorIn1);
  // see if you have a new maxValue
  if (readValue1 > maxValue1) {
    /*record the maximum s ensor value*/
    maxValue1 = readValue1; }
  if (readValue1 < minValue1) {
    /*record the maximum sensor value*/
    minValue1 = readValue1;} }
// Subtract min from max
result1 = ((maxValue1 - minValue1) * 5.0)/1024.0;
return result1;}

```