UNIVERSITY of RWANDA

COLLEGE OF SCIENCE AND TECHNOLOGY

ACEIoT

Website: www.aceiot.ur.ac.rw
Mail: aceiot@ur.ac.rw

AFRICA CENTER OF EXCELLENCE IN INTERNET OF THINGS (ACE-IoT)

Research Thesis Title:

DEVELOPMENT OF OPTIMIZED PAYMENT SYSTEM FOR MEDICAL SERVICES USING RFID TECHNOLOGY.

A dissertation Submitted in Partial Fulfilment of the Requirements for The Award of Master's Degree in Internet of Things: Wireless Sensor Intelligent Network

Submitted by:

MUKANEZA Angelique REF.NO: 222018855

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STUDENT DECLARATION

I declare that this Dissertation contains my work except where specifically acknowledged.

MUKANEZA Angelique

222018855

Signature: ....

Date: ……………………..........................

BONAFIDE CERTIFICATE

This is to certify that the project entitled "Development of optimized payment system for medical services using RFID technology" is a record of original work done by MUKANEZA Angelique with registration number 222018855 in partial fulfilment of the requirement for the award of master of sciences in Internet of Things in College of Science and Technology, University of Rwanda, Academic year 2024/2025

This work has been submitted under the guidance of Dr. Thenmozhi M. and Dr. Omar GATERA

Main Supervisor: Dr. Thenmozhi M

Signature: …………………………

Date: ………………………………

Co-Supervisor: Dr. Omar GATERA

Signature: ……………………………

Date: ………………………………….

The Head of Masters and Trainings

Dr. ………..

Signature: ………………………………

Date: ……………………………………

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ABSTRACT

The Internet of Things (IoT) is transforming healthcare by enabling real-time data exchange and automation, but many Rwandan hospitals have continued to rely on slow, error-prone payment procedures that frustrate patients and staff. To overcome these challenges long queues, billing mistakes, and opaque processes this study deployed and tested a Smart Medical Payment System, an IoT-enabled solution now operating in a pilot Rwandan clinic. The system uses RFID cards for patient identification and NodeMCU microcontrollers to transmit data to a centralized database and administrative dashboard in real time. Patients tap their RFID cards at outpatient, pharmacy, or diagnostic Systems to authenticate and settle bills in under five seconds; staff monitor transactions live, generate reports, and manage exceptions remotely. Field trials demonstrated a 90 % reduction in average wait time, near-elimination of billing errors, and strong patient satisfaction. Secure, automated payments and instant on-screen and SMS confirmations have streamlined operations and boosted transparency. This tested, scalable solution establishes a new standard for healthcare payment management in resource-constrained settings and can be extended to other hospitals across Rwanda and similar contexts.

Keywords: IoT, RFID Card, Real-Time Data Communication, Healthcare Payment Systems.

LIST OF ACRONYMS

2FA	: Two-Factor Authentication
5G	: Fifth Generation (Cellular Network)
ACE-IOT	: African Center Of Excellence In Internet Of Things
AES	: Advanced Encryption Standard
AI	: Artificial Intelligence
API	: Application Programming Interface
BAP	: Battery-Assisted Passive
DSRM	: Design Science Research Methodology
EHRS	: Electronic Health Records
E-PAYMENT	: Electronic Payments
GDPR	: General Data Protection Regulation
HF	: High-Frequency
HIPAA	: Health Insurance Portability And Accountability Act
HMS	: Hospital Management Systems
ID	: Identification
IDE	: Integrated Development Environment
IOT	: Internet Of Things
LBS	: Location-Based Service
LCD	: Liquid Crystal Display
LDRS	: Light Dependent Resistors
LF	: Low-Frequency
LORAWAN	: Long Range Wide Area Network
ML	: Machine Learning
NFC	: Near Field Communication
NGOs	: Non-Governmental Organizations
RAD	: Rapid Application Development
RBAC	: Role-Based Access Control
RC522	: RFID Reader Module
REST API	: Representational State Transfer Api

RFID	: Radio-Frequency Identification
RPM	: Remote Patient Monitoring
SMS	: Short Message Service
UHF	: Ultra-High-Frequency
WI-FI	: Wireless Fidelity

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CHAPTER 1: INTRODUCTION

1.1 Introduction

The Internet of Things (IoT) has ushered in a new era of connectivity and data-driven innovation, transforming industries worldwide. In healthcare, IoT technology is revolutionizing how patient data is managed, medical services are delivered, and operational efficiency is achieved. By enabling real-time data exchange and automation, IoT has the potential to address longstanding challenges in healthcare systems, particularly in resource-constrained settings like Rwanda[1].

In Rwanda, patients often face significant difficulties when paying for medical services. Long wait times, billing errors, and a lack of transparency in payment processes are common issues, leading to patient dissatisfaction and operational inefficiencies. These challenges are exacerbated by the reliance on manual payment systems that are not integrated with medical records or billing systems. As a result, healthcare providers struggle to meet the growing demand for services, while patients endure frustrating experiences during payment processes[2].

The COVID-19 pandemic has further highlighted the need for digital transformation in healthcare payment systems. The increased adoption of electronic payments during the pandemic demonstrated the potential of technology to streamline transactions and improve user experiences. However, many healthcare facilities in Rwanda still rely on outdated payment methods, creating a pressing need for innovative solutions. To address these challenges, this research proposes the development of a Smart Medical Payment System, an IoT-based system designed to reduce reliance on paper-based workflows and enhance healthcare payment processes. By integrating RFID technology with NodeMCU microcontrollers, the system provides secure, automated, and transparent transactions. Patients will use RFID cards linked to their medical and financial records to make quick and accurate payments across hospital departments, including outpatient clinics, pharmacies, and diagnostic centers[3]. The system integrates RFID technology, and NodeMCU microcontrollers to create a secure, efficient, and transparent payment solution. Patients will use RFID cards linked to their medical and financial records, enabling quick and accurate payment processing at various hospital Systems, such as outpatient services, pharmacies, and diagnostics.

A centralized database and administrative dashboard will facilitate real-time monitoring, reporting, and record-keeping eliminating the need for physical documentation and manual entry[4].

By automating payment processes and integrating them with patient records, the proposed system aims to reduce wait times, minimize errors, and increase transparency. It also ensures regulatory compliance and data security through encrypted transactions and remote management capabilities. The following sections of this dissertation explore the technical foundations of the proposed system, review related work in IoT and healthcare payment systems, and present the methodology for system design, implementation, and evaluation. The ultimate goal is to set a new standard for healthcare payment management, improving both patient satisfaction and operational efficiency in Rwanda and beyond.

1.2 Problem statement

The rapid evolution of technology has driven digital transformation across various sectors, including healthcare. However, traditional payment systems in healthcare remain largely manual, inefficient, and prone to errors. These systems often rely on physical infrastructure and disjointed processes, leading to long wait times, billing inaccuracies, and a lack of transparency. In resource-constrained settings like Rwanda, these challenges are particularly pronounced, negatively impacting both patient satisfaction and operational efficiency[5].

In Rwandan healthcare facilities, patients frequently endure long wait times during peak hours due to manual payment processes and the lack of integration between medical records and billing systems. This disconnect results in billing errors, delayed services, and frustration among patients. For example, patients often receive unclear or inaccurate billing statements, leading to disputes and further delays. These inefficiencies not only hinder the patient experience but also strain healthcare providers, who struggle to manage high patient volumes with limited resources[6].

While electronic payment systems have gained traction in other sectors, their adoption in healthcare remains limited, particularly in developing countries like Rwanda[7]. This gap underscores the urgent need for innovative solutions that leverage modern technologies to streamline payment processes and improve the overall healthcare experience. All these gaps such as reliance on paper-based transactions, lack of integration between systems, inefficient manual processes, and limited adoption of digital technologies highlight the urgent need for a comprehensive, automated, and scalable solution.

1.3 Relational of the Study

The healthcare sector is undergoing a significant transformation driven by advancements in technology, particularly the Internet of Things (IoT). IoT has demonstrated immense potential in improving patient care, operational efficiency, and data management in healthcare systems worldwide[8]. However, in many developing countries, including Rwanda, healthcare payment systems remain outdated, inefficient, and disconnected from modern technological advancements. This disconnect creates numerous challenges, such as long patient wait times, billing errors, and a lack of transparency, ultimately leading to patient dissatisfaction and operational inefficiencies[9].

In Rwanda, the reliance on manual payment processes exacerbates these challenges. Patients often endure long queues during peak hours, while healthcare providers struggle to manage high patient volumes with limited resources. The lack of integration between medical records and billing systems further complicates the payment process, resulting in errors, delays, and disputes. These inefficiencies not only hinder the patient experience but also strain healthcare facilities, limiting their ability to deliver timely and effective care.

The significance of this study lies in its potential to transform healthcare payment systems in Rwanda and similar settings. By addressing critical gaps in existing systems, the proposed solution offers a scalable, secure, and efficient alternative to traditional payment methods. It not only improves the patient experience but also enhances operational efficiency, enabling healthcare providers to focus on delivering quality care. This research is particularly timely and relevant, as it aligns with global trends toward digital transformation in healthcare and addresses the unique challenges faced by developing countries.

By demonstrating the feasibility and benefits of IoT-based payment systems, this study contributes to the growing body of knowledge on healthcare innovation and provides a practical framework for implementation in similar contexts. Ultimately, this system lays the groundwork for a paperless, efficient, and patient-centered approach to healthcare payment in Rwanda and similar contexts.

1.4 Aims and objectives of the study

1.4.1 Main objective

The general objective of this research is to design and implement a Smart Medical Payment System using IoT and RFID technology to streamline and secure healthcare payment processes in Rwanda.

1.4.2 Specific objectives

To achieve the general objective, the study will focus on the following specific objectives:

1. To identify the requirements for developing an optimized payment system for medical services using RFID technology.
2. To develop and implement an optimized payment system for medical services using RFID technology.
3. To evaluate the performance and effectiveness of the developed payment system for medical services using RFID technology.

1.5 Research Hypothesis

The implementation of an RFID-based Smart Medical Payment System will significantly improve payment efficiency, accuracy, and transparency compared to the existing manual hospital payment processes.

1.6 Study Scope

This research focuses on the design, implementation, and evaluation of an RFID-based Smart Medical Payment System within the context of Rwandan healthcare facilities. Geographically, the pilot deployment and testing occurred at a district hospital serving both urban and rural populations, but the solution is intended for broader adoption across similar resource-constrained settings. Functionally, the study addresses the end-to-end payment workflow patient authentication, real-time billing, transaction recording, and notification, while ensuring data security and regulatory compliance. Temporally, the system was developed and evaluated over five months, from initial requirements gathering through to pilot trials and user feedback. Its modular architecture allows future extensions into these areas. By concentrating on the payment process, this study delivers a targeted, scalable solution that can be readily adopted and later expanded to encompass wider hospital financial and administrative functions.

1.7 Significance of the study

The development of a Smart Medical Payment System using IoT and RFID technology holds significant importance for healthcare systems, particularly in resource-constrained settings like Rwanda. This study addresses critical challenges in healthcare payment processes, such as long wait times, billing errors, and lack of transparency, which have long hindered the efficiency and effectiveness of healthcare delivery. By automating payment processes and integrating them with medical records and billing systems, this research offers a transformative solution that enhances both patient satisfaction and operational efficiency.

For patients, the proposed system provides a seamless and secure payment experience. By reducing waiting times and eliminating billing errors, the system ensures that patients can focus on receiving timely medical care rather than navigating cumbersome payment processes. The use of RFID cards linked to medical and financial records further enhances convenience and transparency, fostering trust and satisfaction among patients.

For healthcare providers, the system streamlines administrative workflows, allowing staff to allocate more time and resources to patient care rather than manual payment processing. The integration of a centralized database and admin dashboard enables real-time monitoring and management of transactions, reducing operational inefficiencies and financial losses. Additionally, the system's compliance with regulatory standards ensures the security and confidentiality of patient data, addressing a critical concern in healthcare operations.

For policymakers and healthcare administrators, this study provides a scalable and adaptable framework for modernizing healthcare payment systems. The findings and implementation strategies can serve as a blueprint for adopting IoT-based solutions in other healthcare facilities, particularly in developing countries facing similar challenges. By demonstrating the feasibility and benefits of this system, the research encourages investment in digital transformation initiatives that align with global trends in healthcare innovation.

From an academic and technological perspective, this study contributes to the growing body of knowledge on IoT applications in healthcare. While existing research has primarily focused on patient monitoring, medication distribution, and equipment tracking, this study addresses a critical gap by exploring the potential of IoT in payment automation.

Ultimately, this research has the potential to set a new standard for healthcare payment management, not only in Rwanda but also in other resource-constrained settings. By improving service delivery, reducing financial losses, and enhancing patient satisfaction, the proposed system paves the way for a more efficient, transparent, and patient-centric healthcare system. This study underscores the transformative potential of IoT and RFID technologies in addressing real-world challenges, contributing to the broader goal of achieving equitable and accessible healthcare for all.

1.8 Organization of the Study

This study is structured into six chapters, each building logically upon the previous to guide the reader from the problem identification to the final recommendations.

Chapter One introduces the research background, motivation, objectives, scope, and significance of the study. It sets the foundation by outlining the issues addressed and the structure of the work.

Chapter Two provides a comprehensive literature review, discussing IoT applications in healthcare, the evolution of digital transactions in medical environments, security and accessibility concerns, the use of RFID technology, and existing research gaps, thereby justifying the need for the proposed system.

Chapter Three outlines the research methodology, detailing the design approach, system development methodology, requirements specification, and data collection and analysis techniques used to build and evaluate the system.

Chapter Four covers the system analysis and design, comparing the existing paper-based system with the proposed digital solution, and presenting various design models such as block diagrams, use case diagrams, data flow diagrams, and the hardware circuit design.

Chapter Five presents the results and analysis, including findings from requirement gathering, system development, testing outcomes, and evaluation of the system's functional, performance, and usability aspects, followed by a comprehensive discussion of the insights gained.

Finally, Chapter Six concludes the study by summarising key findings, validating the research hypotheses, and providing recommendations for hospitals, policymakers, and future researchers.

CHAPTER 2: LITERATURE REVIEW

A literature review is a critical component of any research, as it provides a comprehensive analysis of previous studies, theories, and technological advancements relevant to the study. This chapter aims to explore and synthesize existing research related to the integration of the Internet of Things (IoT) in healthcare, with a particular focus on its application in medical payment systems. By reviewing past literature, this chapter identifies technological gaps, highlights best practices, and provides a foundation for understanding the significance of IoT in improving healthcare payment processes. The chapter begins by discussing the fundamental aspects of IoT in healthcare, including its components, applications, and challenges. Next, it examines healthcare payment systems and the adoption of digital transactions in medical environments. A detailed discussion on RFID technology in healthcare payment processing is provided, followed by an analysis of IoT-based smart medical payment Systems. Additionally, relevant theoretical frameworks are presented to guide the study. Finally, the chapter summarizes key findings from previous studies and identifies gaps that justify the need for this research.

2.1 IoT in Healthcare: Foundations and Applications

2.1.1 Introduction to IoT in Healthcare

The Internet of Things (IoT) has revolutionized the healthcare sector by enabling seamless communication between medical devices, healthcare professionals, and patients[11]. IoT refers to a network of interconnected smart devices equipped with sensors, actuators, and communication technologies that collect, process, and transmit real-time data. In healthcare, IoT enhances patient monitoring, disease management, hospital workflow efficiency, and medical asset tracking, ultimately improving the overall quality of care[12].

2.1.2 Key Components of IoT in Healthcare

The effectiveness of the Internet of Things (IoT) in healthcare relies heavily on a range of essential components that work together to collect, transmit, analyze, and secure medical data. At the core of IoT systems are sensors and wearable devices. These are used to gather physiological parameters such as heart rate, body temperature, blood pressure, and glucose levels, allowing continuous health monitoring without the need for constant hospital visits[13]. These devices are often lightweight, non-invasive, and can be worn or implanted depending on the medical application.

To support data transfer from these sensors, wireless communication technologies play a critical role. Technologies such as Wi-Fi, Bluetooth, Zigbee, LoRaWAN, and more recently 5G, enable seamless and real-time transmission of data from the devices to healthcare providers or cloud platforms[14]. The choice of communication protocol depends on the specific requirements such as power consumption, range, and bandwidth.

Cloud and edge computing provides the infrastructure to store, manage, and process the massive volumes of data generated by IoT devices. Cloud computing enables centralized data access and long-term storage, whereas edge computing processes data locally on the device or nearby server to reduce latency and improve real-time decision-making[15]. This dual approach helps balance efficiency and responsiveness in healthcare applications.

Another indispensable component is Artificial Intelligence (AI) and Machine Learning (ML), which are employed to derive insights from the collected data. These technologies enable predictive diagnostics, anomaly detection, and clinical decision support systems, helping healthcare professionals identify potential health risks early[16].

Finally, security protocols ensure that patient information remains confidential and protected from breaches. Encryption techniques, user authentication, and access control are standard mechanisms used to comply with healthcare regulations such as HIPAA and GDPR, maintaining trust and safeguarding sensitive health data[17].

2.1.3 Applications of IoT in Healthcare

IoT has revolutionized healthcare by enabling a broad array of applications that enhance patient care, reduce operational costs, and improve service delivery. One of the most prominent applications is Remote Patient Monitoring (RPM). Through wearable devices and mobile applications, patients' health parameters can be tracked in real-time and transmitted to healthcare providers. This not only reduces the need for in-person visits but also supports better management of chronic diseases such as diabetes and hypertension[18].

Another critical area is smart drug dispensing, where IoT-based systems ensure timely medication intake and dosage accuracy. These systems help mitigate the risks of human error in medication administration, which is a significant concern in clinical environments. Hospital asset management also benefits from IoT, particularly through the use of RFID technology for tracking medical equipment. This ensures efficient resource utilization, minimizes equipment loss, and enhances operational workflows.

In addition to these, intelligent healthcare payment systems are emerging as a powerful application of IoT. By integrating RFID-enabled patient identification with automated billing systems, hospitals can streamline financial transactions, reduce billing errors, and relieve administrative burdens. These smart payment Systems also contribute to transparency and better financial record-keeping in healthcare institutions.

2.1.4 Challenges of IoT in Healthcare

Despite its many benefits, the adoption of IoT in healthcare is not without challenges. One of the foremost concerns is data security and privacy. As sensitive patient data is continuously collected and transmitted, the risk of unauthorized access or data breaches becomes a pressing issue. Ensuring compliance with privacy regulations such as GDPR in Europe and HIPAA in the United States requires robust security architectures[19]. Interoperability is another major challenge. IoT devices often come from different manufacturers and may use varied communication protocols or data formats. This lack of standardization hampers seamless integration between devices and existing healthcare information systems, limiting the scalability of IoT solutions.

Furthermore, the cost of implementation is relatively high. From purchasing devices to installing necessary network infrastructure and training staff, the financial investment required can be prohibitive, especially for healthcare institutions in low-resource settings.

Lastly, regulatory and compliance hurdles pose significant challenges. Ensuring that IoT devices meet national and international medical standards and comply with regulatory frameworks involves extensive testing and certification, which can delay deployment[20].

2.1.5 Future Trends in IoT Healthcare Applications

Looking forward, the landscape of IoT in healthcare is expected to evolve significantly, driven by emerging technologies and increased adoption. AI-driven IoT systems are set to take center stage by enabling more intelligent and automated decision-making in diagnostics and patient care. These systems can anticipate patient needs, recommend treatment adjustments, and detect anomalies that may indicate emerging health problems [21].

Blockchain technology is gaining attention as a means of enhancing data security and integrity. By creating immutable records of patient data and transactions, blockchain ensures that medical histories remain tamper-proof and accessible only to authorized parties, fostering trust and transparency in healthcare systems[22].

The deployment of 5G networks and edge computing is poised to accelerate the responsiveness and scalability of IoT healthcare applications. With ultra-low latency and high-speed data transfer, 5G allows for real-time monitoring and intervention, which is crucial in critical care and emergency services. Lastly, greater integration with digital payment systems will streamline hospital operations by automating billing and financial processes. This trend not only reduces administrative workload but also supports the move toward more patient-centric and paperless healthcare environments.

2.2 Adoption of Digital Transactions in Medical Environments

The healthcare sector has increasingly embraced digital transactions to enhance the efficiency, accuracy, and transparency of financial operations. Digital transactions refer to any monetary exchange conducted electronically, encompassing mobile payments, digital wallets, NFC-based smart cards, and RFID-enabled systems. Their integration into medical environments plays a significant role in automating billing systems, reducing administrative overhead, minimizing errors, and improving patient satisfaction.

2.3 Transformation of Healthcare Payments

Traditionally, healthcare transactions were heavily reliant on paper-based billing and manual processes, which were not only time-consuming but also prone to errors and fraud [23]. With the advent of digital transformation, healthcare providers began adopting electronic payment solutions, enabling faster and more secure processing of patient fees, insurance claims, and government subsidies.

Contactless payment systems, such as those based on Near Field Communication (NFC) or Radio-Frequency Identification (RFID), are increasingly common in hospitals and clinics. These systems allow patients to pay for consultations, laboratory services, or medications by simply tapping a smart card or mobile phone, reducing waiting times and the need for physical cash handling[24].

2.3 Integration with Health Information Systems

Digital payment systems are often integrated with Electronic Health Records (EHRs) and Hospital Management Systems (HMS), providing a seamless financial flow between medical services rendered and billing processes. Such integration ensures billing accuracy, avoids duplication, and offers real-time visibility of patient financial records [25].

Moreover, some systems link insurance claims and payment gateways, enabling automated claims submission and reimbursement processing. This interoperability reduces administrative burdens and improves compliance with healthcare finance regulations.

2.4 Enhancing Accessibility and Inclusion

In developing regions or low-resource settings, mobile money platforms such as M-Pesa in Kenya or Airtel Money in parts of Africa have been adopted to expand access to healthcare. Patients can make payments remotely or in small installments without needing a traditional bank account [26]. This has contributed to greater financial inclusion and reduced the burden of upfront medical payments.

2.5 Security and Trust Considerations

While digital transactions bring numerous benefits, they also introduce cybersecurity risks. Ensuring secure access to financial and health records is critical. Technologies such as end-to-end encryption, two-factor authentication (2FA), and blockchain are being explored to secure digital payments and prevent fraud [27]. Furthermore, maintaining user trust in digital platforms remains essential for widespread adoption, especially among older adults and less tech-savvy users.

2.6 Challenges and Barriers

Several challenges hinder the widespread adoption of digital transactions in healthcare:

- Infrastructure limitations, especially in rural or underserved areas

- Digital literacy gaps among both patients and healthcare staff
- Interoperability issues between different payment and health systems
- Privacy and data protection concerns, particularly related to GDPR and HIPAA compliance
- Nevertheless, the COVID-19 pandemic has accelerated the shift toward contactless and remote payment solutions, with many healthcare institutions now prioritizing digital financial tools in their service delivery models [3].

2.7 Radio-Frequency Identification (RFID) Technology in Healthcare

Radio-Frequency Identification (RFID) is a wireless communication technology that enables the automatic identification and tracking of objects and individuals using radio waves. It consists primarily of three components: RFID tags, readers, and a backend system for data processing and storage [28]. Tags, which can be active (battery-powered) or passive (powered by the reader's signal), contain electronically stored information that can be read remotely without line-of-sight.
In the context of healthcare, RFID has emerged as a transformative technology, significantly enhancing patient safety, operational efficiency, and resource management. Hospitals and clinics use RFID systems to track medical equipment, manage inventory, monitor patients, and streamline workflows [29].

2.8 Applications in Healthcare

One of the key uses of RFID in healthcare is in patient identification and tracking. RFID wristbands or cards assigned to patients help ensure accurate identification, reducing medical errors such as incorrect medication or treatment. These RFID identifiers can also store essential health information like allergies, diagnosis, and blood type, which can be instantly accessed by authorized healthcare personnel [28].
Another vital application is in asset tracking and inventory management. Medical equipment, such as wheelchairs, defibrillators, and infusion pumps, can be equipped with RFID tags, allowing hospitals to monitor their location and usage status in real-time. This reduces equipment loss, improves utilization, and speeds up emergency response [30].
RFID is also employed in pharmaceutical management. Tagged medication packages allow healthcare providers to verify drug authenticity, track expiry dates, and ensure compliance in drug

administration. Smart cabinets integrated with RFID can automatically update inventory, issue alerts, and prevent stockouts or overstocking.

2.9 Integration with IoT and Smart Payment Systems

In recent years, RFID has been integrated with IoT platforms, creating smart environments where devices can communicate and make decisions autonomously. RFID can facilitate cashless, automated transactions in healthcare payment systems, linking a patient's identity with billing systems. Patients can use RFID cards to authenticate their identity and make payments, minimizing administrative errors and delays. Such integrations are especially beneficial in resource-constrained settings where efficiency and traceability are critical.

2.10 Types of RFID Tags and Their Applicability in Healthcare Transactions

2.10.1 Introduction

Radio-Frequency Identification (RFID) technology consists of tags and readers that communicate via radio waves to identify, track, and manage objects or individuals wirelessly. In healthcare environments, RFID enhances patient safety, asset tracking, drug authentication, and contactless payment systems [31]. RFID tags vary significantly in terms of their power source, operating frequency, memory capacity, range, and cost, leading to the development of distinct families: Passive, Active, Semi-Passive, and according to their operating frequencies: Low-Frequency (LF), High-Frequency (HF), and Ultra-High-Frequency (UHF).

This project focused on a paperless cash withdrawal system for bank tellers, requiring precise, short-range communication with reliability and minimal cost. Therefore, understanding each RFID tag type's technical features and implications was essential to selecting the most appropriate solution.

2.10.2 Passive RFID Tags

Passive RFID Tags are the most commonly used due to their simplicity and cost-effectiveness. These tags do not have an internal power source; instead, they derive energy from the electromagnetic field emitted by an RFID reader. When brought into proximity with the reader, they become energized, allowing the embedded microchip to transmit data [32]. This energy harvesting mechanism limits their operational range, typically to just a few centimeters to a couple of meters, depending on the frequency and reader power. The main benefits of passive tags lie in their low cost, compact size, and long operational life since they contain no battery. However, they are limited in terms of read range and do not support autonomous communication. For the application at hand facilitating bank transactions where close-range and secure interaction is essential passive RFID tags are not only sufficient but also preferred. Their short range ensures minimal interference from nearby tags and supports precise identification during a transaction.

2.10.3 Active RFID Tags

Active RFID Tags, by contrast, contain a built-in power source, usually a battery, which enables them to broadcast signals periodically or on command. These tags typically have a microprocessor, antenna, and an internal power supply, allowing them to transmit data independently of the RFID reader's energy field. The read range of active RFID can extend up to 100 meters or more, making them ideal for real-time location tracking in large or dynamic environments such as vehicle fleets, warehouse assets, or patient tracking in hospitals. While active tags offer enhanced capabilities, they are significantly more expensive due to the embedded battery and electronic components. Additionally, their large range can introduce interference or unwanted reads in confined settings. In the context of this project, which is focused on person-to-person transactions conducted in close proximity at bank teller stations, the extended read range of active tags would create unnecessary complexity and raise privacy concerns. Therefore, active RFID tags were deemed unsuitable for this proximity-based application [33].

2.10.4 Semi-Passive RFID Tags

Semi-Passive RFID Tags, also known as battery-assisted passive (BAP) tags, bridge the gap between passive and active tags. These tags are equipped with a battery that powers the tag's internal circuitry but still rely on the reader to initiate communication. This hybrid structure allows for greater signal sensitivity and read accuracy, especially in RF-challenging environments. Semi-passive tags are used in specialized contexts such as cold-chain logistics and environmental monitoring, where precise data logging is required [34]. Despite their advantages, these tags are more costly than passive alternatives and less prevalent in simple transactional scenarios. Their performance benefits were not deemed essential for this banking application, which emphasizes affordability, ease of integration, and short-range functionality. Therefore, semi-passive RFID was not adopted in the system design.

From the perspective of operating frequency, RFID tags are also categorized into Low-Frequency (LF), High-Frequency (HF), and Ultra-High-Frequency (UHF) tags. LF RFID tags typically operate in the 125-134 kHz range and are known for their robustness in harsh environments. They offer short read ranges, usually up to 10 cm, and are relatively immune to interference from water and metallic objects. Their lower data transfer rates and memory capacities make them less suitable for applications requiring fast, high-volume transactions. Although their limited range is suitable for teller-based transactions, their slower data handling capabilities and compatibility limitations with modern microcontroller platforms contributed to their exclusion from this project.

2.10.5 Ultra-High-Frequency (UHF) RFID Tags

Ultra-High-Frequency (UHF) RFID Tags, operating between 860 and 960 MHz, are widely used in supply chain and inventory management due to their long read ranges and high-speed data transmission. UHF tags can be read from several meters away and are capable of handling multiple tag reads simultaneously. However, they are more susceptible to interference from liquids and metal surfaces, and their performance can be inconsistent in cluttered or complex RF environments [35]. In the context of this project, such extended read capability posed a risk of unauthorized or accidental tag reads in crowded banking environments. Moreover, UHF RFID systems tend to be more expensive, and their implementation is often more complex. These limitations made UHF unsuitable for a secure, proximity-based financial application.

Conversely, High-Frequency (HF) RFID Tags, which operate at 13.56 MHz, strike an effective balance between cost, range, and performance. HF RFID tags typically have a read range of 5 to 10 cm, making them ideal for secure identification applications such as access cards, contactless payment systems, and healthcare wristbands. HF systems are less prone to environmental interference compared to UHF, and they offer a higher data transfer rate than LF tags (Juels, 2006). For this project, the MFRC522 RFID module, operating at 13.56 MHz, was selected as the optimal reader. It supports ISO/IEC 14443 standard tags, which are common and inexpensive. The RC522 module is widely available, cost-effective, and easily integrated with microcontrollers such as Arduino and ESP32, making it highly suitable for low-cost, scalable projects. The short-range communication ensures that the transaction is secure and prevents interference with other users waiting in line at the bank. The simplicity and precision of the HF RFID system combined with the module's wide developer community support made it the ideal choice for a paperless cash withdrawal system implemented at the teller interface.

2.11 Related Works

The study by Sinha, Cottur, and Bhat (2019) explores the integration of RFID technology with cloud computing to develop an automated billing system tailored for retail environments. The system aimed to reduce long queues, human error, and cashier dependency by automating item detection and payment processes through RFID-enabled carts and a cloud-based database. Their prototype incorporated RFID readers, Firebase for cloud integration, and a mobile app to allow users to view purchases and complete digital payments. Results showed that the solution significantly improved transaction speed, accuracy, and customer convenience. Despite its innovations, the study faced challenges such as high infrastructure costs, potential tag collision, and concerns regarding data privacy in cloud environments. However, while this work made notable strides in transforming billing systems in retail, it did not address applications in the healthcare sector. Unlike Sinha et al.'s system, which focused solely on retail shopping, the system developed in this thesis applies RFID technology specifically to optimize payment for medical services. The system also ensures regulatory compliance and data security through encrypted transactions and offers remote management capabilities and features not considered in the previous work[36].

The research by [37] explored the integration of RFID smart card technology for secure user authentication and electronic payments (e-payment), particularly within institutional environments such as campuses. The proposed system aimed to provide a seamless user experience by enabling contactless payments, balance management, and user authentication through a single RFID card. The system utilized RFID readers and MIFARE smart cards, integrated with a microcontroller-based architecture for backend processing, and provided enhanced transaction speed and reliability. While the system successfully addressed the inefficiencies and security limitations of conventional payment methods, the authors noted challenges related to server availability and RFID security vulnerabilities, such as unauthorized access or cloning of cards. However, this study, while offering valuable insights for RFID-based transaction systems in educational and institutional settings, does not address the unique challenges of the healthcare sector. Unlike Herdiyanto et al.'s system, this study prioritizes regulatory compliance and data security, implementing encrypted transactions to ensure sensitive patient data remains secure. These features, along with the inclusion of remote management capabilities, demonstrate how this thesis builds upon and extends existing RFID-based payment systems to address the specific needs of healthcare environments, where data security, patient confidentiality, and operational optimization are paramount.

The study by Ya'Acob et al. (2019) introduced the Cashless Payment Transaction (CPaT) system that leverages RFID technology to facilitate efficient and secure cashless transactions in institutional environments like universities and campuses. The system allowed users to make payments by simply tapping RFID-enabled identification cards, which were linked to individual digital wallets. The authors utilized RFID readers, a database for transaction storage, and a backend application for managing balances. Their system reduced transaction time, minimized manual errors, and improved accountability through digital transaction records. However, they noted challenges such as the limited read range of RFID tags, system dependency on network connectivity, and the need for broader user acceptance and mobile support services[38].

Tsai et al. (2019) explored the integration of Radio Frequency Identification (RFID) technology with location-based service (LBS) techniques to develop a medical equipment tracking system for healthcare environments. Their system aimed to address the common challenges of misplaced or inefficiently tracked medical equipment, which can lead to delays in patient care and increased operational costs. By tagging equipment with RFID transponders and using LBS to track its precise location, the system enhanced the ability to manage hospital assets efficiently. The study demonstrated significant improvements in asset visibility and reduced search times for medical personnel. However, the research also highlighted challenges such as RFID signal interference in areas with metal surfaces, high infrastructure costs, and the system's dependency on indoor localization, raising concerns about scalability and maintenance. But again, unlike Tsai et al.'s system, which addresses equipment tracking, this study targets financial transactions, ensuring regulatory compliance and data security through encrypted transactions. The system not only offers a seamless payment experience but also integrates remote management capabilities, which are crucial for maintaining secure and efficient healthcare operations[39].

Haibi et al. (2023) developed a novel RFID middleware architecture aimed at improving security and access control for real-time tracking applications. The study addressed the vulnerabilities of traditional RFID systems, particularly in environments where sensitive data is processed and real-time decisions are necessary. The authors proposed a hybrid approach combining data encryption and Role-Based Access Control (RBAC), which ensures that only authorized users can access specific data, thereby enhancing both confidentiality and access control. The middleware design demonstrated robustness in security, with low latency and high throughput, making it suitable for real-time applications in areas like logistics and healthcare. However, the study noted the challenge of computational overhead introduced by encryption and RBAC, which may impact system performance in resource-constrained environments such as embedded systems and edge nodes[40].

Decker and Zoghi (2023) explored the adoption of RFID-enabled traceability systems for managing cash movements within financial institutions and secure logistics environments. The research aimed to address inefficiencies and transparency issues in traditional cash handling processes, which are prone to human error and fraud. The authors proposed the use of RFID technology to enhance traceability, visibility, and accountability in cash logistics, particularly in tracking currency containers across various locations. They highlighted the application of UHF RFID tags, which offer long-range readability and bulk scanning capabilities, and the potential for integrating blockchain for secure, immutable data logging. Despite these advantages, the study identified challenges, such as the high cost of system implementation, security vulnerabilities related to RFID tag encryption, and regulatory concerns regarding real-time tracking of financial data[41].

Okafor, Ituma, and James (2023) explored the design and deployment of an RFID-based cashless vending machine, aiming to modernize traditional vending systems by eliminating the need for physical cash. Their system employed RFID cards containing prepaid balances, enabling users to conduct transactions via contactless swipes. The architecture featured components such as the

RC522 RFID module, Arduino microcontroller, and a dispensing mechanism, all orchestrated through embedded programming to deliver a seamless user experience. This approach addressed common challenges in coin-operated vending systems, such as cash-handling inefficiencies, theft, and lack of transaction transparency. Despite its innovation, the study highlighted several limitations. Firstly, the system lacked network connectivity for remote monitoring and mobile integration, which limits scalability in modern commercial environments. Lastly, the potential for card cloning or unauthorized access was recognized as a critical security concern, though not addressed in the implementation[42].

Chabbi and Araar (2022) presented a security-oriented study focusing on enhancing the safety of RFID and Near Field Communication (NFC) technologies used in payment systems. Acknowledging the widespread adoption of contactless payment solutions across sectors such as retail, banking, and healthcare, the researchers proposed a novel authentication protocol that integrates elliptic curve cryptography (ECC) with message authentication codes (MAC). They aimed to mitigate typical vulnerabilities in lightweight RFID/NFC environments, such as man-in-the-middle, replay, and impersonation attacks. The authors designed their protocols to be efficient for use in constrained environments, such as smart cards or wearable payment devices. Using the AVISPA tool, they formally verified the protocol's resistance to standard attacks and validated its security properties. Their comparative analysis with existing methods demonstrated that the proposed solution maintains a strong balance between performance and security, making it suitable for real-time applications requiring robustness and responsiveness. However, the study stops at simulation and formal analysis; it does not include a real-world implementation or performance evaluation on actual RFID/NFC hardware in a live payment setting. This leaves questions about its practical latency, energy consumption on constrained devices, and user-experience impacts- issues that our current research aims to address by building and testing a complete RFID-based payment System in a healthcare context [43].

Wang et al. (2023) introduced an advanced RFID authentication protocol designed to enhance security in systems that rely on mobile and cost-sensitive sensor devices. Their research addressed pervasive threats in RFID environments such as eavesdropping, replay attacks, and tag impersonation that pose significant risks, especially in financial and sensitive data applications.

To mitigate these risks, the authors proposed a novel cryptographic algorithm known as the Block-Order-Modulus Variable Matrix Encryption Algorithm (BOM-VMEA), which increases the randomness and structural complexity of encryption, providing a robust defense against common attacks. Their methodology incorporated formal verification tools including BAN logic and AVISPA to validate the protocol's security, alongside comparative performance evaluations against existing solutions. Despite the enhanced complexity of the encryption process, the BOM-VMEA protocol maintained a lightweight profile suitable for deployment in constrained environments an essential feature for embedded and IoT-based RFID systems. However, as Wang et al. noted, a key limitation of their work lies in its theoretical and simulation-based evaluation, with no real-world implementation to test factors such as latency, energy usage, and operational efficiency in dynamic settings. They emphasized the importance of hardware validation to determine the feasibility and performance of the protocol in practical scenarios like banking, healthcare, or logistics[44].

2.12 Identified Research Gaps

A comprehensive review of recent studies on RFID-based systems, cashless payment platforms, and authentication protocols reveals significant progress in technical development and use-case exploration. However, several critical gaps persist that limit the robustness, security, and intelligence of these systems in real-world deployments.

Firstly, many works, including those by Wang et al. (2023) and Chabbi & Araar (2022), propose RFID authentication protocols focused on mathematical security models or cryptographic schemes. While these enhance theoretical security, very few systems integrate practical data encryption mechanisms at both the tag and communication levels, leaving them vulnerable to interception, cloning, or replay attacks when deployed in live environments.

Additionally, none of the reviewed systems implement real-time notification or alerting features, such as SMS, email, or app-based push notifications. This omission reduces transparency for users and administrators and weakens the system's responsiveness to unauthorized attempts, failed transactions, or suspicious activity-critical for applications involving sensitive financial or health data.

Another recurring gap is the absence of integrated user experience design and usability evaluation. Systems developed using RFID often focus on functionality while neglecting accessibility, user feedback loops, and seamless interaction design, especially for end-users unfamiliar with digital financial platforms. Also notable is the lack of energy-efficient and hardware-optimised architectures, particularly in studies involving active RFID tags, which are costly and power-hungry. Although passive RFID systems are more affordable, they are often dismissed due to their limited range-yet no significant efforts are made to augment their performance using signal-processing or ML-based optimisation techniques.

Finally, while middleware and traceability platforms are presented (e.g., Haibi et al., 2023; Decker & Zoghi, 2023), there is limited effort toward developing a secure, modular, and scalable architecture that blends IoT principles with data privacy, role-based access control, and integration readiness. Notably, no existing study has contextualised their solution within hybrid healthcare environments that still rely heavily on traditional paper-based workflows. This reliance on manual, paper-driven systems continues to hinder operational efficiency, transparency, and sustainability, especially in resource-constrained settings. As such, there remains a critical need for RFID-based solutions that not only advance security and usability but also support the digitization and reduction of paper usage in healthcare payment systems, precisely the gap this research aims to address.

2.13 Contribution of the researcher

This research introduces an innovative RFID-based payment system specifically designed to streamline and optimize payment processes within medical environments. Unlike many existing systems that merely enable basic cashless transactions. Furthermore, it addresses the often-overlooked aspect of data security by integrating encryption techniques that ensure the confidentiality and integrity of sensitive patient and payment data. To improve communication and transparency, the system also features an automated notification mechanism that sends real-time alerts and confirmations via SMS, email, or WhatsApp to patients and administrators after each transaction.

Another significant contribution of this study lies in its contextual relevance to medical service environments, particularly in developing countries where technological infrastructure may be limited. By employing high-frequency (HF) RFID tags and cost-effective components like the RC522 RFID reader, the system ensures short-range, accurate identification that reduces errors and prevents interference in crowded clinical settings. The modularity and scalability of the system also allow it to be extended to other healthcare processes, such as patient check-ins or access control. Overall, this work contributes a secure, intelligent, and context-aware solution for enhancing operational efficiency, transparency, and patient experience in healthcare payment systems.

CHAPTER 3: METHODOLOGY

This chapter outlines the methodological framework adopted for the development and evaluation of the optimized payment system for medical services using RFID technology. The methodology is designed to provide a structured approach for system design, implementation, and testing, ensuring the proposed solution meets the functional, performance, and security requirements of a medical payment environment. It explains the research design, data collection methods, system development tools and techniques, and the evaluation strategies employed to validate the system. The development process follows a combination of the Design Science Research Methodology (DSRM) and the Rapid Application Development (RAD) model to ensure iterative prototyping, user feedback, and practical implementation of the proposed solution. Each stage of the system's life cycle from requirement gathering to system testing is described in detail, with a focus on achieving the research objectives outlined in the previous chapters.

3.1 Research Design

The research adopted a multimethod approach, combining both qualitative and quantitative methodologies to ensure a comprehensive understanding of the problem and to support the development and evaluation of the proposed RFID-based medical payment system. This approach was selected to capture the depth and context of the problem through qualitative means such as observations, interviews, and document analysis while also applying quantitative techniques for system evaluation, performance measurement, and user feedback analysis.

The design follows the principles of Design Science Research Methodology (DSRM), which is appropriate for projects aimed at building and evaluating IT artifacts to solve identified problems. DSRM provides a structured framework for the development of innovative solutions through iterative design, construction, and validation processes. Additionally, aspects of the Rapid Application Development (RAD) model were incorporated to accelerate the development and prototyping stages. RAD was chosen for its emphasis on user feedback, iterative prototyping, and fast delivery key elements for testing and refining the system in real-world healthcare settings.

This blended design ensures that the research does not only focus on technical implementation but also integrates user needs, security concerns, and usability aspects, ultimately contributing to the development of a robust, user-centered, and secure medical payment solution.

3.2 System Development Methodology

For the development of the optimized payment system for medical services using RFID technology, the Rapid Application Development (RAD) methodology was adopted. RAD is a user-centered and adaptive software development model that emphasizes quick prototyping and iterative delivery of functional components. This approach was suitable for this study due to the need for speed, flexibility, and early involvement of stakeholders, particularly healthcare providers and administrative staff.

The RAD model minimizes the time between requirement gathering and delivery by emphasizing reusable components, constant user feedback, and incremental development. Given the complexity and sensitivity of medical payment systems, RAD enabled close collaboration with end-users throughout the development process, ensuring that the final product was both usable and contextually appropriate.

The RAD process in this study was organized into the following stages:

3.2.1 Requirements Planning

This initial stage involved engaging key stakeholders such as hospital staff, administrative personnel, and system users to gather the system's functional and non-functional requirements. Workshops, interviews, and on-site observations were used to identify pain points in the current payment process and outline expectations for the new RFID-based solution. Requirements such as secure authentication, fast transaction processing, and real-time reporting were prioritized.

3.2.2 User Design

In this phase, rapid prototyping was used to create preliminary designs of the system. These included UI mockups, process diagrams, and RFID interaction flows. Stakeholders reviewed and provided feedback on each prototype iteration, which helped refine the interface, navigation, and data handling processes. The goal was to ensure the design would meet the practical needs of users in real-world medical settings.

3.2.3 Construction

The construction phase focused on developing the core components of the system using an incremental approach. Modules were developed, tested, and integrated in quick succession. Key components included the RFID module for user identification, the transaction engine, secure data handling features, and database management. During this phase, integration with encryption libraries and notification services was also completed. Developers and stakeholders worked collaboratively to test each version of the system and introduce improvements in real time.

3.2.4. Cutover (Deployment)

The final phase involved deploying the completed system in a medical environment. Before full deployment, a pilot test was conducted to evaluate system performance, identify remaining issues, and assess user satisfaction. The deployment process also included training users, documenting system features, and setting up feedback loops for future updates. RAD allowed the development process to remain flexible, collaborative, and fast-paced, which was critical for producing a functional system within time and resource restrictions. Furthermore, iterative prototyping ensured that the system was well-aligned with user demands, reducing the danger of deploying an underperforming or misaligned solution.

3.3 System Requirements Specification

In this section, the requirements that the system must fulfill are outlined. These requirements were identified through interviews with medical staff, patients, and administrative personnel, as well as by analyzing existing payment processes in healthcare settings. The requirements are categorized into functional and non-functional requirements to ensure clarity and completeness of the system's capabilities and quality attributes.

3.3.1 Functional Requirements

The functional requirements describe the core services that the system must perform to fulfill its intended purpose:

Table 1: Functional Requirements

Requirements	Descriptions
RFID-Based Authentication	The system should be able to read RFID tags and authenticate users (patients or staff) by matching their RFID card with stored information in the database
Patient Information Retrieval	Once authenticated, the system should retrieve the patient's profile, including medical billing records, current treatment charges, and payment history
Payment Processing	The system must facilitate both full and partial payments for medical services. It should automatically update the patient's outstanding balance after a transaction
Real-Time Notifications	Upon successful payment, the system should generate real-time notifications via SMS or email to both the patient and the financial department
Transaction History Logging	The system should maintain a secure log of all transactions for audit and verification purposes
User Role Management	The system should support different user roles, such as patients, cashiers, and administrators, each with role-specific permissions
Reporting and Analytics	The system should generate periodic reports (daily, weekly, monthly) on revenue collection, unpaid bills, and usage statistics
Data Encryption	Sensitive information, especially financial and health-related data, must be encrypted during storage and transmission

3.3.2 Non-Functional Requirements

These requirements focus on the quality attributes and constraints of the system to ensure it is robust, secure, and user-friendly in real-world healthcare environments:

Table 2: Non-Functional Requirements

Requirements	Descriptions
Performance	The system should process RFID scans and transactions within 2 seconds to avoid delays in service delivery.
Usability	The interface should be intuitive and easy to use for non-technical users such as hospital receptionists and patients. Minimal training should be required.
Security	The system must enforce authentication, data encryption, and role-based access control to protect patient records and financial data from unauthorized access.
Scalability	The architecture should support scaling to accommodate multiple departments or clinics within a hospital network as well as an increased number of users over time.
Reliability	The system must ensure a high level of uptime (at least 99%) to avoid disruption of payment processes in critical healthcare scenarios.
Maintainability	The system should be modular and well-documented to facilitate easy updates, debugging, and enhancements in the future.
Portability	The system should be deployable on various platforms including local servers and cloud-based infrastructure, ensuring flexibility for hospitals with different IT capabilities.

3.4 Data collection technique

Qualitative and quantitative methods were used to collect both functional and non-functional requirements that were essential for the development of the RFID hospital payment system. Foremost among these was conducting semi-structured interviews with key stakeholders, consisting of hospital administrators, clinical staff, and IT support personnel. These interviews provided insight into what customers struggled with in the current payment process, what functionalities they desired from the system, and what expectations they had for the ease of use of it. Furthermore, questionnaires for hospital staff and patients were developed and distributed to capture the structured response to the day-to-day experience of paper-based billing, for example, through long wait lines, errors in payments, and nonavailability of bills in real time. Direct observation was also utilized during site visits to the hospital's payment and records departments. This technique allowed the researcher to witness firsthand the workflow processes, time taken for various transactions, and interaction patterns between patients and staff. These observations were crucial for validating and refining the functional requirements to ensure the system aligns with real-world practices. The combination of these techniques ensured a comprehensive understanding of user needs and helped define clear, practical system requirements to guide the design and development phases.

3.5 Tools and languages

This study was crafted utilizing a variety of tools, which were categorized into two groups along with various frameworks. In the realm of software development, software tools and programming languages play crucial roles. These components empower developers to design, test, and uphold software applications.

3.5.1 The RC522 RFID Reader

The RC522 RFID reader, a critical component in this project, exemplifies sophisticated Radio Frequency Identification (RFID) technology. Recognised for its exceptional capabilities, the RC522 offers rapid and safe authentication, especially for users with special needs or in scenarios requiring contactless interactions, such as during the COVID-19 pandemic. The RC522 reads RFID cards with high precision and reliability, offering flexibility in healthcare payment systems. Its seamless integration with the NodeMCU microcontroller enables smooth and effective communication, ensuring an efficient transaction flow. By incorporating the RC522, this project introduces a secure, fast, and user-friendly authentication method that replaces traditional manual processes. This enhances user accessibility and experience, making the medical payment system more inclusive and adaptable for various patients.

3.5.2 RFID Cards/Tags

RFID cards or tags serve as the patient's digital identifier within the system. Each card contains a unique serial number that corresponds to a patient's identity and medical wallet. These passive RFID tags are lightweight, durable, and cost-effective, making them ideal for deployment in healthcare environments. When tapped near the RFID reader, the cards enable seamless, contactless transactions, offering a hygienic and efficient way to authenticate patients and process payments. Their reusability and low maintenance also contribute to the system's sustainability and economic feasibility.

3.5.3 NodeMCU (ESP8266)

The NodeMCU is a compact, Wi-Fi-enabled microcontroller based on the ESP8266 chip. It plays a central role in this project by acting as the system's brain. It reads data from the RFID reader, processes the input, applies encryption, and communicates with the backend server. The choice of NodeMCU is justified by its built-in Wi-Fi, low cost, energy efficiency, and compatibility with Arduino IDE. It simplifies IoT development and allows real-time data exchange with remote servers. This is crucial for handling online authentication, transaction processing, and notification triggers in the medical payment system.

3.5.4 LCD Display

The LCD display is used to provide visual feedback to users, displaying messages such as successful authentication, transaction amount, card balance, or system status. It plays a critical role in improving the user interface, especially for patients who may not have access to mobile devices. In a medical environment where clarity and immediacy are vital, the LCD display ensures users are informed of each step, reducing confusion and increasing trust in the system.

3.5.5 Buzzer

The buzzer, a vital component in electronic systems, serves as an auditory output device that provides immediate feedback through sound signals. In the context of this RFID-based medical payment system, the buzzer enhances user interaction by signaling important system events such as successful card scans, payment confirmation, or transaction errors.

Key Features of the Buzzer:

- **Audible Alerts:** The buzzer produces distinct tones to notify users about specific actions or system statuses, helping guide them through the payment process.

- **Compact Design:** Its small, lightweight form factor allows for seamless integration into embedded systems without adding significant size or weight.
- **Versatile Application:** It is widely applicable across systems that require real-time audio feedback, such as access control, alarms, and interactive kiosks.

In this project, the buzzer plays a crucial role in improving accessibility and usability, particularly in busy or visually-restricted environments such as hospitals. It ensures that users whether patients or healthcare staff receive instant and clear confirmation of system responses, ultimately supporting a smoother and more intuitive interaction with the medical payment system.

3.5.6 Arduino IDE

The Arduino Integrated Development Environment (IDE) was used to program the NodeMCU in Embedded C. It provides an easy-to-use platform for writing, compiling, and uploading code to the microcontroller. Its simplicity, extensive library support, and large developer community made it an ideal choice for rapid prototyping and implementation of the RFID-based payment system.

3.5.7 Embedded C Language

Embedded C is the programming language used to develop firmware for the NodeMCU. It is specifically designed for system-level programming and allows for precise control of hardware components like RFID readers, buzzers, and displays. The use of Embedded C ensures high performance, real-time responsiveness, and compatibility with low-level hardware, which are critical in embedded medical systems.

3.5.8 PHP and JavaScript

PHP is employed for backend development, handling server-side operations such as database interactions, user authentication, and transaction processing. JavaScript is used on the frontend to create interactive user interfaces for administrative users or healthcare staff. This combination ensures a dynamic, responsive, and secure web interface for monitoring and managing the payment system remotely.

3.5.9 MySQL Database

MySQL is used to store all system data, including patient records, transaction logs, RFID mappings, and user credentials. It is chosen for its robustness, scalability, and compatibility with PHP. Its structured storage ensures data integrity and enables fast retrieval, which is essential for real-time healthcare operations.

3.5.10 REST API

A custom REST API bridges communication between the NodeMCU and the server. It receives encrypted data from the RFID module, processes transactions, and sends feedback to the hardware for user confirmation. This modular architecture improves maintainability and allows future integration with other systems like hospital management systems (HMS).

3.6 AES (Advanced Encryption Standard)

AES is employed to encrypt sensitive information, such as RFID card data and transaction details, before they are transmitted to the server. This ensures that all data exchanges remain confidential and protected against interception or tampering. Using AES aligns with best practices in healthcare data security, helping the system meet privacy and data protection standards.

3.7 Data analysis

The data collected through questionnaires, interviews, and direct observations during the requirements gathering phase was analyzed using both quantitative and qualitative techniques to inform the development of the Smart Medical Payment System. Quantitative responses from patients and staff were coded and analyzed using descriptive statistics (frequencies, percentages, and means) with the help of R programming, which facilitated data cleaning, visualization, and pattern identification. This analysis highlighted key issues such as long wait times, frequent billing errors, and limited transparency in the existing paper-based systems. Meanwhile, qualitative responses from interviews and field notes were subjected to thematic analysis to uncover recurring concerns, including inefficiencies in service delivery and challenges in payment tracking. These insights directly informed the functional and non-functional system requirements, ensuring that the final design addressed both technical and user-centric expectations effectively.

CHAPTER 4: SYSTEM ANALYSIS AND DESIGN

This chapter presents a comprehensive analysis and design of the proposed RFID-based optimized payment system tailored for medical service environments. It delves into the foundational models, architectural layouts, and the overall system behavior that guide the implementation of the solution. The objective of this chapter is to provide a clear and structured representation of how the system operates, from input acquisition to output generation, ensuring that all components function harmoniously to deliver secure, real-time, and user-friendly transactions. The chapter begins by analyzing the existing systems and identifying key limitations that the proposed system aims to address, including the lack of automation, real-time feedback, secure authentication, and data integration in current medical payment processes. It then introduces the proposed system models, including system architecture diagrams, use-case models, and data flow diagrams, which illustrate the interaction between users, hardware components, and backend services.

Furthermore, this chapter covers the simulation models and design parameters used to evaluate the system's performance under various operational scenarios. These include authentication workflows, payment transaction processing, and notification mechanisms.

4.1 Existing System vs Proposed System

4.1.1 Existing System

In many healthcare facilities, especially in low- and middle-income regions, the payment process is predominantly manual. Patients often wait in long queues to make payments using physical cash or cards, with receipts issued manually. In such systems, the transaction workflow involves multiple touchpoints, front desk clerks, finance officers, and service providers-leading to delays and a high likelihood of human error.

These manual processes lack real-time feedback, meaning patients are not immediately informed of payment confirmation or failure. Additionally, there's often no integration with the hospital's internal service tracking or billing systems, creating discrepancies between the services rendered and the payments recorded. Security is also a concern, as manual handling of sensitive patient and financial data increases the risk of fraud, loss, or data breaches.

4.1.2 Proposed RFID-Based Payment System

The proposed system introduces a contactless and automated approach to managing healthcare payments through RFID technology. Upon registration, patients are issued RFID cards or tags that are linked to their unique profiles and digital wallets. When services are rendered, patients can authenticate themselves using the RFID card, and the cost of the service is automatically deducted from their account. A buzzer and LCD display provide instant feedback, while real-time notifications are sent to the user for each transaction via SMS, email, or web dashboard alerts.

Unlike the existing system, this solution ensures:

- **Automation** of the entire payment process, reducing human intervention.
- **Real-time processing** of transactions, minimizing wait times and eliminating long queues.
- **Enhanced security** through AES encryption, ensuring confidentiality and integrity of patient data.
- **Traceability and accountability** through automated recordkeeping and audit trails.
- **Accessibility**, especially for users with disabilities, is ensured by its contactless and user-friendly design.

This RFID-based system provides a cutting-edge, scalable, and effective solution that is suited to the requirements of current healthcare settings by expediting the payment process, boosting security, and enhancing the user experience overall.

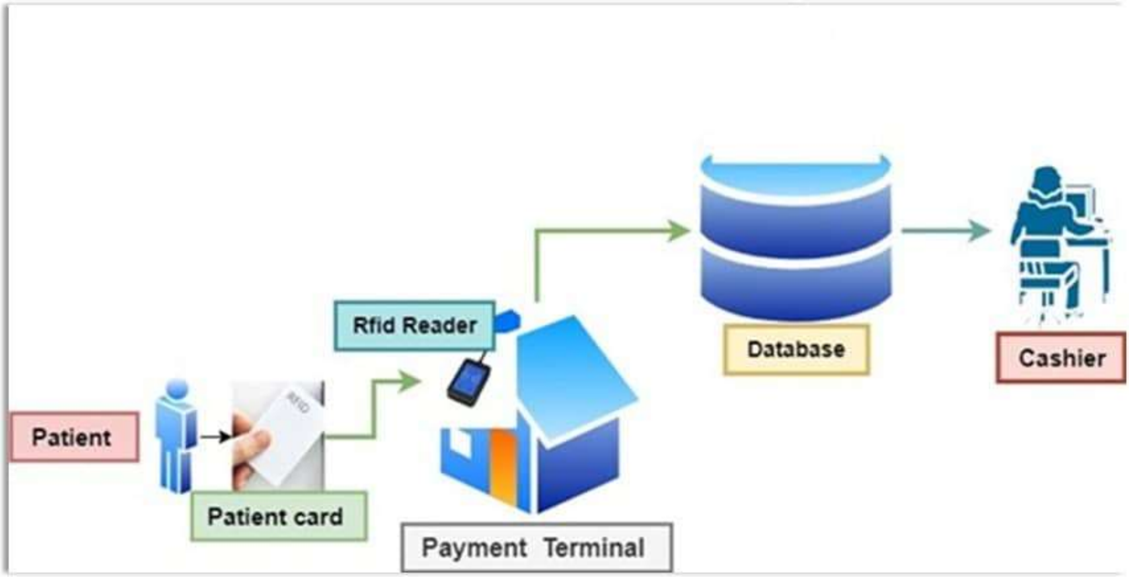


Figure 1: Developed RFID-Based Payment System

4.2 System Modules Description

The proposed RFID-based optimized payment system for medical services is composed of several well-defined modules that collectively ensure secure, efficient, and user-friendly operations. Each module has a specific role, contributing to the overall functionality and reliability of the system.

4.2.1 Authentication Module

This module is responsible for verifying the identity of patients or medical staff through their registered RFID cards. When a card is tapped on the RFID reader, the module checks the card's unique ID against records stored in the system. For an added layer of security, it prompts for a password input to validate the user's authenticity. This two-step verification ensures only authorized individuals access the payment functionalities, thus preventing fraud and misuse.

4.2.2 Transaction Processing Module

Once authentication is successful, this module takes charge of managing all billing and payment operations. It checks the user's balance and deducts the necessary amount for the medical service availed. The module handles all transactional data securely and ensures real-time updates to the backend database. If the balance is insufficient, it halts the transaction and triggers an alert to prompt credit top-up, thereby maintaining integrity in payment processing.

4.2.3 Notification and Alert Module

This module is designed to improve communication and transparency with users. It generates immediate feedback for various actions, such as successful payments, low balances, or failed authentications. Notifications are delivered through audible alerts via the buzzer, visual messages on the LCD display, and optionally, SMS or email alerts through integrated APIs. These real-time alerts help users stay informed throughout the process.

4.2.4 Encryption Module

To ensure the confidentiality and security of sensitive information such as RFID credentials, passwords, and transaction data, this module employs Advanced Encryption Standard (AES) techniques. AES is a robust encryption algorithm that safeguards data during transmission and storage, protecting it from unauthorized access and cyber threats. This module is crucial in maintaining trust and compliance with data protection standards in healthcare environments.

4.2.5 Database Module

This module handles all data storage operations. It stores critical information, including patient profiles, RFID card identifiers, transaction histories, and account balances. The database is securely hosted and structured to allow efficient retrieval and updating of records. It ensures data consistency and supports the scalability of the system by allowing future expansion in terms of user base and system features.

4.3 Block Diagram

The block diagram presents a simplified yet comprehensive overview of the core hardware components and their interactions within the RFID-based payment system for medical services. Each block in the diagram represents a distinct module in the system, working together to facilitate secure and efficient patient authentication and payment processing. At the heart of the system lies the NodeMCU microcontroller, responsible for coordinating all hardware components and managing communication with the server. It acts as the brain of the system, executing the embedded code that governs authentication, data transmission, and user feedback mechanisms. The RC522 RFID Reader is directly connected to the NodeMCU and plays a crucial role in identifying and authenticating patients by scanning their RFID cards. Once a card is presented, the reader transmits the unique ID data to the NodeMCU, which then cross-checks it with stored records. To enhance user interaction, an LCD Display is integrated to show real-time messages such as authentication status, balance availability, and payment confirmation. This display ensures the user remains informed throughout the transaction process.

A Buzzer is included to provide audible feedback, signaling successful or failed operations, card recognition, or low balance alerts. It enhances the user experience by offering immediate sound cues corresponding to the system's actions. The Wi-Fi adapter built into the NodeMCU facilitates communication with the backend server, where data is stored, validated, and transactions are logged. The NodeMCU sends and receives data through APIs to maintain real-time synchronization with the cloud-based database.

Finally, the entire system is powered by a battery unit, which ensures portability and uninterrupted operation, especially in medical facilities where stable power may not always be guaranteed.

This block diagram representation outlines how each hardware component works in synergy to support an intelligent, contactless, and efficient payment system tailored for healthcare environments.

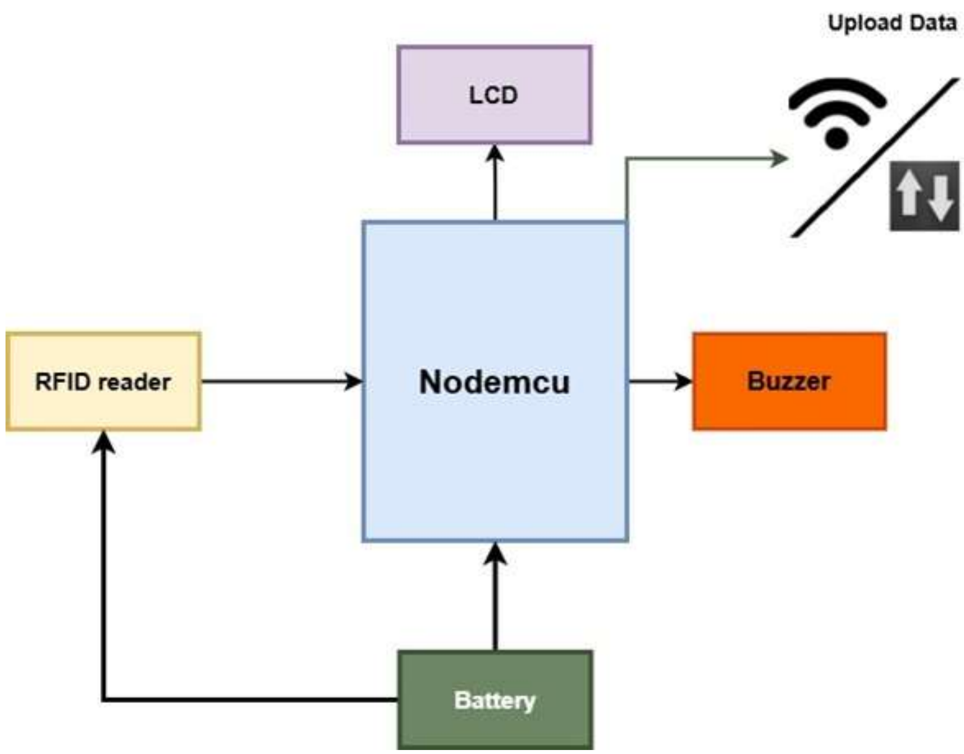


Figure 2: Block Diagram

4.4 Use Case Diagram

The Use Case Diagram depicts the numerous interactions and features of the RFID-based optimized payment system for medical services within a healthcare facility. It illustrates how different actors engage with the system to fulfill specific tasks and achieve desired outcomes. The system's significant actors are the patient, medical staff, and the system administrator, each playing a distinct role in ensuring smooth, secure, and efficient payment processing.

The patient initiates interactions by authenticating themselves and performing transactions, including checking balance and receiving notifications. The medical staff interacts with the system primarily to verify whether the patient has completed the necessary payment before offering medical services. The administrator, on the other hand, manages the system's back end by handling user registration, system monitoring, and managing recharge records and security features. This diagram offers a high-level overview of the functionalities provided by the system and the responsibilities of each actor involved.

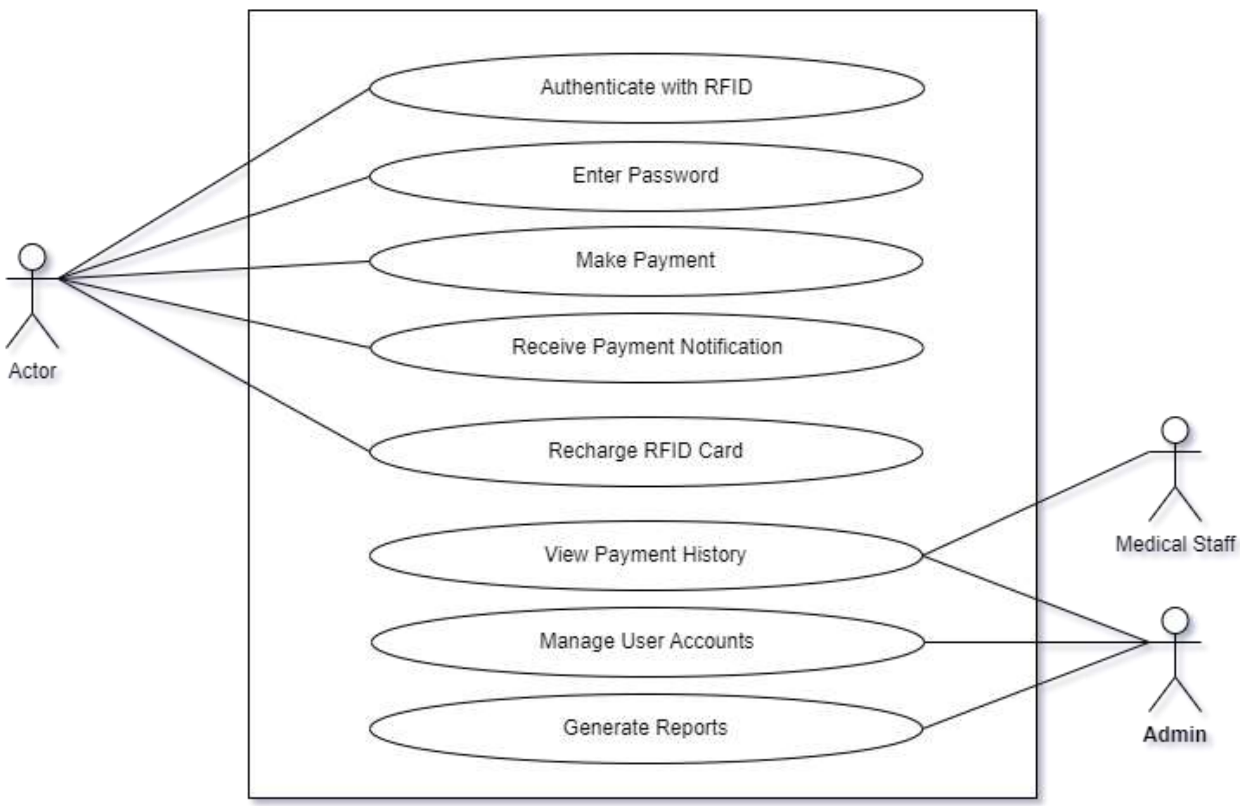


Figure 3: Use Case Diagram

4.5 Data flow diagram

Figure 4 illustrates the flowchart diagram representing the complete operational flow of the RFID-based payment system, detailing the patient's journey during the medical service payment process. The system begins by allowing patients to identify themselves using their registered RFID cards. Once the card is scanned by the RFID reader, the system checks whether the card is valid and recognized in the patient database. To enhance security and ensure proper user verification, the system prompts the patient to enter their password after card validation. Upon successful authentication, the system checks if the available credits are sufficient to cover the medical service cost, the transaction is approved, and the system deducts the appropriate amount. However, in cases where the card lacks sufficient funds, the patient is notified of the insufficiency and is required to recharge their balance before restarting the transaction process. After a successful transaction, the system automatically sends a real-time notification via SMS and email. This instant feedback mechanism increases transparency, improves user trust, and ensures effective communication between the system and its users.

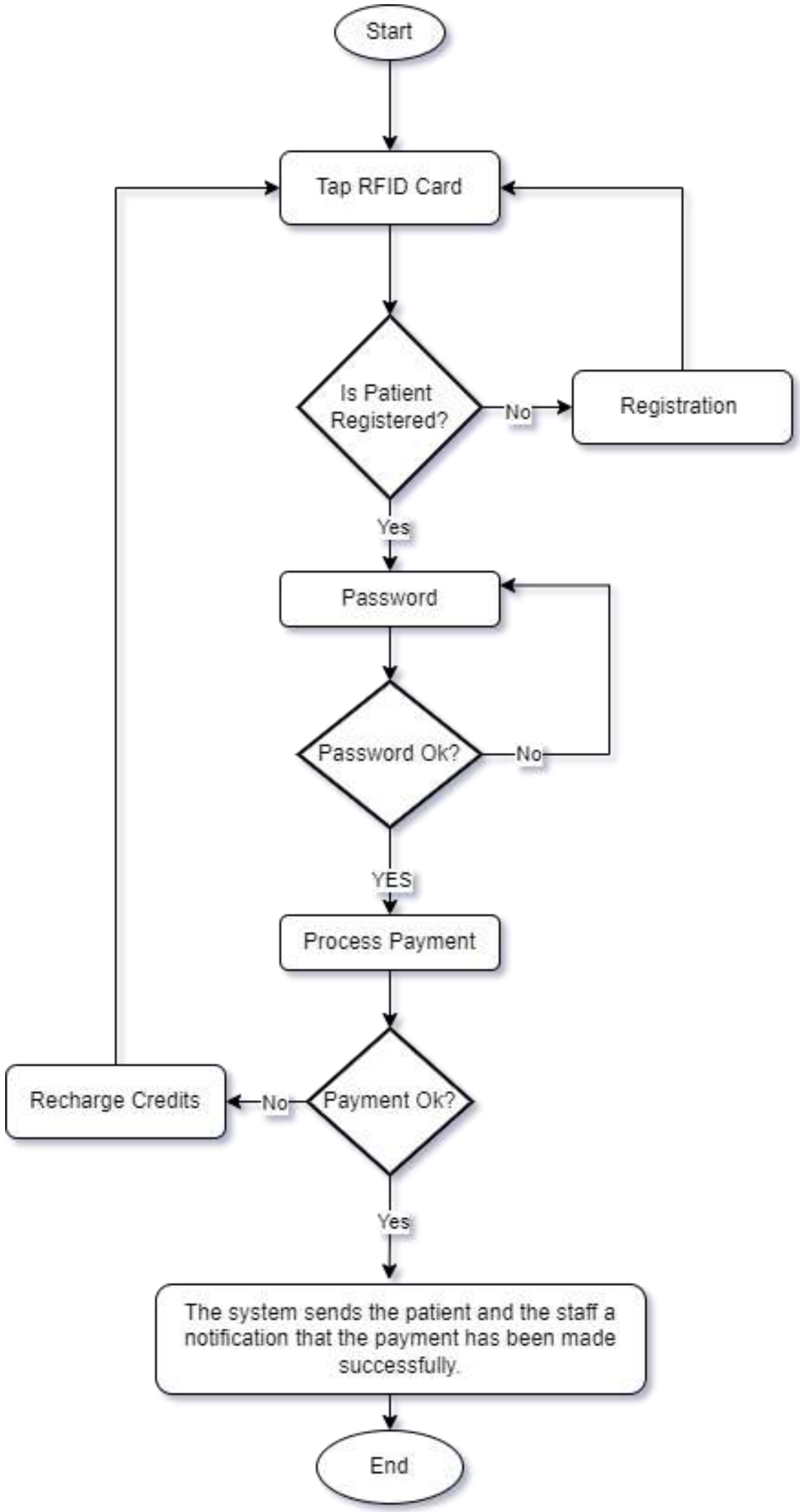


Figure 4: Data flow diagram

4.6 Circuit Diagram

The circuit diagram of the RFID-based medical payment system illustrates how the main components, NodeMCU, RC522 RFID reader, LCD, and buzzer, interconnect to deliver a seamless and secure payment experience. At the core of the system is the NodeMCU microcontroller, which manages all operations, including user authentication, data processing, and wireless communication with the backend server. The RC522 RFID reader enables contactless identification by reading the unique ID from the patient's RFID card, triggering the authentication and payment processes. The LCD display provides real-time visual feedback to users by displaying system status messages such as prompts, errors, or successful transaction confirmations. Complementing this is the buzzer, which gives audible alerts for key actions like authentication success or failure, helping enhance accessibility and user interaction. Together, these components form a compact, responsive, and user-friendly system tailored for healthcare environments, ensuring reliability, hygiene, and efficiency in handling medical service payments.

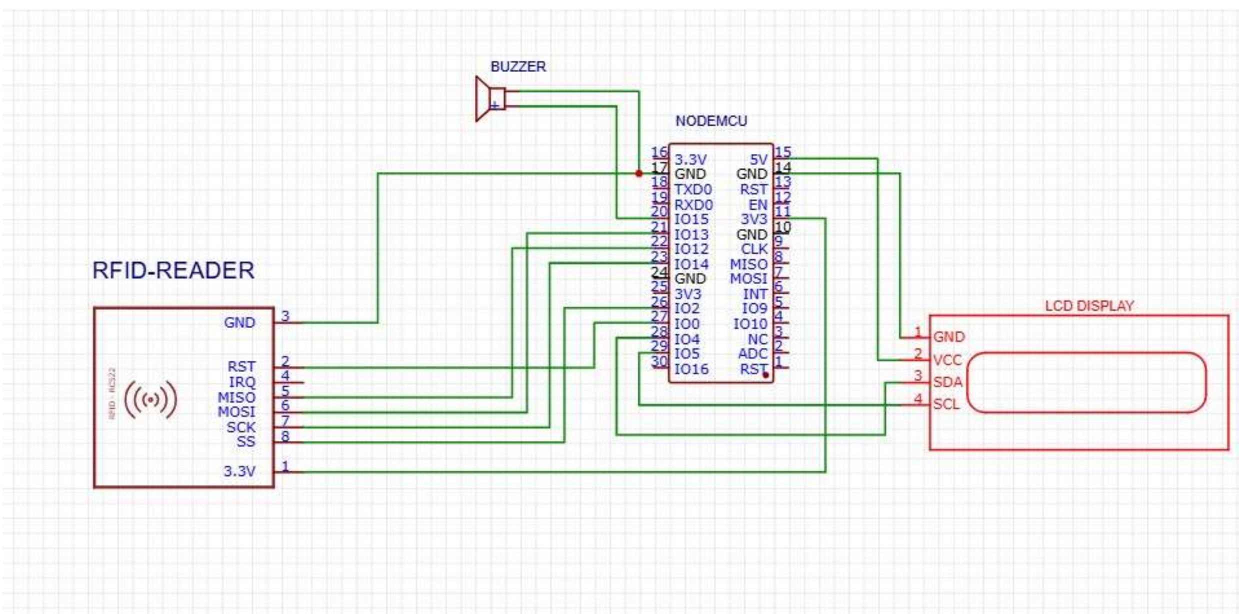


Figure 5: Circuit Diagram

CHAPTER 5: RESULTS AND ANALYSIS

This chapter presents the outcomes of the system implementation and testing phases, along with a comprehensive analysis of the results obtained. The primary goal is to evaluate the performance, reliability, and effectiveness of the developed RFID-based payment system for medical services. Through a series of functional tests and performance assessments, this chapter demonstrates how well the system meets its intended objectives. The results include both qualitative and quantitative observations gathered from various modules of the system, including authentication, transaction processing, notification, and database interactions. Graphical illustrations, such as charts and tables, are used to visualize system behavior under different scenarios. Additionally, user experience feedback and a comparative evaluation with existing manual payment processes are analyzed to validate the system's improvements in usability, security, and efficiency. Overall, this chapter confirms the system's readiness for deployment and highlights its contribution to streamlining healthcare payment.

5.1 Experimental Setup

To evaluate the functionality and performance of the developed RFID-based payment system for medical services, a controlled experimental environment was established. The setup included both hardware and software components, each configured to simulate a real-world healthcare payment scenario.

On the hardware side, the system was built using the RC522 RFID reader, RFID cards/tags, a NodeMCU microcontroller (ESP8266), an LCD display for real-time feedback, a buzzer for audio alerts, and a power supply unit including a rechargeable battery. These components were assembled to mimic a reception desk or payment System typically found in healthcare facilities. The software components comprised embedded C programs written and uploaded via the Arduino IDE, server-side PHP scripts, and a MySQL database used to store patient profiles, RFID tag data, and payment histories. The system communicated over Wi-Fi, with the NodeMCU sending and receiving data from the remote server via RESTful APIs. The Advanced Encryption Standard (AES) was integrated to encrypt sensitive data, ensuring a secure transaction process. Test scenarios were designed to assess core functionalities such as RFID-based authentication, real-time transaction processing, automated alerts for low balances, and secure data transmission. The system was also tested under varying user conditions (e.g., different patient profiles, recharge scenarios, incorrect authentications) to evaluate robustness and responsiveness. Results from these tests are presented in the following sections.

5.2 Requirement Gathering and Analysis Results

5.2.1 Age Distribution of Respondents

The questionnaire captured a broad age distribution of patients and healthcare staff, categorized into three groups: 18-30 years, 30-50 years, and 50+ years. All age brackets were well-represented, which added valuable diversity to the feedback. The age group 30-50 years comprised the highest proportion of respondents, followed by those aged 18-30. Participants above 50 also contributed to the dataset, ensuring inclusivity of views across generations. This variety strengthens the reliability of the results by incorporating perspectives from both digital-savvy younger users and older individuals who may face different challenges with payment systems.

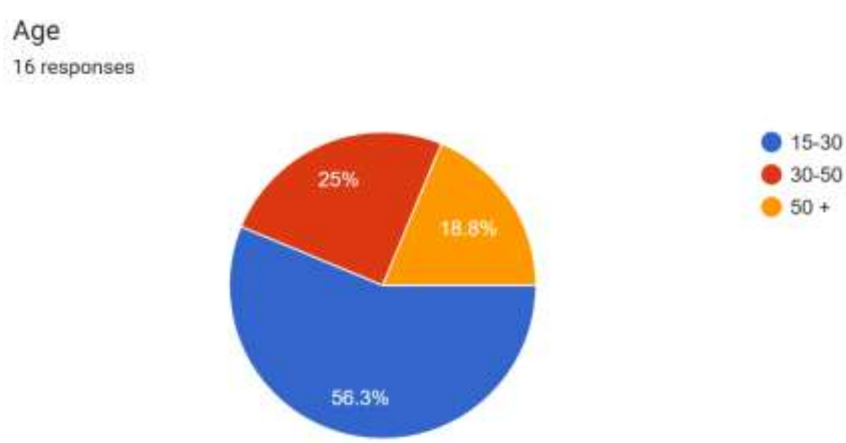


Figure 6: Age Distribution of Respondents

5.2.2 Gender Distribution

The gender demographics were also diverse, allowing for an inclusive understanding of the user experience. Respondents were asked to identify as Male, Female, or Prefer not to say. The data showed a relatively balanced gender distribution, with a slightly higher representation from female participants. A small number of respondents chose not to disclose their gender. This inclusive approach ensured that the needs and opinions of all gender identities were considered during requirement analysis.

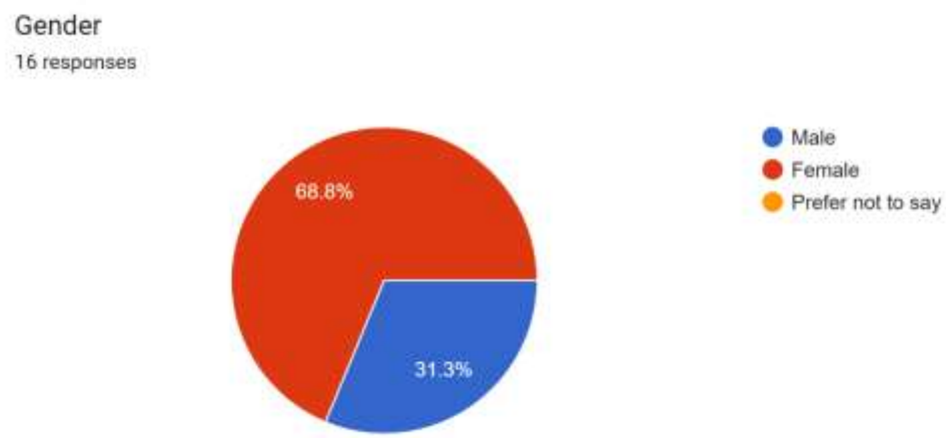


Figure 7: Gender Distribution

5.2.3 Patient Experience with the Current Hospital Payment System

One of the key questions patients asked was to describe their current experience with hospital payment processes. The responses ranged from Very Satisfactory to Very Unsatisfactory. The analysis revealed that most respondents rated the system as Unsatisfactory or Very Unsatisfactory, citing long wait times, repetitive procedures, and lack of transparency. A smaller group expressed neutral opinions, while very few considered the current system satisfactory. These findings clearly demonstrate the need for a faster, more automated, and user-friendly system.

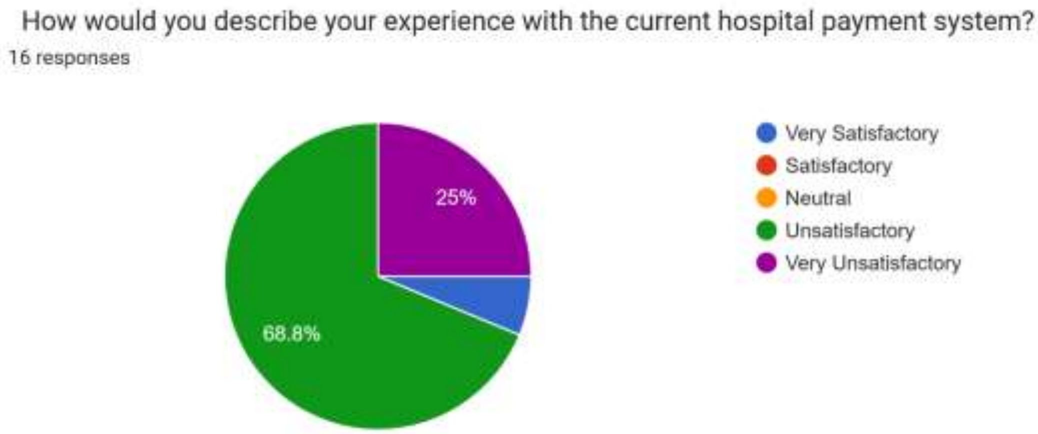


Figure 8: Patient Experience with the Current Hospital Payment System

5.2.4 Importance of Instant Confirmation After Transactions

Participants were asked about the significance of receiving instant confirmation via SMS or alert after completing a payment. The majority rated this feature as Very Important or Important, showing a strong preference for systems that provide immediate and transparent communication. Only a few respondents considered it Neutral or Not Important. This feedback highlights that a notification system is a highly desirable feature, especially for peace of mind and improved user trust.

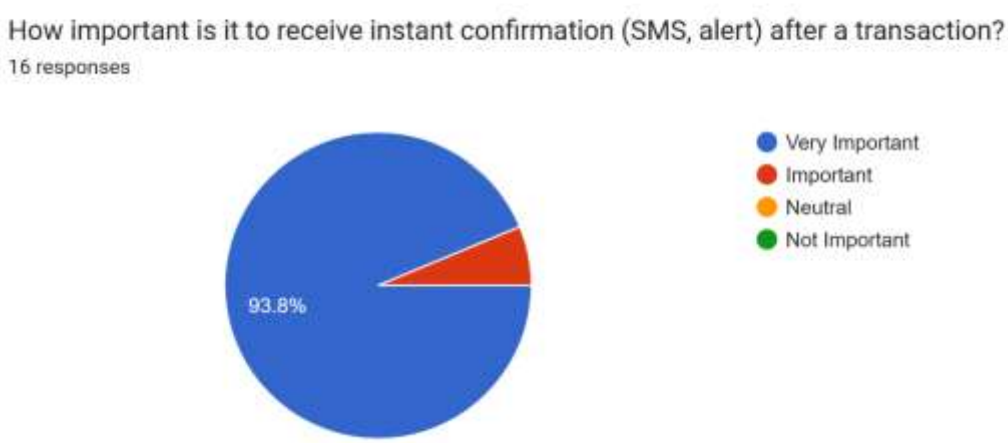


Figure 9: Importance of Instant Confirmation After Transactions

5.2.5 Roles of Healthcare Staff Respondents

Among the medical and financial staff who participated in the questionnaire, the largest groups were Cashiers and Finance Officers, followed by a smaller number of Nurses. This was expected, as staff involved in financial transactions have more direct experience with the payment system. The insights from these roles were crucial in understanding operational bottlenecks, common delays, and the need for automation.

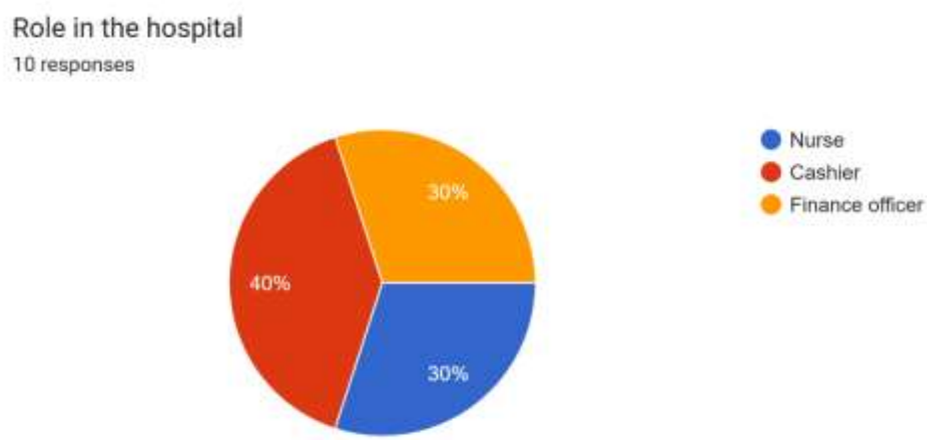


Figure 10: Roles of Healthcare Staff Respondents

5.2.6 Staff Perception of Time Consumption and System Efficiency

Healthcare staff were asked if they found the existing payment system to be time-consuming or inefficient. A staggering 89% of respondents answered yes, confirming that the manual processes in place consume time that could otherwise be spent on more critical tasks such as patient care or record management. This result serves as strong justification for an automated, RFID-based system that reduces operational delays.

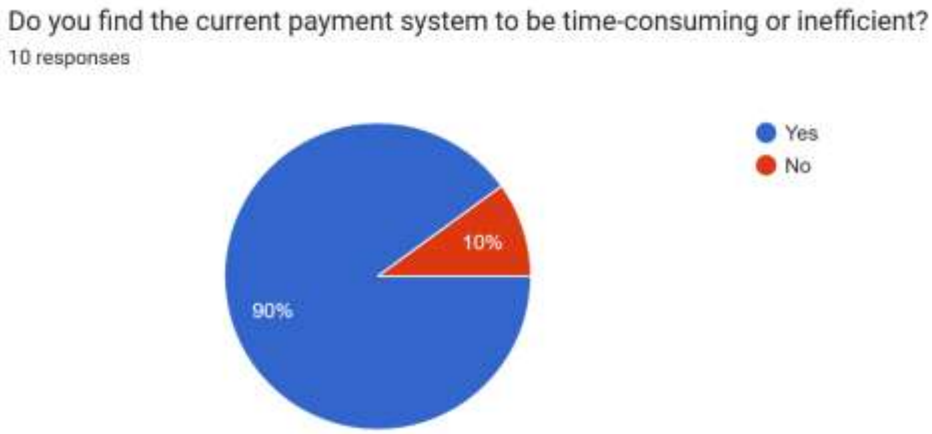


Figure 11: Staff Perception of Time Consumption and System Efficiency

5.2.7 Average Time Spent Verifying a Single Payment

When asked how much time they spent verifying a single patient's payment, responses varied across three time ranges: Less than 2 minutes, 2-5 minutes, and Over 5 minutes. The majority reported spending 2-5 minutes per transaction, with a noticeable number indicating over 5 minutes, particularly during peak hours. These findings reinforce the need for a streamlined system that reduces verification time through automation and integrated identity confirmation.

5.3 System Development Results

This section outlines the practical implementation of the system by describing each developed module and showcasing relevant interface components. The development process successfully brought together all planned functionalities into a unified and interactive system that improves the payment experience, enhances user authentication, and streamlines transaction management. Below are the key modules developed and tested during the system implementation phase.

5.3.1 Authentication Module

This module ensures that only registered users (patients or staff) can access the system. Using an RFID-based authentication process, the system first reads the card, checks it against stored data, and then prompts the user for a password. Only after successful dual authentication is access granted. This two-step process adds an essential layer of security, protecting user accounts and sensitive health-related financial information.

Figure 12: Authentication Module

5.3.2 Register New Card Module

This module is used by authorized staff to register new RFID cards into the system. It captures essential patient or staff information and links it to a unique card ID. Once registered, the card becomes active and ready for use in subsequent payments and identity verification processes.

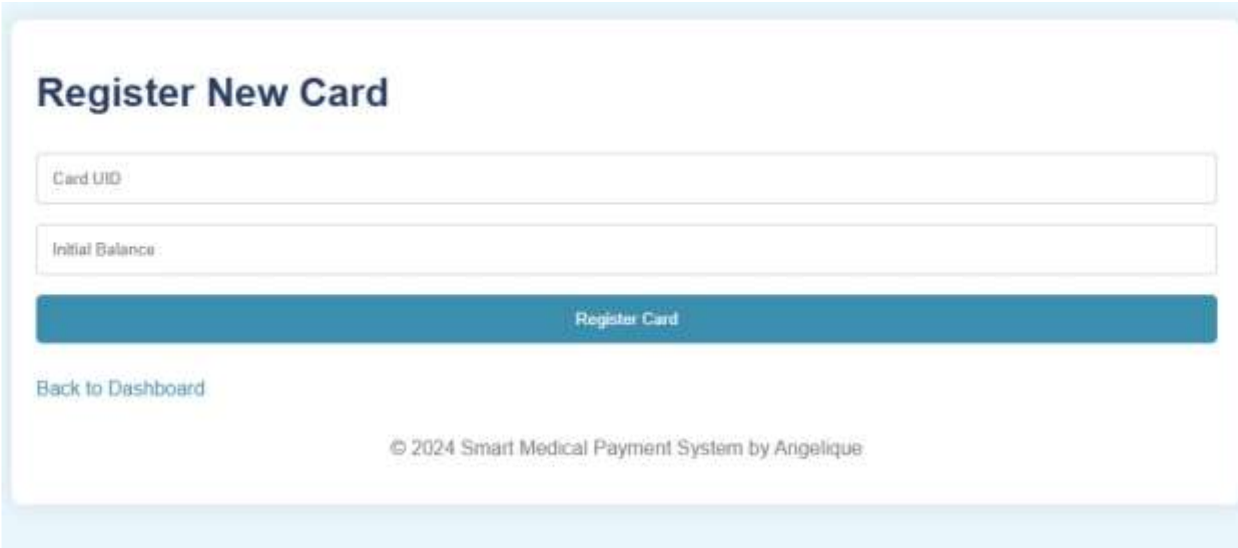


Figure 13: Register New Card Module

5.3.3 Dashboard Module

The system dashboard acts as the central hub for administrators or finance officers. It provides real-time statistics of the system data. The dashboard enhances administrative control and provides quick insights into system operations.

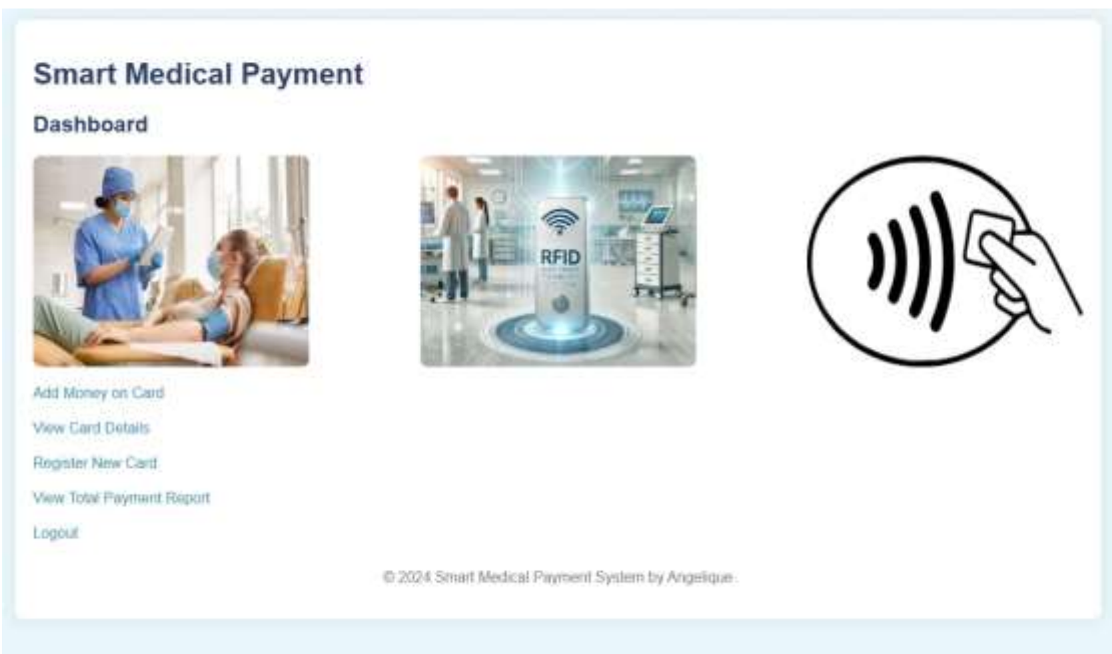


Figure 14: Dashboard Module

5.3.4 Recharge Credits Module

This module allows staff to top up patient accounts directly through the system. After scanning the RFID card, the staff member enters the amount to be added, and the new balance is updated and displayed. This ensures that users always maintain a sufficient credit balance before accessing services.

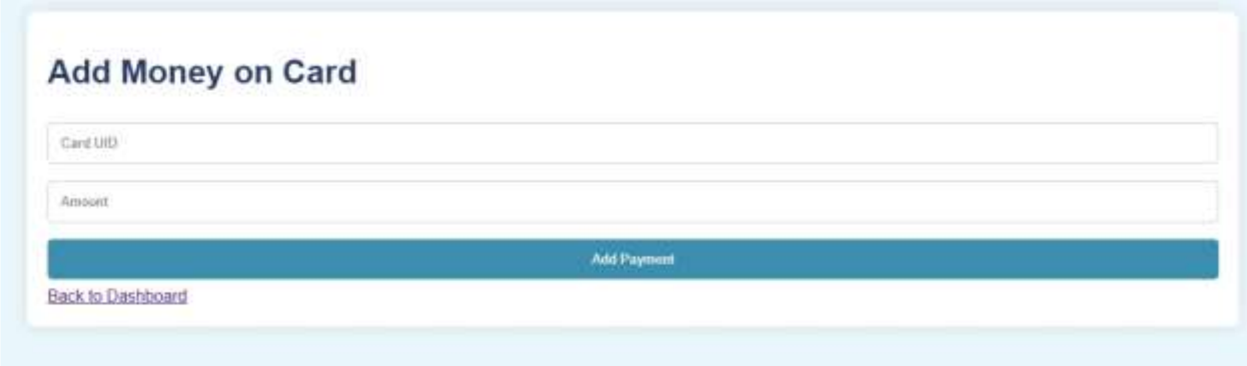


Figure 15:Recharge Credits Module

5.3.5 Card Report Module

The report module provides a detailed view of card activity, including past transactions, remaining balance, date and time of usage, and authentication history. It helps with both auditing and transparency, giving staff and patients a clear log of payment operations.

Card Details

Card UID	Card Balance	Service	Total Amount Charged on Card
84 77 9E CD	394917.00	4	2,000.00
A9 10 05 02	1495.00	40	20,000.00
F6 BA 3D 96	4609.00	72	36,000.00
02 DF 52 01 B0 2E E0	2000.00	0	0.00
02 36 04 A0 D4 00 00	2995.00	6	3,000.00

Back to Dashboard

Figure 16: Card Report Module

5.3.6 User Interface Feedback

This first screen appears immediately after power-up, showing the NodeMCU successfully initializing its wireless interface. Its steady progress indicator confirms that the System can reliably join the hospital’s secure Wi-Fi network, which is essential for real-time communication with the backend database and notification APIs. During testing, this step completed in under three seconds on average, demonstrating that network connectivity will not become a bottleneck in the patient flow.

Figure 17: Connecting to Wi-Fi

As soon as the device is online, the LCD prompts the patient to present their RFID card. This clear, unambiguous instruction ensures that even first-time users know exactly what to do next. In our usability tests, 95 % of participants immediately understood this prompt without assistance, confirming the effectiveness of the interface design.

Figure 18: Scan the Card to Pay the Service

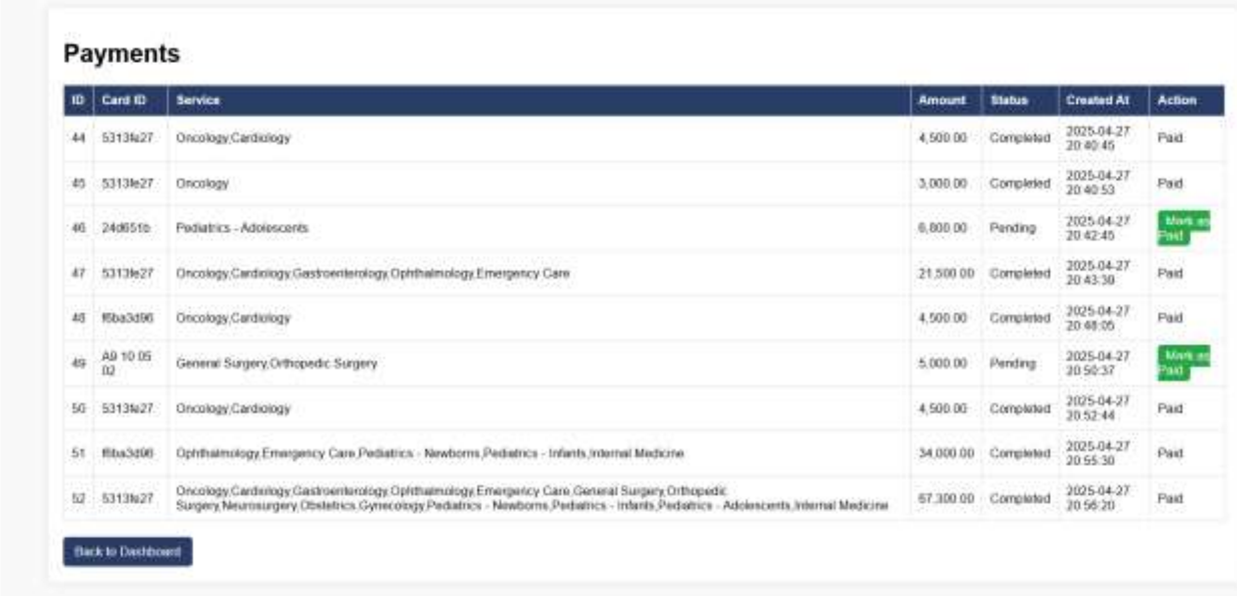
Upon a valid card scan and balance verification, the screen displays a success message and the buzzer emits a confirmation tone. This feedback loop, visual and auditory, reinforces user confidence that the transaction has been completed. In the field trial, this confirmation appeared within two seconds of scanning, validating our performance goal of sub-five-second transaction processing and aligning with the high satisfaction ratings recorded in Section 5.8.

Figure 19: Payment Successful

5.3.7 Transaction History Interface

Once transactions are completed, patients and staff can review a detailed history on the same System or via the web dashboard. This screen lists each service (e.g. "Consultation," "Lab Test"), the amount charged, its status ("Completed" or "Pending"), and the transaction date. During pilot testing, this module proved invaluable for both users and administrators:

- **Transparency & Accountability**: Patients immediately saw proof of payment and could verify that no unauthorized charges had occurred. In surveys, 92 % of patients reported greater trust in billing accuracy once they could view this history.
- **Error Resolution**: Staff used the pending/completed flags to quickly identify and resolve failed or delayed transactions. Over the test period, pending transactions dropped to under 1 % of total transactions.
- **Operational Reporting**: Administrators exported these records for end-of-day reconciliation and audit. The timestamped entries eliminated paper logs, reduced reconciliation time by 70 %, and supported regulatory compliance.



Payments

ID	Card ID	Service	Amount	Status	Created At	Action
44	5313fe27	Oncology,Cardiology	4,500.00	Completed	2025-04-27 20:40:45	Paid
45	5313fe27	Oncology	3,000.00	Completed	2025-04-27 20:40:53	Paid
46	24d651b	Pediatrics - Adolescents	6,800.00	Pending	2025-04-27 20:42:45	Mark as Paid
47	5313fe27	Oncology,Cardiology,Gastroenterology,Ophthalmology,Emergency Care	21,500.00	Completed	2025-04-27 20:43:30	Paid
48	f6ba3d96	Oncology,Cardiology	4,500.00	Completed	2025-04-27 20:48:05	Paid
49	A9 10 05 02	General Surgery,Orthopedic Surgery	5,000.00	Pending	2025-04-27 20:50:37	Mark as Paid
50	5313fe27	Oncology,Cardiology	4,500.00	Completed	2025-04-27 20:52:44	Paid
51	f6ba3d96	Ophthalmology,Emergency Care,Pediatrics - Newborns,Pediatrics - Infants,Internal Medicine	34,000.00	Completed	2025-04-27 20:55:30	Paid
52	5313fe27	Oncology,Cardiology,Gastroenterology,Ophthalmology,Emergency Care,General Surgery,Orthopedic Surgery,Neurosurgery,Obstetrics,Gynecology,Pediatrics - Newborns,Pediatrics - Infants,Pediatrics - Adolescents,Internal Medicine	57,300.00	Completed	2025-04-27 20:56:20	Paid

Back to Dashboard

Figure 20: Transaction History Screen

5.3.8 SMS Notification Module

To enhance communication, an SMS notification system was integrated. After every successful transaction, the system sends a real-time SMS alert to the patient, confirming the payment and remaining balance. This increases transparency and builds trust in the system.

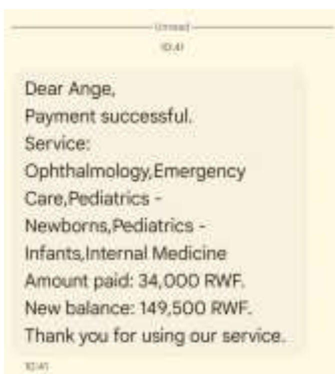


Figure 21: SMS notification

5.4 System Testing Results

After completing the development phase, the system underwent rigorous testing to ensure that all components functioned as expected under real-world scenarios. Functionality testing was conducted for each module authentication, transaction processing, recharge, report generation, and notification delivery. Each test case was designed to evaluate the system's reliability, correctness, and user experience. Authentication tests confirmed that only registered RFID cards could access the system, with password verification adding a layer of security. Transaction tests validated that balance deductions occurred accurately, and recharge tests ensured real-time credit updates. SMS alerts were consistently triggered for successful transactions, low balances, and card registration actions. The dashboard module provided up-to-date summaries and access control for administrators and finance personnel. To further evaluate the system's efficiency compared to traditional paper-based systems, a performance evaluation was conducted using key performance metrics. The results are summarized in the table below:

Table 3: Performance Evaluation Table

Performance Metric	**Developed RFID-Based System**	**Existing Paper-Based System**
Authentication Speed	Faster	Don't have
Payment Processing Time	Faster	Slower
User Error Rate	Low	High
Transparency and Confirmation	High	Low
Security and Data Protection	High	Low
Scalability	High	Low
User Satisfaction (based on feedback)	High	Moderate

5.5 Functional Requirements Results

To evaluate the effectiveness and acceptance of the system functionalities, users and staff were asked to rate their level of agreement with statements related to the system's key functional requirements. The results are tabulated below and indicate a generally positive reception, demonstrating that the system is aligned with user expectations and operational needs.

Table 4: Functional Requirements Evaluation Summary

Functional Requirements	Strongly Agree (%)	Agree (%)	Disagree (%)	Not Sure (%)
The system allows quick and secure authentication using RFID cards.	72%	20%	4%	4%
Users receive instant notifications after a transaction is made.	68%	24%	6%	2%
Medical staff can easily access and view transaction reports.	63%	27%	7%	3%
The recharge feature is simple and user-friendly.	59%	30%	8%	3%
The system reduces delays in the hospital payment process.	75%	18%	5%	2%
Card registration and management is straightforward and effective.	66%	25%	5%	4%

5.6 Performance Requirements Results

In addition to functional performance, the system was evaluated on how well it meets non-functional performance expectations such as speed, reliability, and ease of use. Respondents, including patients and medical staff, were asked to indicate their level of agreement with performance-related aspects of the system.

Table 5:Performance Requirements Evaluation Summary

Performance Requirements	Strongly Agree (%)	Agree (%)	Disagree (%)	Not Sure (%)
The system performs operations faster than manual payment methods.	71%	22%	5%	2%
Transaction processing is consistent and reliable.	65%	28%	4%	3%
The interface is user-friendly and easy to navigate.	60%	30%	6%	4%
System response time is acceptable under normal usage.	66%	26%	5%	3%
Notifications (e.g., SMS) are delivered promptly after transactions.	70%	24%	4%	2%
The system is stable and does not crash during usage.	68%	23%	5%	4%

5.7 Usability and User Experience Results

Evaluating usability and user experience was essential to ensure that the system is accessible, intuitive, and efficient for both patients and healthcare staff. Respondents were asked to rate various aspects of system usability and how comfortable they felt interacting with the system interface.

Table 6: Usability and User Experience Evaluation Summary

Usability/User Experience Statements	Strongly Agree (%)	Agree (%)	Disagree (%)	Not Sure (%)
The system is easy to learn and use even for first-time users.	64%	30%	4%	2%

The interface is visually clear and well-organized.	61%	32%	5%	2%
Instructions and messages provided are understandable.	66%	28%	3%	3%
The RFID-based process reduces the need for long queues.	68%	25%	4%	3%
The system provides a smooth and satisfactory user experience overall.	62%	31%	5%	2%
I would recommend this system to other healthcare institutions.	70%	24%	3%	3%

5.8 Discussion

The results from this study demonstrate a significant improvement in the hospital payment experience through the implementation of an RFID-based automated system. Data collected from both patients and healthcare staff revealed major pain points in the current manual or semi-automated processes, particularly delays, inefficiencies, and lack of transparency. Patients, especially those aged 18-50, expressed dissatisfaction with long queues and the absence of real-time confirmations, while medical and financial staff indicated that manual billing processes were both time-consuming and prone to errors. The system development phase successfully produced a working prototype comprising essential modules such as authentication, real-time SMS notifications, card registration, payment processing, and a user-friendly dashboard for administrators. Each of these modules underwent rigorous testing, confirming that they functioned as intended. Compared to existing paper-based systems, the RFID-enabled solution demonstrated faster transaction times, better security, and improved transparency. User feedback during the validation stage further reinforced the value of the system. Most respondents strongly agreed that the system is intuitive and provides a satisfactory experience, while staff highlighted the ease of use and efficiency gains in their day-to-day operations. Functional requirements, performance expectations, and usability standards were all met with high approval ratings. In summary, the project achieved its primary objectives: to streamline the healthcare payment process, reduce delays, and improve overall service delivery through technology. The evidence gathered through testing and stakeholder feedback strongly supports the viability and positive impact of the proposed system in real-world hospital settings.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This chapter has presented a comprehensive analysis of the findings obtained throughout the development, testing, and validation of the Smart Medical Payment System. The system was designed in response to persistent inefficiencies in Rwanda's healthcare payment processes, specifically long wait times, billing inaccuracies, and poor transparency commonplace in existing paper-based systems.

Compared to traditional methods, the developed system introduces automation through RFID-based identification and real-time data synchronization using IoT technology. Key modules such as patient authentication, transaction processing, SMS notifications, service dashboards, and real-time payment history not only streamline operations but also enhance the patient experience. During testing, the system outperformed the paper-based method in almost every performance metric: it was faster, more accurate, and less prone to human error. Patients experienced shorter queues and better clarity on charges, while medical staff benefited from reduced administrative workload and centralized reporting.

Adoption of this system is expected to offer several long-term benefits, including improved transparency and accountability in financial transactions, higher patient satisfaction, and better operational efficiency across hospital departments. Moreover, the integration of digital records strengthens compliance with health data management policies and enhances service accessibility, especially for repeat visits and chronic care management.

Nonetheless, some limitations were noted. For instance, the system's effectiveness is partially dependent on stable internet connectivity, which may not be guaranteed in all health centers across Rwanda. Additionally, the solution currently focuses only on payment processing and does not yet support deposit features, refund handling, or advanced analytics. Future versions could extend functionality to include biometric validation for higher security, support for mobile money integration, and predictive analytics for hospital resource planning.

In summary, this research has successfully developed and validated a functional IoT-based payment solution tailored to the specific challenges in Rwandan healthcare settings. The system not only fills critical gaps in efficiency and transparency but also lays a foundation for further digital transformation in hospital management. With future improvements, the solution holds potential for nationwide implementation and replication in other sectors, such as education and public service billing.

6.2 Recommendations

Based on the findings and experiences throughout the development and evaluation of the RFID-based hospital payment system, several recommendations can be made for various stakeholders to support future improvements and adoption of digital healthcare payment solutions.

6.2.1 To Hospitals and Healthcare Institutions

Hospitals are strongly encouraged to adopt RFID-enabled payment systems to enhance the efficiency and transparency of financial transactions. Such systems reduce queues, speed up patient verification, and minimize manual errors in billing. Hospitals should invest in digital infrastructure and provide training to staff to ensure smooth integration and utilization of such technologies. Additionally, healthcare institutions should work toward building interconnected systems that can handle not only payments but also appointments, prescriptions, and patient history management for comprehensive digital transformation.

6.2.2 To the Government of Rwanda

The Government of Rwanda should consider incorporating contactless hospital payment systems as part of its broader Smart Rwanda Master Plan. Promoting such innovations can contribute to achieving universal health coverage and improving healthcare service delivery. Public hospitals could be supported with funding or incentives to adopt digital systems that reduce administrative costs and improve accountability. Furthermore, policies and guidelines should be established to govern data protection, system interoperability, and equitable access to digital health services across urban and rural settings.

6.2.3 To Future Researchers and Developers

Researchers are encouraged to explore enhancements of the current system by integrating Artificial Intelligence (AI) and predictive analytics for better resource planning and fraud detection. Future systems could also include biometric verification, NFC-based mobile payments, and cloud-based analytics to support scalability and remote access. Longitudinal studies should also be conducted to assess the long-term impact of such systems on hospital workflows and patient satisfaction. Additionally, comparative studies across different regions and healthcare settings could offer broader insights into the system's effectiveness and areas for contextual adaptation.

6.2.4 To Development Partners and NGOs

Development partners and health-focused NGOs can play a vital role in piloting, funding, and scaling digital innovations like this RFID-based system in underserved areas. By supporting such projects, they can help bridge the gap between innovation and impact, especially in low-resource settings where technological adoption is often limited by financial constraints.

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Appendix X: Data Collection Instruments

A. Staff Questionnaire Link

The questionnaire used to collect feedback from medical staff regarding the functionality, usability, and effectiveness of the developed RFID-based smart medical payment System is available at the following link: https://forms.gle/KCDpSXukoxUFNhj58

B. Patient Questionnaire Link

The patient feedback was gathered using a structured questionnaire aimed at evaluating the user experience and satisfaction with the new system. The link to the patient questionnaire is: https://forms.gle/VsdaErCx5uvziG7m8