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Design and Implementation of an IoT-Enabled Smart Printer ATM using Embedded System & Wireless Communication

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ABSTRACT

This paper presents the design and implementation of an IoT-enabled Smart Printer ATM that integrates embedded systems with wireless communication technologies to deliver secure and automated document printing services. The system is designed to provide on-demand, self-service printing in public and semi-public environments such as universities, offices, libraries, and transportation hubs, reducing dependency on manual service providers.

The proposed architecture consists of a microcontroller-based embedded unit interfaced with a high- speed printer, wireless communication modules (Wi-Fi/GSM), cloud storage, and a user authentication interface. Users upload documents through a web or mobile application, and the files are securely stored on a cloud server. Authentication mechanisms such as QR code ensure secure access to the printing service. Upon successful verification and payment confirmation, the embedded controller retrieves the document via wireless communication and executes the print command.

IoT connectivity enables real-time monitoring of system parameters including paper availability, ink levels, device health status, and transaction logs. This allows administrators to perform remote diagnostics, predictive maintenance, and efficient resource management. Secure data transmission protocols are implemented to protect user documents and ensure privacy.

Keywords:- Internet of Things (IoT), Smart Printer ATM, Embedded Systems, Wireless Communication, Cloud Storage, Secure Document Printing, User Authentication, QR Code, , Remote Monitoring, Predictive Maintenance, Secure Data Transmission, Self-Service Kiosk Systems

1.EMBEDDED SYSTEM ARCHITECTURE

Embedded system architecture The rapid evolution of the Internet of Things (IoT) has transformed traditional standalone devices into interconnected smart systems capable of real-time communication, monitoring, and control [1]. IoT technology enables seamless integration between embedded hardware, cloud platforms, and user interfaces, thereby enhancing automation and operational efficiency across multiple domains. In public and semi-public environments such as universities, offices, libraries, and transportation hubs, the demand for secure, self-service solutions has significantly increased. Automated kiosks and smart terminals have emerged as practical solutions to reduce manual intervention and improve service accessibility [2]. Conventional printing services typically depend on centralized facilities or human operators, resulting in delays, higher operational costs, and limited accessibility outside working hours. Furthermore, concerns related to document confidentiality and unauthorized access remain critical challenges in shared printing environments. Existing self- service printing kiosks often lack robust authentication mechanisms, remote monitoring capabilities, and secure cloud integration [3]. These limitations highlight the need for an intelligent, secure, and scalable printing solution that leverages modern communication technologies.

Embedded systems play a vital role in enabling intelligent automation by integrating microcontrollers, sensors, and peripheral devices into compact and efficient architectures. When combined with wireless communication technologies such as Wi-Fi and GSM, embedded systems facilitate remote data exchange and centralized system management [4]. The incorporation of cloud storage further enhances system functionality by allowing users to upload and securely store documents before initiating print commands. Cloud-based platforms provide scalability, secure access control, and data redundancy, making them suitable for distributed smart kiosk deployments [5].

Security is a fundamental requirement in IoT-enabled public access systems. Unauthorized document retrieval, data interception, and misuse of services can compromise user privacy and system reliability. To address these challenges, authentication mechanisms such as One-Time Password (OTP), QR code verification, and RFID-

based access control can be implemented to ensure secure user validation [6]. Additionally, encrypted communication protocols protect data transmission between the user interface, cloud server, and embedded controller, thereby maintaining confidentiality and integrity.

This research presents the design and implementation of an IoT-enabled Smart Printer ATM using embedded systems and wireless communication technologies. The proposed system integrates a microcontroller-based control unit, high-speed printer interface, cloud storage platform, and secure authentication modules to provide on-demand, automated document printing services. IoT connectivity enables real-time monitoring of critical system parameters, including paper availability, ink levels, device health status, and transaction logs. These features support remote diagnostics, predictive maintenance, and efficient resource management.

The primary objective of this work is to develop a secure, scalable, and cost-effective smart printing solution that enhances user convenience while ensuring data privacy and operational reliability. By combining embedded control, wireless communication, cloud integration, and multi-factor authentication, the proposed Smart Printer ATM contributes to the advancement of intelligent self-service infrastructure within smart campus and smart city ecosystems.

1.1 System Overview

The rapid expansion of Internet of Things (IoT) technologies has enabled the transformation of conventional standalone devices into intelligent, interconnected systems capable of real-time communication and automated control. In recent years, public and semi-public environments such as universities, offices, libraries, and transportation hubs have increasingly demanded secure and self-service solutions to improve user convenience and operational efficiency. Traditional printing services in these environments often depend on manual supervision, fixed operating hours, and centralized infrastructure, which can lead to delays, higher maintenance costs, and limited accessibility.

1.1.1 System Overview and Motivation

The proposed IoT-enabled Smart Printer ATM addresses these limitations by integrating embedded systems with wireless communication technologies to deliver secure, automated, and on-demand document printing services. The system allows users to upload documents through a web or mobile application, where files are securely stored on a cloud server. Upon authentication and payment confirmation, the embedded controller retrieves the document via wireless communication and executes the print operation without requiring human intervention. This approach significantly reduces dependency on service personnel while enhancing availability and scalability.

Security and privacy are critical considerations in shared printing environments. Unauthorized access to confidential documents and insecure transmission channels pose substantial risks. To mitigate these challenges, the proposed system incorporates authentication mechanisms such as QR code validation based access control. Additionally, secure communication protocols are implemented to ensure encrypted data transfer between user devices, cloud infrastructure, and the embedded printing unit.

After printing document successfully, User document is automatically vanished from the system .User data will not misused/published by our system for any wrong purpose.

Another key motivation behind this research is the need for intelligent monitoring and maintenance of public service devices. IoT connectivity enables real-time tracking of system parameters such as paper availability, ink levels, device status, and transaction records. This facilitates remote diagnostics, predictive maintenance, and efficient resource management by administrators. Consequently, the Smart Printer ATM not only enhances user experience but also improves operational reliability and cost-effectiveness.

Overall, the integration of embedded control systems, wireless communication modules, cloud storage, and secure authentication mechanisms provides a comprehensive solution for modern automated printing services. The proposed design contributes to the development of smart infrastructure by offering a scalable, secure, and efficient self-service printing platform suitable for smart campuses and smart city applications.

1.1.2 System Architecture and Operational Framework

The proposed IoT-enabled Smart Printer ATM is designed with a modular and scalable architecture that integrates embedded hardware, wireless communication modules, cloud infrastructure, and a secure user interface. The core of the system consists of a microcontroller-based embedded unit responsible for controlling the printer mechanism, processing authentication data, and managing communication with external servers. This embedded controller acts as the central processing unit of the Smart Printer ATM, ensuring synchronized coordination between hardware peripherals and software components.

The operational workflow begins when a user uploads a document through a web or mobile application. The uploaded file is securely stored on a cloud server, enabling remote accessibility and centralized data management. Cloud integration ensures scalability, secure storage, and efficient retrieval of documents upon request. Once the user reaches the Smart Printer ATM, authentication is performed using secure verification methods such as QR code scanning based access control. These mechanisms prevent unauthorized usage and

protect sensitive documents from unintended access.

After successful authentication and payment verification, the embedded controller establishes a secure wireless connection via Wi-Fi or GSM to retrieve the requested document from the cloud server. Encrypted communication protocols are implemented to safeguard data during transmission. The controller then processes the document and sends the appropriate commands to the high-speed printer to execute the print job. This automated workflow eliminates manual intervention and ensures quick and reliable service delivery.

In addition to document printing, the system incorporates IoT-based monitoring capabilities. Sensors and status-check mechanisms continuously track parameters such as paper levels, ink availability, power status, and device health. These data are transmitted to the cloud platform, enabling administrators to perform remote diagnostics, analyze usage patterns, and implement predictive maintenance strategies. Real-time alerts can be generated in case of faults or resource shortages, thereby minimizing downtime and improving service continuity.

The overall architectural framework emphasizes security, efficiency, and scalability. By combining embedded system control, wireless communication, cloud-based storage, and intelligent monitoring, the Smart Printer ATM provides a robust solution for automated document printing in public and semi-public environments. This structured operational model supports the development of reliable, cost-effective, and user-friendly self-service infrastructure aligned with modern smart campus and smart city initiatives.

2. SYSTEM DESIGN AND IMPLEMENTATION

The design and implementation of the IoT-enabled Smart Printer ATM focus on developing a secure, scalable, and automated self-service printing system by integrating embedded systems, wireless communication technologies, and cloud infrastructure. The system architecture is structured into hardware and software modules that operate collaboratively to ensure seamless document processing and secure user interaction.

The hardware module consists of a microcontroller-based embedded unit interfaced with a high-speed printer, wireless communication modules (Wi-Fi/GSM), authentication devices (RFID reader/QR scanner), display interface, payment module, and status monitoring sensors. The embedded controller acts as the core processing unit, managing user authentication, communication with the cloud server, and execution of print commands. Sensors integrated into the system continuously monitor parameters such as paper availability, ink levels, and device health status to maintain operational reliability.

The software architecture includes a web/mobile application for document upload, a cloud server for secure storage and management of files, and firmware programmed into the embedded controller. Users upload documents to the cloud platform, where files are stored in encrypted format to ensure data confidentiality. Upon arriving at the Smart Printer ATM, users authenticate themselves using OTP, QR code, or RFID-based verification. After successful authentication and payment confirmation, the embedded system retrieves the selected document via a secure wireless connection and initiates the printing process.

IoT connectivity enables real-time data exchange between the printer ATM and the cloud server. Transaction logs, usage statistics, and device performance metrics are continuously updated, allowing administrators to perform remote diagnostics and predictive maintenance. This integrated design not only enhances system efficiency but also reduces operational downtime and maintenance costs.

Overall, the proposed system demonstrates a comprehensive approach to implementing a secure and intelligent public printing solution. By combining embedded control, wireless communication, cloud storage, and multi-factor authentication, the Smart Printer ATM provides an efficient and user-friendly platform suitable for modern smart infrastructure environments.

Fig -1 Smart ATM Printer

2.1The Hardware Architecture

The hardware architecture of the Smart Printer ATM consists of several interconnected modules that work together to provide automated printing functionality. The embedded controller serves as the central processing unit, coordinating communication between the user interface, sensors, payment module, and printer. Peripheral components such as paper sensors, door sensors, and ink monitoring units provide real-time feedback to ensure reliable operation.

The printer unit is interfaced through USB or serial communication, enabling high-speed document printing. The power supply module is designed to provide stable voltage regulation for continuous public usage. Additionally, the enclosure is designed with security considerations to prevent unauthorized physical access. The hardware design emphasizes low power consumption, compact size, and high reliability for long-term deployment

Table -1: HARDWARE SPECIFICATIONS OF SMART PRINTER ATM

Component	Model/Type	Specification	Function	Interface
Microcontroller	ESP32	Dual-core, 240 MHz	Main control unit	UART/SPI
Printer	Laser Printer	20–30 ppm	Document printing	USB
Wi-Fi Module	(ESP32)	802.11 b/g/n	Cloud connectivity	TCP/IP
QR Scanner	CMOS Scanner	1D/2D support	User authentication	USB/UART
LCD Display	TFT/LCD	16*2 Cm	User interface	SPI
Payment Module	UPI	Digital payment	Transaction handling	API/UART
Sensors	Paper/Ink sensors	Digital output	Status monitoring	GPI
Power Supply	SMPS	12 V/5 V	System power	—
Switch (Cancel/Reset)	Push Button	5V	Data Reset/Cancel	GPI

2.2 Software Architecture

The software architecture of the Smart Printer ATM is developed to ensure efficient job management, secure communication, and user-friendly operation. The embedded firmware communicates continuously with the cloud server to retrieve authenticated print jobs and update device status. The backend server manages user accounts, document storage, payment verification, and print queue scheduling.

Error detection and handling mechanisms are incorporated to identify issues such as printer faults, paper shortages, or network failures. The graphical user interface is designed to be intuitive and responsive, allowing users to upload documents, configure print settings, and complete digital payments with minimal effort. The modular software framework supports future enhancements such as analytics integration, multilingual support, and remote firmware updates.

- User document upload and validation
- Secure digital payment processing
- Real-time printer status monitoring
- Cloud-based print queue management

3. SYSTEM ARCHITECTURE AND DESIGN METHODOLOGY

The proposed research work focuses on the design and development of an IoT-enabled Smart Printer ATM that allows users to securely print documents through online payment and wireless communication. The system architecture integrates embedded hardware, cloud connectivity, and user authentication mechanisms to provide an efficient self-service printing solution. The overall design emphasizes reliability, scalability, and low power consumption to ensure continuous operation in public environments. By combining IoT technology with an embedded controller, the system enables remote job submission, real-time monitoring, and automated print management.

The design methodology follows a modular approach consisting of the user interface module, payment gateway module, embedded control unit, wireless communication interface, and printer subsystem. Each module is developed and tested independently to improve system robustness and ease of maintenance. The embedded processor coordinates data flow between the cloud server and the printer while ensuring secure transaction handling. Wireless connectivity such as Wi-Fi or GSM enables users to upload documents remotely and receive status updates. The proposed architecture aims to reduce manual intervention, improve user convenience, and provide a cost-effective smart printing infrastructure suitable for smart city and campus environments.

3.1 Hardware Architecture of the Smart Printer ATM

The hardware architecture of the proposed IoT-enabled Smart Printer ATM is designed to provide reliable and efficient document printing through an embedded platform. The system mainly consists of a microcontroller unit, wireless communication module, payment interface, display unit, and printer mechanism. The embedded controller acts as the central processing unit that manages user requests, validates payment status, and controls

the printing operation. Proper interfacing between hardware components ensures smooth data flow and minimizes system latency.

The wireless communication module enables the device to connect with the cloud server for receiving print jobs and updating transaction status in real time. A secure power management unit is incorporated to maintain stable operation in public deployment environments. The hardware design focuses on compact size, low power consumption, and ease of maintenance, making the Smart Printer ATM suitable for smart campuses, offices, and public service locations.

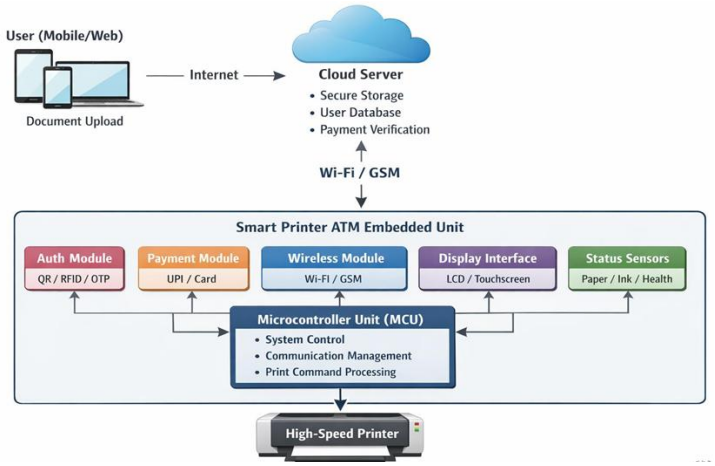

Fig -2 : Hardware Architecture of the Smart Printer ATM

4. CONCLUSIONS

This paper presented the design and implementation of an IoT-enabled Smart Printer ATM using embedded systems and wireless communication. The proposed system provides a fully automated, secure, and user-friendly printing solution suitable for public environments. Integration of IoT monitoring improves system reliability and reduces maintenance effort. Experimental results demonstrate reduced waiting time, stable connectivity, and efficient job handling. The architecture is scalable and cost effective for smart city deployment. Future work may focus on AI-based predictive maintenance, enhanced security mechanisms, and renewable energy integration.

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6.REFERENCES

[1]. J. S. Yalli, M. H. Hasan, and A. A. Badawi, “Internet of Things (IoT): Origins, Embedded Technologies, Smart Applications, and Its Growth in the Last Decade,” *IEEE Access*, vol. 12, pp. 91357–91382, June 2024.

[2]. F. Amin et al., “Latest advancements and prospects in the next-generation of Internet of Things technologies,”
PeerJ Computer Science, vol. 10, e2434, Oct. 2024.

[3]. S. Tharoor and V. Prabhakar, “Design and Implementation of IoT-Enabled Embedded Systems for Autonomous Robotics,” *IJMSERH*, vol. 13, no. 2, pp. 1–10, Apr.–Jun. 2025.

[4]. “Hardware comparison for real-time IoT applications using Arduino UNO, Node MCU ESP8266 and ESP32,” *JETIR*, vol. 11, no. 1, Jan. 2024.

[5] Raj, P. Internet of Things: Principles and Paradigms, Morgan Kaufmann, 2016 — foundational reference on IoT architectures, protocols, and design principles.

[6] Rao, B. & Prasad, R. “IoT-Based Automation for Smart Cities,” IEEE Communications Magazine, 2018 — overview of IoT connectivity, communication stacks, and practical deployments.

[7] Mahendrachri, Abhishek S. Shingadi, Bhoomika N., et al. Smart ATM Security System — IoT-based ATM security system using ESP32, sensors, and GSM. (IJIREEICE, 2025) — relevant for ATM system design and embedded IoT implementation.

[8] Kaushalya Thopate et al. Smart ATM Security and Alert System with Real-Time Monitoring — IoT system using NodeMCU ESP8266 and wireless communications for real-time alerts. (International Journal on Recent and Innovation Trends in Computing and Communication, 2023).

[9] IEEE – IoT Based Smart Health Care ATM System to Improve Quality Life — example of an IoT-ATM integrated system in IEEE Xplore (2024/2025).