An IoT-based Pay-As-You-Go System for Motorcycle Loan Repayment and Monitoring

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ABSTRACT
This paper presents a framework for affordable motorcycle ownership using Internet of Things (IoT) technologies and a micro-financing repayment model. The system integrates GPS, GSM, microcontrollers, and an intuitive user interface to enable lenders to track motorcycle usage, automate billing, and remotely manage motorcycles purchased through loan schemes. Prototype testing evaluated data accuracy, repayment computation, and system responsiveness. Results demonstrated reliable travel data capture, transparent repayment records, and effective fleet monitoring via a centralized dashboard. Automated monitoring improved accountability, reduced misuse, and enhanced lender borrower communication. These findings indicate that the platform provides a scalable, digitally driven approach to mobility financing, increasing operational efficiency, transparency, and equitable access to transportation. By supporting sustainable, income-generating mobility opportunities, the system demonstrates the potential of IoT-enabled platforms to optimize loan management and foster trust in digitally mediated transportation services.

General Terms
IoT Systems, Micro-Financing, Real-Time Monitoring, Asset Tracking, Remote Management, Usage-Based Billing, Data-Driven Decision Making, Fleet Management, Youth Empowerment, Digital Lending Platforms, Mobile Connectivity, Location-Based Services, Risk Mitigation, Smart Mobility.

Keywords
IoT, Motorcycle Lending, Pay-As-You-Go Model, GPS Tracking, GSM Communication, Micro-Financing, Real-Time Monitoring, Usage-Based Repayment, Remote Asset Management, Sensor Data, Fleet Management, Youth Empowerment, Digital Mobility Solutions, Asset Security.

1. INTRODUCTION
Youth unemployment remains a significant socio-economic challenge in many countries, with many young adults unable to access productive opportunities due to limited capital and restricted credit options. The motorcycle transport sector has emerged as a vital source of income generation within informal urban and rural economies, offering an accessible pathway to self-employment. Despite this growing reliance on motorcycles for livelihood creation, ownership remains out of reach for many low-income youths because of high upfront purchasing costs and rigid loan repayment schemes that fail to reflect daily income variability.

Conventional financing models further intensify these challenges. Borrowers are often burdened with fixed repayment obligations that are poorly aligned with fluctuating earnings, while lenders face persistent risks related to loan defaults, recovery difficulties, and asset theft. Existing literature highlights these limitations, noting that current micro-lending structures inadequately respond to borrowers' financial instability and expose lenders to substantial operational risks [7]. Although IoT-based tracking technologies have been widely adopted for fleet monitoring and asset management, they rarely integrate real-time usage metrics into the financial logic governing loan repayment, leaving a critical gap in the design of equitable and secure asset-financing mechanisms.

To address these challenges, this paper proposes a smart pay-as-you-go motorcycle model that leverages IoT technology to link loan repayments directly to actual motorcycle usage, measured in kilometers. The system incorporates embedded sensors, GPS modules, and GSM connectivity to enable real-time asset monitoring, dynamic repayment calculations, and remote-control capabilities in cases of non-payment or theft. By integrating usage data with a flexible financial engine, the proposed solution enhances fairness, transparency, and risk mitigation for both borrowers and lenders. This paper presents the system's design and architecture, reports on the testing and evaluation of a working prototype, and discusses the implications of this approach for digital micro-lending, financial inclusion, and mobility entrepreneurship.

2. RELATED WORK
Motorcycle-based transport systems have grown rapidly across Sub-Saharan Africa over the past decade, becoming a crucial source of employment and income generation for young people [10]. In Kenya, for example, more than 1.5 million motorcycles are in active use within the transport service sector, supporting thousands of livelihoods nationwide [6], [15]. Despite this socio-economic relevance, motorcycle ownership remains restricted for many potential riders due to high acquisition costs and financing structures that are not tailored to low-income or unbanked populations.

Several commercial financing models have emerged to address this gap, including Watu Credit, M-KOPA Mobility, and Mogo, which provide structured loan products equipped with GPS-based tracking and mobile money repayment options [1], [2], [9]. These solutions typically employ telematics to enhance lender oversight, and some incorporate remote immobilization when borrowers default. However, most rely on fixed or semi-flexible repayment schedules that do not incorporate real-time usage data. Their proprietary nature also limits adaptability, cost-effectiveness, and scalability for community-based lenders, cooperatives, or local governments.

In parallel, a substantial body of research in IoT and embedded systems has investigated asset tracking using microcontrollers, GPS modules, and GSM communication. Such systems have been widely implemented in fleet management, logistics, and urban transportation applications [3], [5], [8]. While these technologies offer reliable real-time monitoring capabilities, their integration with embedded financial mechanisms—such as distance-based billing or automated loan enforcement—remains limited. Existing implementations focus primarily on location tracking rather than linking sensor-derived usage metrics to repayment models.

A more relevant precedent can be found in the energy sector, where Pay-As-You-Go (PAYG) solar systems have demonstrated the potential of IoT-enabled prepayment technologies in low-income and low-connectivity settings. Companies such as M-KOPA Solar and Azuri Technologies have shown that GSM-connected devices can support secure, scalable systems for automated payments and remote device control [2], [4]. Although these models have proven successful in energy access, their application within the mobility sector has been minimal.

This paper builds on these strands of work by proposing a hybrid, usage-linked financing model that integrates GPS based tracking, microcontroller automation, and distance-triggered financial enforcement into a unified platform. The key contributions of this study include:

(i) integration of sensor derived usage data with dynamic repayment logic;

(ii) remote immobilization to enhance security and enforceability;

(iii) adoption of open-source hardware for cost effective deployment; and

(iv) a modular, web-based dashboard for real time lender and rider interaction.

Unlike existing proprietary systems, the PAYG approach developed in this study is designed for easy adoption by micro-lenders, SACCOs, NGOs, and public-sector youth programs, addressing key challenges related to affordability, flexibility, and scalability.

3. PROPOSED PAYG SYSTEM

The system offers a novel integration of hardware and software components to monitor, manage, and enforce motorcycle loan repayment based on real-time distance traveled. Its architecture follows a four-layered design as illustrated in Figure 1.

The system architecture integrates satellite-based positioning, embedded control, and web-enabled data processing to facilitate remote tracking and automated computation of operational parameters. A GPS receiver acquires real-time location data transmitted from navigation satellites.

Fig. 1. above, Proposed PAYG System architecture showing the GPS receiver, microcontroller, communication module, web server, and database for remote monitoring

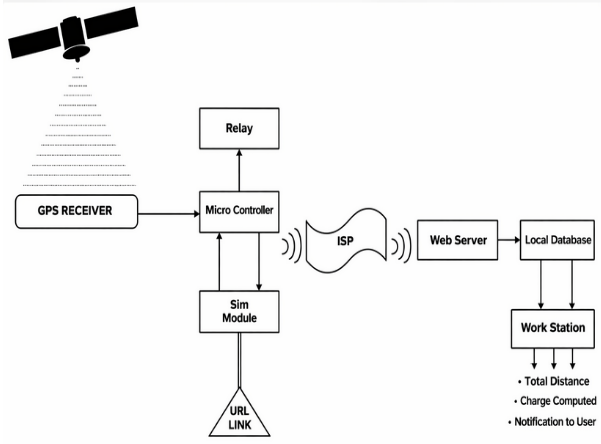

Figure 1:System Architecture

This data is forwarded to a microcontroller, which functions as the central processing unit of the embedded subsystem. The microcontroller simultaneously interfaces with a relay module for actuation control and a SIM communication module for data transmission.

Through the SIM module, the system establishes a cellular link that enables the microcontroller to send encoded URL-based telemetry to an Internet Service Provider (ISP). The ISP forwards the transmitted data to a remote web server, where the information is stored in a local database for further processing. A workstation retrieves the stored records and computes key metrics such as total distance traveled and corresponding charges. The workstation also manages user notifications, completing the data flow from physical sensing to information delivery. This layered architecture ensures reliable communication, efficient data handling, and scalability for real-time monitoring applications.

3.1 Hardware Layer

The system integrates multiple hardware components to enable intelligent monitoring, communication, and control in a motorcycle-based tracking and security framework [5][10][11][13]. At its core, an Arduino Uno microcontroller coordinates all sensing and communication processes, serving as the primary controller for device operation. Geolocation data are continuously acquired through the Neo-6M GPS module, which supplies the microcontroller with real-time positional information essential for computing the distance traveled. A SIM5320E GSM module facilitates dependable two-way communication between the field device and the backend server, ensuring that operational data and system commands are exchanged over cellular networks. To enhance system security, a piezoelectric sensor is incorporated to detect unauthorized access or physical tampering with the motorcycle. Additionally, a relay module is employed to enable remote interruption of the motorcycle's ignition system, supporting enforced shutdown during loan default conditions or in response to security threats. This integrated configuration provides a robust, responsive, and scalable architecture suitable for real-time tracking and automated control applications.

3.2 Communication Layer

The Arduino gathers data from the GPS and piezoelectric sensor, processes it locally, and transmits it via GSM using HTTP over GPRS to a cloud-based API endpoint. This process ensures low latency and supports SMS alerts or control commands from the server.

3.3 Data Processing and Control Layer
Similar to [8] all incoming telemetry data are stored in a MariaDB relational database for structured querying and long-term archiving at the server end. A dedicated back-end logic engine processes this data to derive key operational and financial indicators. Specifically, the system computes the rider's daily travel distance, determines the corresponding loan repayment dues based on predefined financial models, and identifies potential tampering events through anomaly detection routines. In addition, the back-end can automatically trigger vehicle immobilization commands in accordance with lender-defined rules and risk thresholds. These real-time analytics capabilities enable lenders to continuously monitor rider behavior, assess repayment patterns, and enforce credit-risk mitigation measures with improved accuracy and timeliness.

3.4 User Interface Layer
A lightweight web application, developed using open-source software stacks, serves as the primary user interface for both riders and lenders. The platform delivers individualized daily summaries to riders, including total distance traveled, outstanding repayment dues, and the operational status of the on-board monitoring system. For lenders, the application provides a comprehensive dashboard that visualizes fleet wide performance metrics, real time alerts, and historical usage trends. In addition to monitoring functions, the interface incorporates enforcement tools that enable lenders to issue commands such as immobilization and configuration updates based on predefined credit-risk policies. By integrating these capabilities within an accessible web-based environment, the system enhances transparency, supports data driven decision making, and facilitates efficient management of large distributed fleets.

3.5 Design Layer
In this study, we present a working prototype supported by a complete hardware setup and system architecture that together form the foundation of the proposed platform. The prototype was implemented as a fully integrated system combining embedded hardware, firmware, and a coordinated software and data-flow pipeline. As a functional proof-of-concept, it demonstrates the practical feasibility of a deployable, low-cost IoT-based motorcycle financing solution suitable for resource-constrained environments.

The hardware module includes GPS and GSM communication units, distance-sensing components, and microcontroller-based control circuitry, enabling continuous asset monitoring and secure remote interaction. The accompanying software stack manages real-time data acquisition, usage computation, state management, device control, and communication with the backend service. By integrating these elements, the working prototype shows how asset tracking, distance based billing, and automated loan enforcement can be combined into a coherent, self-contained system ready for real world testing and potential scaling.

3.6 Hardware Setup
The core microcontroller, an Arduino Uno, was integrated with Neo-6M GPS module and SIM5320E GSM module, forming the backbone of location tracking and data transmission. A piezoelectric sensor was attached to the body casing to detect unauthorized tampering or bypass attempts. Additionally, a relay switch was installed in line with the motorcycle's ignition system to allow for remote shutdown via a server command.

All components were housed in a weatherproof, tamper resistant casing as illustrated in Figure 2 below. Power was drawn from the motorcycle battery and regulated using a buck converter to protect the electronics. The system was tested to ensure continued GPS lock and GSM communication even during bumpy rides and variable voltage conditions typically experienced during motorcycle movements.

4. RESULTS AND DISCUSSIONS
The live testing phase demonstrated reliable system performance across all major functional components. The prototype consistently acquired GPS telemetry, maintained stable cloud communication, and generated accurate distance-based billing outputs. Throughout trials conducted in semi-urban and peri-urban environments, the hardware sustained uninterrupted connectivity with both the GPS and GSM modules. The location data achieved an accuracy margin of approximately ±1.5 m, which was sufficient for precise tracking and for validating repayment computations. Furthermore, the distance derived payment calculations closely matched manually derived estimates, thereby confirming the credibility and robustness of the repayment model. Beyond technical performance, the system illustrates a transformative approach to expanding access to productive assets by integrating digital enforcement with flexible, usage-based repayments. This dual capability allows lenders to significantly reduce asset-related risk and gain real-time visibility into borrower behavior, while enabling riders to access financing without traditional constraints such as guarantor requirements. However, several operational challenges emerged during testing.

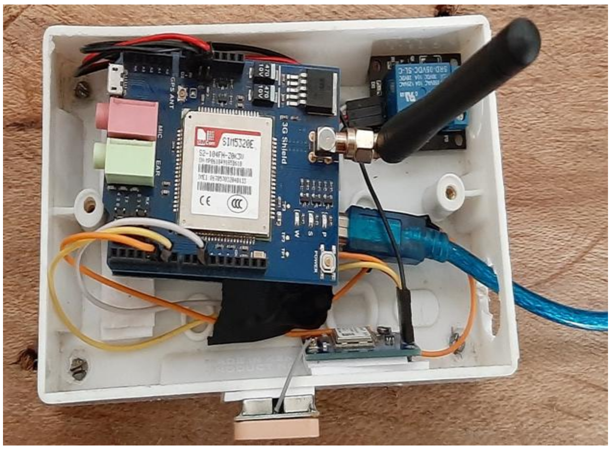

Figure 2:System Casing

Intermittent mobile network instability affected real-time data transmission, and limited microcontroller memory-imposed constraints on data buffering and processing. These issues can be mitigated by adopting optimized buffer mechanisms or transitioning to more capable IoT platforms such as the ESP32. Additionally, occasional GPS refresh delays may hinder tracking precision in rural areas with weak satellite visibility, indicating a need for enhanced positioning algorithms or hybrid localization techniques in future iterations.

To illustrate the behavior of the positioning and communication subsystems during system initialization, Figures 3 below and 4 above, present below representative excerpts from the real-time serial logs obtained during GPS acquisition and cellular network configuration. These logs provide direct insight into the step-by-step execution of device commands, responses, and network-level processes under test conditions.

Figure 3. Representative real-time serial output captured during GPS module data acquisition and tracking. The output contains standard NMEA-0183 sentences GPGLL (latitude/longitude), GPRMC (minimum GPS data), GPGGA (fix data), and GPVTG (course and ground speed) received at ~1 Hz. Each entry includes a timestamp and decoded message providing geographic coordinates, fix status, satellite count, altitude, speed, and course over ground. Variations between consecutive entries reflect normal changes in satellite geometry and signal quality. The output was used to verify GPS lock stability, update consistency, and overall module performance under test conditions.

Figure 4, Representative serial communication log showing the configuration and network initialization sequence for the cellular Internet of Things (IoT) module using Attention (AT) command instructions.

Figure 3: GPS Testing

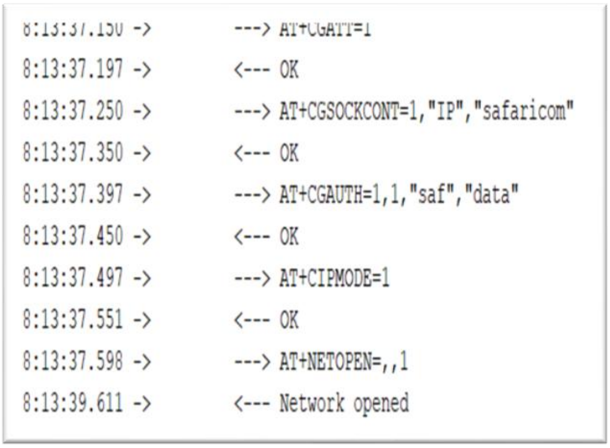

Figure 4: Network Testing

The log records the exchange between the module and the host controller during Packet Data Protocol (PDP) context setup, authentication, and network activation. Commands such as AT+CGSOCKCONT (Configure Socket Connection), AT+CGAUTH (Configure Authentication), AT+CIPMODE (Configure IP Data Mode), and AT+NETOPEN (Open Network) are issued sequentially, each followed by an OK response indicating successful execution. The final message, "Network opened," confirms successful establishment of the data connection, enabling subsequent transmission of application-layer packets during testing.

5. CONCLUSION AND RECOMMENDATION

The hardware configuration described comprising the Arduino Uno, Neo-6M GPS module, SIM5320E GSM module, piezoelectric sensor, and relay driven ignition control provides a functional foundation for motorcycle monitoring and security applications. However, transitioning this prototype level assembly into a commercial product requires substantial refinement. While the Arduino Uno effectively coordinates sensor and communication tasks in experimental settings, commercial deployment typically demands a custom-designed PCB integrating an industrial-grade microcontroller to ensure enhanced durability, reduced form factor, and optimized power efficiency. Similarly, the Neo-6M GPS and SIM5320E GSM modules are suitable for functional validation but would need to be replaced with automotive-rated positioning and communication modules that comply with regional telecommunication and electromagnetic compatibility regulations. The piezoelectric sensor and relay module can be incorporated into commercial designs, provided they are redesigned with vibration-resistant mounts, moisture protection, and fail-safe circuit architecture to withstand prolonged field conditions. Therefore, while the prototype demonstrates technical feasibility, achieving commercial production demands hardware optimization, regulatory certification, environmental hardening, and integration into a unified, manufacturable electronics platform.

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