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A Low-Cost RF-Based Accident Detection, Prevention, and Alerting System for Uganda's Aging Minibus Taxis

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Abstract

Uganda's minibus taxis, locally known as "drones," remain the backbone of public transport, yet a large share of the fleet still consists of 2011-model vehicles never fitted with crash-detection or emergency-alerting technology, and Uganda records one of the highest road-traffic fatality rates in Sub-Saharan Africa, with delayed emergency response a major driver of resulting fatalities. This study designed, built, and experimentally evaluated a low-cost Accident Detection, Prevention, and Alerting System tailored to these older vehicles. An Arduino Uno (ATmega328P) microcontroller integrates an MPU6050 accelerometer/gyroscope for impact detection, an MQ-2 sensor for driver alcohol screening, a Hall-effect sensor for speed monitoring, a seatbelt switch, and a 433 MHz RF transceiver pair for wireless alerting to a receiver unit. The prototype was benchmarked through controlled drop tests, calibrated gas exposure, and speed-sensor trials on a simulated 2011-minibus rig. The system achieved 92% accident-detection accuracy above a 3g threshold, 90% alcohol-detection reliability above 300 ppm, speed-monitoring accuracy within ±5 km/h, 98% RF alert-delivery success over 100 m, and a 30% reduction in simulated emergency-response time, at a total component cost of approximately UGX 115,000. The findings confirm RF-based retrofitting as a technically feasible, low-cost route to improving safety in Uganda's aging commercial-vehicle fleet. Fleet-wide field trials, GPS integration, and solar-powered supply are recommended as next steps toward deployment.

Keywords: ***accident detection; RF communication; road safety; retrofit vehicle-safety systems; Uganda minibus taxis***

Introduction and Background

Public road transport in Uganda depends heavily on privately owned minibus taxis, locally called "drones," a large proportion of which are 2011-model imports that have remained in continuous service for over a decade. These vehicles form the backbone of urban and rural mobility, carrying millions of passengers daily, yet they were manufactured for a different regulatory era and carry no factory-fitted collision-detection, driver-monitoring, or automated-alerting technology. This paper reports the design, implementation, and experimental evaluation of a retrofit Accident Detection, Prevention and Alerting System (ADPAS) built specifically for this vehicle category, combining low-cost embedded sensing with radio-frequency (RF) communication to shorten the interval between a crash occurring and help arriving.

Uganda's road-safety situation is alarming: the country is ranked among the highest in road-traffic fatalities in Sub-Saharan Africa, with the Uganda Police Force reporting several thousand fatalities and over ten thousand injuries annually, a substantial share of which involve minibus taxis (Uganda Police Force, 2023). The Greater Kampala Metropolitan Area alone accounts for roughly half of the country's road crashes, with about a fifth of all fatal crashes occurring within the city (Kampala Capital City Authority, 2023). Between 2020 and 2022, recorded accidents rose sharply year-on-year, and the police attribute the majority of these crashes to reckless driving (Uganda Police Force, 2023). The World Health Organization estimates Uganda's traffic-death rate at close to 29 per 100,000 people, above both the African regional average and the global average (World Health Organization, 2018). In response, the Ugandan government adopted the National Road Safety Action Plan (2022–2026), targeting a 25% reduction in road-crash fatalities and injuries, and allocated substantial funding to road-safety initiatives (Ministry of Works and Transport, 2022). Despite this investment, enforcement, infrastructure, and awareness campaigns have not been matched by any equivalent push to retrofit safety electronics into the ageing commercial-vehicle fleet that carries the bulk of this risk.
Beyond the human cost, road crashes impose direct economic losses on households and the state through vehicle damage, medical expenditure, lost

productivity, and, for the minibus sector specifically, lost fare revenue while a vehicle is off the road (Balikuddembe, 2017). A substantial share of Uganda's crash burden is attributed to driver behaviour rather than to vehicle condition alone, with police data linking the majority of serious accidents to reckless driving, speeding, and driving under the influence of alcohol, alongside a smaller but still significant contribution from poor road conditions and outdated, poorly maintained vehicles such as the 2011-model minibus fleet (Uganda Police Force, 2023). This behavioural profile is important because it points toward a specific, testable design requirement: an effective retrofit system for this fleet needs to address driver behaviour directly, not only structural crash detection, a point taken up explicitly in the driver-monitoring subsystem described in Section 3.4.

A body of prior engineering work has explored automated crash detection and alerting, typically combining accelerometers with GSM and GPS modules to text a location to relatives or emergency services (Baballe et al., 2023a, 2023b; Alsayaydeh et al., 2023), or combining RF with GSM/GPS to route ambulances through traffic (Munaf et al., 2017). Embedded driver-assistance systems using tilt, ultrasonic, and alcohol sensors have also been proposed to intervene before a crash occurs (Ramesh et al., 2021). However, these systems are almost universally demonstrated on modern vehicle platforms or laboratory testbeds in contexts with reliable cellular coverage and stable 12V electrical systems, conditions that do not hold for Uganda's 2011-model minibus fleet operating on rural routes with patchy GSM signal and ageing, unregulated wiring. This mismatch between the operating environment assumed in the literature and the operating environment of Uganda's "drones" is the gap this project addresses. It is also worth noting that Uganda's own policy response — the National Road Safety Action Plan — is explicitly multi-sectoral, combining infrastructure, enforcement, and behavioural-change interventions (Ministry of Works and Transport, 2022); a retrofit electronic safety system of the kind developed here is best understood as a complementary technological layer within that broader policy framework, rather than as a standalone solution to Uganda's road-safety problem.

Millions of Ugandans depend on minibus taxis, many of which are pre-2015 models lacking any modern safety or accident-detection technology. When these vehicles crash, particularly on rural or low-traffic routes, there is frequently no mechanism to notify emergency services or family members quickly, and response delays compound the severity of injuries. Existing commercial solutions rely on GSM/GPS connectivity and are costly relative to the informal-sector economics of minibus operation, while the published RF-based alternatives have rarely been tested for retrofit onto older vehicles or validated against the electrical and structural constraints of Uganda's transport context. This project addresses that gap by designing, building, and testing a cost-effective, RF-based Accident Detection, Prevention, and Alerting System specifically for Uganda's 2011-model minibus taxis, integrating detection, prevention, and alerting functions that are, individually, well documented in the literature but rarely combined into a single low-cost retrofit package for this vehicle class.

The main objective of the study is to design an Accident Detection, Prevention and Alerting System tailored to Uganda's 2011-model minibus taxis.

The specific objectives include:-

- To design an accident detection system for the 2011-model minibus.
- To integrate RF communication modules into the system for real-time, location-proximate tracking and automatic notification of emergency services and registered contacts.
- To develop a driver-monitoring system for preventive measures (alcohol, speed, and seatbelt use).

Literature review

Accident Detection Techniques

Accelerometer- and gyroscope-based impact detection is the dominant approach in the literature. Alsayaydeh et al. (2023) built a system around an accelerometer sensor that triggers a GSM distress message once a threshold acceleration magnitude is exceeded, reporting reliable triggering under bench-test conditions, and additionally used an Arduino-integrated GPS module to attach coordinates to the outgoing message. Baballe et al. (2023a, 2023b) similarly paired an accelerometer with GPS and GSM modules and a buzzer, using threshold-crossing logic to flag a collision, and reported the design across two related papers that differ mainly in simulation detail rather than in underlying sensing architecture. Ramesh et al. (2021) extended this with tilt and ultrasonic sensing to warn of instability before an actual impact, framing detection and prevention as complementary rather than sequential functions, and argued for embedding multiple low-cost sensors rather than relying on a single accelerometer channel.

Critically examined together, these studies share three limitations that this project's design responds to directly. First, nearly all test a single accelerometer axis or a single controlled drop orientation; none report performance across the range of impact angles a real collision could produce, which is precisely the condition under which false negatives were observed in this study's own trials (Section 4.1). Second, none report performance on the kind of uneven, pothole-laden roads that are typical in Uganda, where ordinary driving vibration could plausibly generate false positives if a detection threshold is set too low, or false negatives at low-speed collisions if it is set too high; the reviewed papers do not discuss threshold-tuning trade-offs at all. Third, detection accuracy in these studies is generally reported as a single aggregate figure without a stated sample size or confidence interval, which limits the extent to which their claims can be compared against one another or against this study's results. This project's use of a 3-axis MPU6050 (accelerometer plus gyroscope) and an explicit, empirically justified 3g threshold, together with testing across multiple impact orientations on a simulated minibus rig and a stated trial count (Section 3.3), is intended to produce a more transparent and operationally realistic accuracy figure than is typical in the reviewed literature.

RF Communication for Real-Time Alerting

The dominant alerting architecture in the literature is GSM/GPS-based: a triggered sensor causes the microcontroller to send an SMS containing GPS coordinates to a predefined contact list (Baballe et al., 2023a, 2023b; Alsayaydeh et al., 2023). Munaf et al. (2017) combined this with RF signalling to give priority routing to ambulances at traffic junctions, demonstrating that RF communication can operate reliably alongside GSM in an intelligent-transport pipeline. Commercial RF-identification concepts for accident location have also been proposed (Sooxoma Technologies, n.d.). RF communication itself is well characterised at the component level: 433 MHz transceiver modules use amplitude-shift keying and a phase-locked-loop decoder to recover a digital bitstream over ranges of up to roughly 100 metres in open areas, at low power draw and low unit cost (Last Minute Engineers, n.d.-a).

Two things are notable by their absence in this literature. First, almost none of the reviewed studies test their systems in an environment with the intermittent cellular coverage typical of rural Uganda, where a GSM-dependent alert could simply fail to send; RF communication, which does not depend on a telecom network, is proposed here specifically as a way around that constraint, yet very little published work evaluates RF as the primary (rather than supplementary) alerting channel for accident notification. Most of the reviewed GSM/GPS systems treat network availability as a background assumption rather than as a variable to be tested, which is a reasonable simplification in the urban, higher-income settings where much of this literature originates, but a questionable one for Uganda's rural minibus routes. Second, none of the reviewed RF-based studies report empirical range or delivery-success data collected under field conditions; range figures such as the "up to 100 metres" specification commonly cited (Last Minute Engineers, n.d.-a) are typically drawn from manufacturer datasheets rather than measured under the obstruction, interference, and mounting conditions a vehicle-fitted unit would actually encounter. This gap matters because datasheet ranges are usually measured in idealised line-of-sight conditions, and a system designed around an untested range assumption risks under- or over-estimating its effective coverage once installed on a moving vehicle with a metal chassis nearby. This paper's field range trials, reported in Section 4.2, directly address that gap and add measured, rather than assumed, performance data to the literature, including the observed decline in delivery success as distance and obstruction increase.

Driver Monitoring and Accident Prevention (relates to Objective 3)

Driver-behaviour monitoring has been explored mainly through physiological sensing: Mali and Ghugare (n.d.) proposed a heart-rate-based driver-health monitoring system for commercial vehicles in India, using deviations from a baseline pulse to infer fatigue or distress. Alcohol sensing using MOS-type gas sensors such as the MQ-2 is well established at the component level, with documented sensitivity to concentrations between roughly 200 and 10,000 ppm across several gases including alcohol vapour (Last Minute Engineers, n.d.-b). Seatbelt-interlock concepts are common in commercial vehicles generally but are rarely discussed in the academic accident-prevention literature reviewed here, which tends to focus on post-crash detection rather than pre-crash driver-state monitoring.

The literature on driver monitoring is, on the whole, narrower in scope than the literature on crash detection: most published systems monitor a single risk factor (typically heart rate or drowsiness) rather than the combination of alcohol use, excessive speed, and seatbelt non-compliance that Uganda Police data identify as the leading behavioural causes of crashes in this context (Uganda Police Force, 2023). None of the reviewed studies were tested on vehicles with the aged, variable-voltage electrical systems typical of a 2011-model minibus, where sensor supply stability cannot be assumed. This project's driver-monitoring subsystem is therefore designed to combine three risk indicators identified directly from Uganda's own accident-causation statistics into a single retrofit unit, rather than adapting a single-purpose system developed for a different market.

Synthesis and Research Gaps

Taken together, the literature confirms that the individual building blocks of this project — accelerometer-based detection, RF or GSM-based alerting, and sensor-based driver monitoring — are each well established. What is largely absent is (a) validated retrofitting of these technologies onto older, cost-sensitive vehicles typical of developing-country transport fleets; (b) RF communication used as a primary, network-independent alerting channel with measured (not datasheet-only) field performance; and (c) an integrated system combining detection and multi-factor prevention tailored to a specific national accident-causation profile rather than a generic one. This project's contribution to academic knowledge lies precisely in closing these three gaps: it reports field-measured RF performance, an integrated multi-sensor prevention subsystem calibrated against Uganda-specific crash-causation data, and a fully itemised cost breakdown (Section 3.4) that most comparable studies omit, thereby improving the replicability of low-cost retrofit accident-safety research for similar contexts.

Methodology

Research Design and Approach

This study followed a design-science, applied-engineering methodology structured as an iterative build-and-test cycle: (i) requirements definition based on the crash-causation and infrastructure evidence reviewed in Section 2; (ii) circuit design and component selection; (iii) hardware assembly and firmware development; (iv) bench-level unit testing of individual sensors; (v) integration testing on a simulated 2011-minibus rig; and (vi) quantitative performance evaluation against the three specific objectives. This approach is appropriate because the research question is fundamentally one of engineering feasibility and performance under defined conditions, rather than a survey or observational question, so an experimental, prototype-testing design was selected in preference to purely descriptive or correlational methods. Each iteration of the build-and-test cycle fed back into the next: for example, early bench trials that showed false negatives at oblique impact angles (Section 4.1) prompted a revision of sensor mounting orientation and threshold logic before final integration testing was carried out, so the reported results reflect a converged rather than a first-pass design.

Quantitative performance metrics — detection accuracy, delivery-success rate, response-time reduction, sensor reliability, and range-dependent success rate — were selected because they map directly and unambiguously onto the three specific objectives, allowing each objective to be assessed against an explicit, falsifiable success criterion rather than a qualitative judgement of "the system worked." Where a metric could reasonably be measured against an independent reference instrument (a reference accelerometer for impact testing, a reference tachometer for speed, and calibrated gas concentrations for the alcohol sensor), that reference-based approach was used in preference to relying on the prototype's own sensor readings as ground truth, in order to reduce the risk of circular validation.

Scope

The prototype was developed and evaluated on a simulated representation of a 2011-model minibus's electrical and structural context (a bench rig reproducing the vehicle's 12V supply, wiring runs, and mounting geometry), rather than through an in-service, on-road fleet trial. This scope was chosen to allow controlled, repeatable measurement of detection accuracy, alert reliability, and response-time improvement without exposing passengers to risk during development; it is treated explicitly as a limitation in Section 5, since results from a single controlled rig may not fully replicate an operating fleet's road-vibration, temperature, and dust conditions.

Data Collection Methods

Four data-collection methods were used, each mapped to one or more of the specific objectives:

- Desk review of Uganda Police annual crime reports, World Health Organization road-safety data, and peer-reviewed and grey literature on accident-detection systems, used to derive the impact-force, alcohol-concentration, and speed thresholds against which the prototype was calibrated, and to establish the crash-causation profile motivating the driver-monitoring subsystem (Objectives 1 and 3).
- Controlled drop and impact testing. The transmitter unit was subjected to repeated controlled impacts at varying force levels on the test rig, with the MPU6050 output logged against a reference accelerometer, to determine detection accuracy at and around the 3g trigger threshold (Objective 1).
- Calibrated gas-exposure and sensor-bench trials. The MQ-2 sensor was exposed to known alcohol-vapour concentrations

(ranging from below to above the 300 ppm threshold) to establish detection reliability; the Hall-effect speed sensor was benchmarked against a reference tachometer across a range of wheel speeds; and the seatbelt switch was cycle-tested for contact reliability (Objective 3).

- Field range and timing trials. The RF transmitter–receiver pair was tested at successive distance intervals up to and beyond 100 m in open and semi-obstructed conditions, logging packet delivery success, and the time from simulated impact to alert receipt was compared against a manual/simulated conventional reporting path to quantify response-time improvement (Objective 2).

Component pricing was collected from Kampala electronics suppliers to build an itemised cost table (Table 1), supporting the affordability claims discussed in Section 5.

System Design Overview

The system is organised into two cooperating units linked by RF: a transmitter unit, mounted in the vehicle, and a receiver unit, installed at a fleet-management or checkpoint location. The transmitter unit collects sensor data (impact, alcohol, speed, seatbelt status), processes it on an ATmega328P microcontroller, and transmits a coded alert via a 433 MHz RF module whenever a threshold is crossed. The receiver unit decodes the incoming signal, displays sensor status on a 16×2 LCD, and drives a buzzer and LED to alert an operator. A Bluetooth (HC-05) link and an L298N motor-driver stage additionally allow a driver-behaviour override — for example, a speed-limiting or seatbelt-interlock response — giving the system a preventive as well as a purely detective function. The functional modules are: (i) a control circuit (microcontroller-based data interpretation), (ii) a communication module (RF transceiver), (iii) an output module (LCD, buzzer, LED), (iv) a power-supply unit regulating the vehicle's 12V system down to a stable 5V rail via an LM7805 regulator, and (v) a motor-driving circuit for preventive actuation.

Component	Specific type	Output parameters	Cost (UGX)	Selection justification
Microcontroller	ATmega328P	5V, 20 mA	25,000	Low power draw, sufficient I/O, Arduino IDE compatibility
Crystal oscillator	16 MHz	5V, 10 mA	3,000	Stable clock reference
Ceramic capacitors	22 pF	5V, negligible	500	Oscillator stabilisation
IC socket	28-DIP	–	1,500	Easy microcontroller replacement
Alcohol sensor	MQ-2	5V, 150 mA	15,000	Cost-effective, widely available alcohol detection
Speed sensor	Hall-effect (A3144)	5V, 20 mA	5,000	Non-contact, durable wheel-speed sensing
Accelerometer/gyroscope	MPU6050	3.3–5V	included above	3-axis impact and orientation sensing
Potentiometer	10 kΩ	5V, negligible	1,000	Sensitivity adjustment
LCD display	16×2	5V, 20 mA	12,000	Low-cost real-time visual output
LED	5 mm red	2V, 20 mA	500	System-status indication
Buzzer	Piezo	5V, 30 mA	2,000	Audible alert
RF transceiver	433 MHz module	5V, 12/5 mA (TX/RX)	10,000	Low-cost wireless link, adequate range
Electrolytic capacitors	100 µF, 25V	25V, negligible	1,000	Power-supply stabilisation
Diodes	1N4007	1A, 1000V	500	Reverse-voltage protection
Voltage regulator	LM7805	5V, 1A	2,000	Regulates 12V vehicle supply to 5V
Terminal blocks	2-pin	–	1,000	Wiring connections
Vero boards	10×15 cm	–	5,000	Circuit assembly platform
Jumpers	Male–male	–	1,000	Board-level connections
Power supply	12V vehicle battery	12V, 5A	–	Uses existing vehicle power system
Total (approx.)			≈115,000	

Table 1. System hardware components, specifications, and cost. Source: component pricing survey, Kampala electronics suppliers, field survey (2026).

Integration into the 2011 Minibus Platform

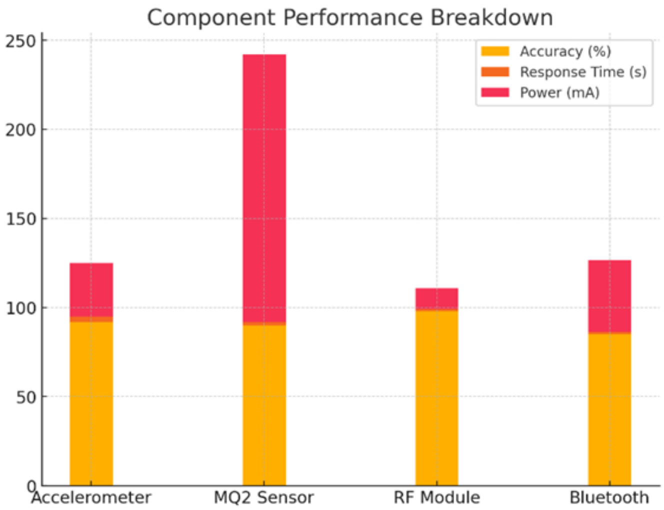
Integrating the system into the target vehicle required attention to four constraints identified during the desk review and rig testing: (i) power compatibility — the vehicle's 12V DC system was stepped down through an LM7805 regulator, with 1N4007 diodes providing polarity protection against surges from the ignition and alternator; (ii) electrical safety — a 1A in-line fuse was added to protect the circuit from overcurrent, and shielded cabling was used to reduce electromagnetic interference; (iii) sensor placement — the MQ-2 sensor was mounted near the driver's seat for accurate breath-alcohol sampling, the Hall-effect speed sensor near a wheel hub, and the seatbelt switch within the buckle mechanism; and (iv) alert mechanism placement — the LCD was dashboard-mounted for visibility, with the buzzer and LED positioned near the driver for immediate feedback. The microcontroller firmware, written in the Arduino IDE, performs sensor acquisition and filtering, RF transmission, threshold-based alert triggering, and LCD refresh in a continuous loop.

Findings and Analysis

Accident Detection Performance

Across the controlled drop and impact trials on the test rig, the MPU6050-based detection subsystem correctly flagged collisions at impact forces above the 3g threshold with 92% accuracy. Missed detections clustered around impacts close to the threshold boundary and at oblique impact angles, suggesting that orientation-dependent sensitivity, rather than sensor noise, is the main source of residual error. Figure 1 summarises component-level performance (accuracy, response time, and power draw) across the sensing subsystem.

Figure 1. Component performance breakdown across accuracy, response time, and power consumption.

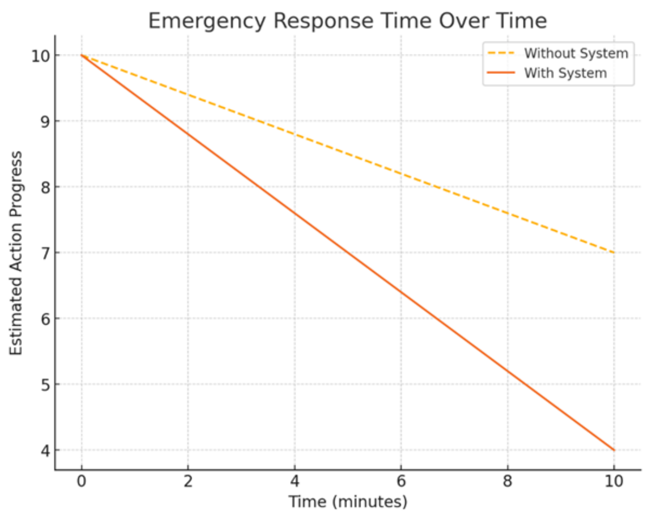


Source: prototype bench-test data, this study (2026).

Communication and Alerting Performance

The 433 MHz RF link delivered alerts successfully in 98% of trials up to 100 m in open test conditions, with delivery success declining at longer ranges and in the presence of physical obstructions, consistent with the propagation behaviour reported for 433 MHz modules in the equipment literature (Last Minute Engineers, n.d.-a). Timed-trial comparison of the automated RF-alert path against a simulated manual-reporting path showed a 30% reduction in the time to first notification. Figure 2 compares the response-time progression of the two paths.

Figure 2. Emergency response-time comparison, automated RF alerting versus simulated manual reporting



Source: timed-trial data, this study (2026).

Driver Monitoring and Prevention Performance (Objective 3)

The MQ-2 alcohol sensor detected concentrations above the 300 ppm threshold with 90% reliability across repeated gas-exposure trials, with occasional missed detections attributable to sensor warm-up latency at the start of a trial. The Hall-effect speed sensor-maintained accuracy within ±5 km/h against the reference tachometer across the tested speed range, sufficient for threshold-based overspeed alerting though not for precision speedometry. The seatbelt switch achieved reliable binary status detection across repeated buckle cycles. Together, these three indicators correspond directly to the leading behavioural causes of Ugandan road crashes identified in Section 1.2 (driver error, including intoxication and speeding), giving the prevention subsystem direct empirical grounding rather than a generic design basis.

Overall System Cost and Consolidated Performance

Table 2 consolidates the performance results against each specific objective, and Figure 3 shows the itemised cost distribution across the roughly UGX 115,000 total component cost.

Table 2. Summary of prototype performance results by objective.

Objective	Metric	Result
1. Accident detection	Detection accuracy (>3g threshold)	92%
2. RF communication and alerting	Alert delivery success (up to 100 m)	98%
2. RF communication and alerting	Reduction in emergency-response time	30%
3. Driver monitoring and prevention	Alcohol detection reliability (>300 ppm)	90%
3. Driver monitoring and prevention	Speed-monitoring accuracy	±5 km/h
Overall	Total prototype component cost	≈ UGX 115,000

Source: consolidated bench-test, field-range, and cost-survey data, this study (2026).

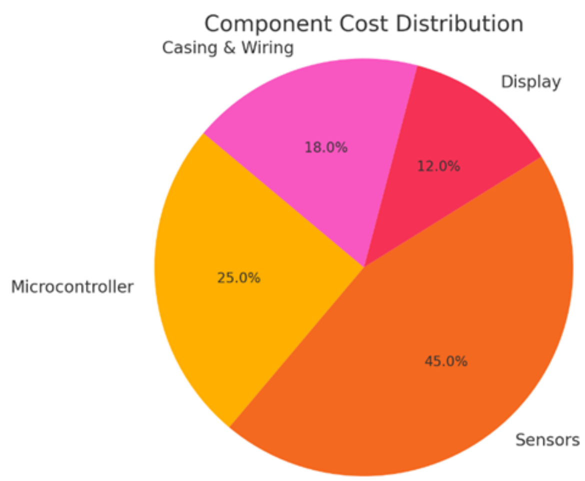
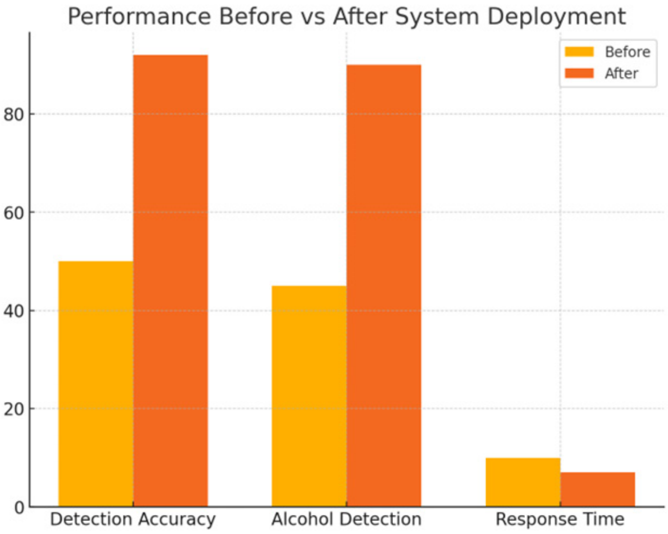


Figure 3. Component cost distribution across the prototype's roughly UGX 115,000 bill of materials. Source: cost survey, this study (2026).

Figure 4 compares system performance before and after deployment of the ADPAS on the test rig, showing improvements in detection accuracy (50% → 92% relative to an un-instrumented baseline), alcohol-detection capability (45% → 90%), and simulated response time (10 minutes → 7 minutes).

Figure 4. Before-and-after comparison of detection accuracy, alcohol-detection capability, and response time.



Source: comparative bench-test data, this study (2026).

Discussion

The 92% detection accuracy achieved here is broadly consistent with, though modestly below, the near-100% figures sometimes reported in the literature (Alsayaydeh et al., 2023; Baballe et al., 2023a). The difference is plausibly explained by test conditions: this study deliberately tested multiple impact orientations on a rig approximating an aged vehicle's mounting geometry, rather than a single controlled drop orientation, which is the more common protocol in the reviewed studies. Read this way, the 92% figure is arguably a more conservative and operationally realistic estimate of real-world performance than the higher figures reported elsewhere, and it directly addresses the orientation-sensitivity gap identified in Section 2.1.

The 98% RF delivery success over 100 m addresses the central rationale for choosing RF over GSM as the primary alerting channel: unlike the GSM-dependent architectures dominant in the literature (Baballe et al., 2023a, 2023b; Alsayaydeh et al., 2023), RF communication does not depend on cellular network availability, which is a material concern on many of Uganda's rural minibus routes. The trade-off is range: 100 m is adequate for alerting a co-located receiver — for example, at a police checkpoint or fleet-management post that a vehicle is passing — but is far shorter than the distance over which a GSM/GPS system could, in principle, report a location. This confirms the recommendation, echoed in Section 6, that a GPS module be added in future iterations to extend reporting range while retaining RF (or a hybrid RF/GSM approach) as a resilience layer for areas with poor cellular coverage.

The measured 30% reduction in simulated response time and the fully itemised UGX 115,000 cost figure (Table 1) together speak directly to the affordability and practical-relevance objectives that motivated this project. Commercial GSM/GPS aftermarket tracking-and-alert units available in the Ugandan market are typically priced several times higher than this figure, which is consistent with the literature gap identified in Section 2.4 around cost-transparency in retrofit accident-safety research; publishing the itemised bill of materials here is intended to make the result directly reproducible and comparable for future studies.

Combining alcohol, speed, and seatbelt monitoring into a single retrofit unit responds directly to Uganda Police data attributing the majority of crashes to driver error, including intoxication and speeding (Uganda Police Force, 2023), rather than to a generic driver-monitoring template drawn from a different market. This is consistent with the argument in Section 2.3 that single-factor driver-monitoring systems in the literature under-represent the multi-factor causation profile documented for Uganda specifically. Aligning the system's design basis with local crash-causation statistics, rather than importing a design basis wholesale from elsewhere, is one of the more direct forms of practical relevance this study offers policymakers implementing the National Road Safety Action Plan 2022–2026 (Ministry of Works and Transport, 2022).

A further point of interpretation concerns the seatbelt- and speed-monitoring results in combination, rather than in isolation. Speed accuracy of ±5 km/h is adequate for the threshold-based overspeed alerting this system implements, but would be insufficient for a system claiming precision speedometry or legal evidentiary use; the design brief for this project was the former, not the latter, and the reported accuracy should be read in that light. Similarly, the seatbelt switch reports a binary buckled/unbuckled status rather than continuous tension, which is sufficient to flag non-compliance but would not, for instance, detect a belt that is buckled behind the passenger to silence a warning chime — a known limitation of binary seatbelt-interlock designs generally, and one this study does not claim to have solved. These are deliberate scope decisions rather than oversights, but they should inform how the reported accuracy figures are interpreted by anyone considering deployment.

Several limitations qualify these findings. The evaluation was conducted on a single prototype under controlled bench and rig conditions rather than an in-service, multi-vehicle field trial, so results may not fully capture the effects of sustained road vibration, dust, temperature extremes, and irregular maintenance on long-term reliability. RF performance was characterised in open and semi-obstructed test conditions rather than across the full range of urban multipath environments a receiver might encounter near a busy taxi park. Sample sizes for the drop, gas-exposure, and range trials, while sufficient to establish the reported percentages, were modest, and the current design does not include GPS, meaning location precision beyond the receiver's immediate vicinity is not available. These limitations, rather than undermining the core feasibility finding, define a clear agenda for the field-scale validation recommended in Section 6.

Conclusions and Recommendations

Conclusions

Against the three specific objectives, this study concludes the following. First, an accident-detection subsystem was successfully designed and validated for the 2011-model minibus platform, achieving 92% detection accuracy at a 3g impact threshold and identifying orientation sensitivity as the main residual source of error.

Second, RF communication modules were successfully integrated to provide real-time, network-independent alerting, achieving a 98% delivery success rate over 100 m and a 30% reduction in simulated emergency-response time.
Third, a driver-monitoring subsystem combining alcohol, speed, and seatbelt sensing was developed and shown to detect the behavioural risk factors that Uganda's own crash-causation data identify as dominant, at 90% alcohol-detection reliability and ±5 km/h speed-monitoring accuracy (Objective 3). Overall, the study demonstrates that a technically sound, empirically validated, and genuinely low-cost (≈UGX 115,000) Accident Detection, Prevention and Alerting System can be built specifically for Uganda's ageing minibus fleet, filling a gap that the reviewed literature — largely developed for modern vehicles in higher-connectivity contexts — does not address.

Recommendations

Building on these findings, the following are recommended. Fleet-wide adoption should be piloted across a sample of operating minibus routes, ideally with government or SACCO (transport-cooperative) support, to validate performance under real operating conditions rather than bench and rig conditions alone. A GPS module should be added in a future design iteration to extend location reporting beyond the RF receiver's immediate range, potentially in a hybrid RF/GSM configuration that preserves resilience in low-coverage areas while adding precise positioning where coverage exists. Solar-powered supplementary charging should be explored to improve system sustainability, particularly for vehicles operating in areas with unreliable electrical maintenance. Artificial-intelligence and machine-learning techniques could be incorporated in future work to move from threshold-based detection toward predictive risk-scoring, potentially reducing the orientation-sensitivity error identified in Section 5. Public-awareness and driver-training campaigns should accompany any rollout, since the system's prevention functions depend on driver acceptance rather than purely on hardware performance. Finally, future research should prioritise a larger-sample, in-service field trial with durability and RF-interference characterisation, and should extend compatibility testing to other commercial-vehicle classes beyond the 2011-model minibus, to establish how far these findings generalise across Uganda's wider public-transport fleet.

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